Development of Emissions-Estimating Methodologies for Broiler Operations

Draft

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Sectors Policies and Programs Division
Research Triangle Park, NC 27711

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Executive Summary

In 2005, the EPA offered animal feeding operations (AFOs) an opportunity to participate in a voluntary consent agreement referred to as the Air Compliance Agreement (Agreement) (70 FR 4958). Under the Agreement, participating AFOs provided the funding for the National Air Emissions Monitoring Study (NAEMS) – a two-year, nationwide emissions monitoring study of animal confinement structures and manure storage and treatment units in the broiler, egg-layer, swine, and dairy industries. The purpose of this study was to gather baseline uncontrolled emissions data that would be used to develop by the EPA to develop emission estimating methodologies (EEMs). The NAEMS began in the summer of 2007 and consisted of 25 monitoring sites located in 10 states. At the animal confinement sites, the study collected process and emissions data for ammonia (NH_3), hydrogen sulfide (H_2S), total suspended particulate matter (TSP), particulate matter (PM) with aerodynamic diameters less than 10 micrometers (PM_{10}), PM with aerodynamic diameters less than 2.5 micrometers ($PM_{2.5}$) and volatile organic compounds (VOCs).

In accordance with the Agreement, the EPA developed EEMs for animal housing structures and manure storage and treatment units using the emissions and process data collected under the NAEMS and other relevant information submitted to the EPA in response to its Call for Information (76 FR 3060). The EEMs will be used by the AFO industry to estimate daily and annual emissions for use in determining their regulatory responsibilities under the Clean Air Act (CAA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA).

This report presents the background information, data collected, data analyses performed, statistical approach taken and the EEMs developed by the EPA for confinement structures used in the broiler industry. The EEMs provide emissions estimates of the following pollutants for grow-out and decaking/full litter clean-out periods: NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs.

The EPA developed the EEMs using emissions and process information collected from one broiler operation in California (site CA1B) and from two broiler operations in Kentucky (sites KY1B- and KY1B-2). At the CA1B site, monitoring was conducted in two houses from 2007 to 2009. At the Kentucky sites, monitoring was conducted in a single house at each location from 2006 to 2007. Monitoring at site CA1B was conducted under the NAEMS while monitoring at the Kentucky sites was sponsored by Tyson Foods. Because the quality assurance project plan (QAPP) and site monitoring plans for the Tyson study were developed to be consistent with the NAEMS, the EPA considered the data collected under the Tyson study to be an integral part of the NAEMS.

For broiler grow-out periods, the EPA used the emissions and process parameter data collected at the California and Kentucky sites and SAS statistical software to develop the EEMs. To accommodate varying levels of available input data, the EPA developed three EEMs for grow-out periods: EEMs that uses bird inventory data as input parameters (I EEMs); EEMs that uses bird inventory and ambient parameters (IA EEMs) and EEMs based on bird inventory, ambient and confinement parameters (IAC EEMs). For the I EEMs, the input parameters are total bird inventory in the house and their average weight which are typically recorded manually by growers. For the IA EEMs, the input parameters include the bird inventory parameters and ambient temperature and relative humidity. The ambient data can be obtained by either a monitoring system installed at the farm or from a representative local meteorological station. For the IAC EEMs, the input parameters include the bird inventory, ambient meteorological parameters and confinement parameters (i.e., house temperature and relative humidity). A monitoring system that recorded confinement parameters would have to be installed in the broiler house if the IAC EEM is used to determine emissions.

For litter decaking and clean-out periods, the EPA developed emissions factors that relate pollutant emissions to the mass of birds raised on the litter since the previous decaking or full litter clean-out activity and to the duration of the decaking or clean-out period. The EPA considered using regression analyses to develop separate methods for litter decaking and clean-out periods, but rejected this approach due to the relatively small number of emissions and process parameter data values collected during these periods. Also, applying the regression analyses to litter decaking and clean-out periods was further complicated because the data did not fully represent the manner in which the house doors and openings were managed and the specific activities undertaken during these periods while gas and PM sampling were conducted.

1.0 INTRODUCTION

There are approximately 1 million livestock and poultry farms in the United States. About one-half of these farms raise animals in confinement, which qualifies them as Animal Feeding Operations (AFOs) (USDA, 2007 Census of Agriculture). AFOs are potential sources of the following emissions: ammonia (NH_3), hydrogen sulfide (H_2S), total suspended particulate matter (TSP), particulate matter with aerodynamic diameters less than 10 micrometers (PM_{10}), PM with aerodynamic diameters less than 2.5 micrometers ($PM_{2.5}$) and volatile organic compounds (VOCs).

This report presents emissions-estimating methodologies (EEMs) for determining uncontrolled emissions from a broiler confinement barn. The EEMs were developed based on data collected in the National Air Emissions Monitoring Study (NAEMS) and other relevant information obtained through the EPA's January 19, 2011, Call for Information (see Section 4.0).

The EPA's previous effort to quantify potential emissions from this source sector and the evolution of the Air Compliance Agreement, are described in Section 1.1. Section 1.2 outlines the requirement for the NAEMS established by the Air Compliance Agreement. Section 1.3 describes how the data collected during the NAEMS was used to develop the EEMs.

1.1 EPA's Consent Agreement for Animal Feeding Operations

In August 2001, the EPA published methodologies for estimating farm-level emissions from AFOs in the beef, dairy, swine and poultry (broilers, layers and turkeys) animal sectors (*Emissions from Animal Feeding Operations*, Draft, August 2001). To develop the methodologies, the EPA: (1) identified the manure management systems typically used by AFOs in each animal sector, (2) developed model farms, (3) conducted literature searches to identify emission factors related to model farm components (e.g., confinement, manure handling and treatment system) and (4) applied the emission factors to the model farms to estimate annual mass emissions.

After publication of the EPA's 2001 report, the EPA and the United States Department of Agriculture (USDA) jointly requested that the National Academy of Science (NAS) evaluate the current knowledge base and the approaches for estimating air emissions from AFOs. In its 2003 report (*Air Emissions From Animal Feeding Operations: Current Knowledge, Future Needs*, National Research Council), the NAS concluded the following: reliable emission factors for AFOs were not available at that time; additional data were needed to develop estimating methodologies; current methods for estimating emissions were not appropriate; and the EPA should use a process-based approach to determine emissions from an AFO.

In January 2005, the EPA announced the voluntary Air Compliance Agreement with the AFO industry. The goals of the Air Compliance Agreement were to reduce air pollution, monitor AFO emissions, promote a national consensus on methodologies for estimating emissions from AFOs and ensure compliance with the requirements of the Clean Air Act (CAA), the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA).

To develop the Air Compliance Agreement, the EPA worked with industry representatives, state and local governments, environmental groups and other stakeholders. Approximately 2,600 AFOs, representing nearly 14,000 facilities that included broiler, dairy, egg layer and swine operations, received the EPA's approval to participate in the Air Compliance Agreement. Participating AFOs paid a civil penalty, ranging from $200 to $100,000, based on the size and number of facilities in their operations. They also contributed approximately a total of $14.6 million to fund the NAEMS.

As part of the Air Compliance Agreement, the EPA agreed not to sue participating AFOs for certain past violations of the CAA, CERCLA and EPCRA, provided that the AFOs comply with the Air Compliance Agreement's conditions. However, the Air Compliance Agreement does not limit the EPA's ability to take action in the event of imminent and substantial danger to public health or the environment. The Air Compliance Agreement also preserves state and local authorities' ability to enforce local odor or nuisance laws. After the EPA publishes the final emissions-estimating methodologies (EEMs) for the broiler, swine, egg layer and dairy sectors, participating AFOs must apply the final methodologies for their respective sectors to determine what actions, if any, they must take to comply with all applicable CAA, CERCLA and EPCRA requirements. If a participating facility ***does not*** trigger CAA, CERCLA or EPCRA permitting or release notification requirements based on the data collected, the facility will have 60 days from the publication date of the final EEMs to submit a written certification to EPA confirming compliance with current applicable requirements under these regulations. If a participating facility ***does*** trigger CAA, CERCLA or EPCRA permitting or release notification requirements, the facility will have 120 days from the publication date of the final EEMs to apply for any required permits under the CAA, or submit any required release notifications under CERCLA or EPCRA. Finally, AFOs that did not participate in the Air Compliance Agreement can use the appropriate EEMs for their sectors to determine what, if any, measures they must take to comply with applicable CAA, CERCLA and EPCRA requirements.

1.2 National Air Emissions Monitoring Study for AFOs

1.2.1 Overview of Emissions and Process Parameters Monitored

In the early planning stages of the NAEMS, representatives from the EPA, USDA, AFO industry, state and local air quality agencies and environmental organizations met to discuss and define the parameters that would be collected by the study. The goal was to develop a comprehensive list of parameters that must be monitored to provide a greater understanding and accurate characterization of emissions from AFOs. By monitoring these parameters, the EPA would have the necessary information to develop EEMs for uncontrolled emissions of particulate matter, ammonia, hydrogen sulfide and volatile organic compounds from animal feeding operations.

The Air Compliance Agreement provided guidance on the emissions and process parameters to be monitored under the NAEMS and the specific components that were to be included in the emissions monitoring plans. In addition, the Air Compliance Agreement identified the technologies and measurement methodologies to be used to measure emissions and process parameter data at each of the broiler, dairy, egg layer and swine monitoring sites. The Air Compliance Agreement required that an on-farm instrument shelter (OFIS) for housing monitoring equipment be located at each site and that the following parameters be monitored for 24 months:

- NH_3 concentrations using a chemiluminescence or photoacoustic infrared gas analyzer.
- CO_2 concentrations using a photoacoustic infrared gas analyzer, or equivalent.
- H_2S concentrations using a pulsed fluorescence gas analyzer.
- $PM_{2.5}$ concentrations using a gravimetric, federal reference method for $PM_{2.5}$ for at least one month per site.
- PM_{10} concentrations using a tapered element oscillating microbalance (TEOM).
- TSP concentrations using an isokinetic, multipoint gravimetric method.
- VOC concentrations using a sampling method that captures a significant fraction of the 20 analytes determined by an initial characterization study of confinement VOC emissions to be the greatest contributors to total VOC mass.
- Animal activity, manure handling, feeding and lighting operation.
- Total nitrogen and total sulfur concentrations determined by collecting and analyzing feed, water, and manure samples.
- Environmental parameters (heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction and solar radiation).

- Feed and water consumption, manure production and removal, animal mortalities and production rates.

The Air Compliance Agreement also required that sites estimate the ventilation air flow rate of mechanically ventilated confinement structures by continuously measuring fan operational status and building static pressure and applying field-tested fan performance curves and by directly measuring selected fan air flows using anemometers.

There were some variations in process parameters collected, as not all were applicable to each animal type or site. Additionally, some of the sites may have opted to collect more than required by the Air Compliance Agreement. Table 1-1 lists the process parameters monitored at the NAEMS broiler sites. Section 4.0 discusses the data submitted to EPA, including the amount of data received, in more detail.

Table 1-1. Process Parameters Monitored at the NAEMS Broiler Sites

Parameter		Units
Confinement conditions	Temperature	^oC
	Relative humidity	%
	Activity (personnel and bird)	Volts DC
	Light operation	On/off
	Feeder operation	On/off
	Brood heater operation	On/off
Ventilation rate estimation	Fan operation[a]	On/off
	House differential static pressure[a]	Pascals (Pa)
Meteorological conditions	Ambient temperature	^oC
	Ambient relative humidity	%
	Barometric pressure	kPa
	Solar radiation	Watts/m^2
	Wind speed	ft/sec
	Wind direction	Degrees
Bird population	Bird age	Days
	Bird inventory	No. of birds
	Average bird mass	kg
Nitrogen mass balance	Feed consumption rate	lb
	Water consumption	gal
	Feed nitrogen content	mg/g
	Water nitrogen content	mg/liter
	Incoming bedding addition rate	lb
	Incoming bedding nitrogen content	mg/g
	Litter volume	ft^3
	Litter nitrogen content	mg/g

[a] Fan operation, differential static pressure and fan performance curves were used to calculate the ventilation flow rate of the broiler house.

1.2.2 NAEMS Monitoring Sites

The EPA provided oversight for the NAEMS and the team of researchers assembled from the following eight universities: Purdue University, Iowa State University, University of California-Davis, Cornell University, University of Minnesota, North Carolina State University, Texas A&M University and Washington State University. Table 1-2 lists the monitoring sites that were established under the NAEMS. The researchers conducted monitoring at 25 different sites in 9 states (California, Indiana, Iowa, New York, North Carolina, Oklahoma, Texas, Washington and Wisconsin). Consistent with the NAEMS Monitoring Protocol, the monitoring sites selected for the NAEMS provided representative samples of typical broiler, egg-layer, swine and dairy operations.

For the broiler sector portion of the NAEMS, monitoring was conducted at the California site (CA1B) from 2007 to 2009. Tyson Foods sponsored an earlier monitoring study at the Kentucky sites (KY1B-1 and KY1B-2) from 2006 to 2007. However, the quality assurance project plan (QAPP) and site monitoring plans for the Tyson study were developed to be consistent with the NAEMS. Therefore, for the purposes of developing methodologies for estimating emissions from broiler operations, the EPA considers the data collected at the Tyson study sites to be an integral part of the NAEMS.

Table 1-2. NAEMS Monitoring Sites

State	County	Site Name	Type of Operation Monitored
California	Stanislaus	CA1B	Broiler (2 Houses)
California	San Joaquin	CA2B	Egg-Layer (2 High-Rise Houses)
California	San Joaquin	CA5B	Dairy (2 Barns)
Iowa	Marshall	IA4B	Swine Sow (2 Barns, 1 Gestation Room)
Iowa	Jefferson	IA3A	Swine Finisher (1 Lagoon)
Indiana	Wabash	IN2B[a]	Egg-Layer (2 Manure-Belt Houses)
		IN2H[a]	Egg-Layer (2 High-Rise Houses)
Indiana	Carroll	IN3B	Swine Finisher (1 “Quad” Barn)
Indiana	Clinton	IN4A	Swine Sow (1 Lagoon)
Indiana	Jasper	IN5B[b]	Dairy (2 Barns, 1 Milking Center)
Indiana	Jasper	IN5A[b]	Dairy (1 Lagoon)
North Carolina	Nash	NC2B	Egg-Layer (2 High-Rise Houses)
North Carolina	Duplin	NC3B	Swine Finisher (3 Barns)
North Carolina	Bladen	NC3A	Swine Finisher (1 Lagoon)
North Carolina	Duplin	NC4A[c]	Swine Sow (1 Lagoon)
		NC4B[c]	Swine Sow (2 Barns, 1 Gestation Room)
New York	Onondaga	NY5B	Dairy (1 Barn, 1 Milking Center)
Oklahoma	Texas	OK3A	Swine Finisher (1 Lagoon)
Oklahoma	Texas	OK4A[c]	Swine Sow (1 Lagoon)
		OK4B[c]	Swine Sow (2 Barns, 1 Gestation Room)
Texas	Deaf Smith	TX5A	Dairy (Corral)[d]

Table 1-2. NAEMS Monitoring Sites

State	County	Site Name	Type of Operation Monitored
Washington	Yakima	WA5A[c]	Dairy (1 Lagoon)
		WA5B[c]	Dairy (2 Barns)
Wisconsin	Saint Croix	WI5A[c]	Dairy (2 Lagoons)[e]
		WI5B[c]	Dairy (2 Barns)
Kentucky	Union	KY1B-1	Broiler (1 House)
	Hopkins	KY1B-2	Broiler (1 House)

[a] Two different types of barns located at the same site were monitored.
[b] Monitoring occurred on two separate dairy farms in Jasper County, IN.
[c] Barns and lagoons were located at the same site.
[d] The reported emission estimates represent the entire corral.
[e] Instrumentation was deployed around two of the lagoons in the three-stage system. The emissions from the two lagoons were reported as a combined value.

1.3 Emission Estimating Methodology Development

Consistent with the Air Compliance Agreement, the EPA developed methodologies for estimating air pollutant emissions from broiler confinement operations using the emissions and process data collected under the NAEMS and other relevant information obtained through the EPA’s January 19, 2011, Call for Information (see Section 4.0). Based on the results of the its analysis of emissions trends (see Section 6.0), the EPA developed separate EEMs for broiler grow-out periods and for periods when litter on the confinement house floor was decaked or fully removed from the house (see Section 2.0 for a description of the broiler industry and production processes).

The EPA developed grow-out and decaking/litter clean-out period EEMs for the following pollutants: NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs. Section 7 describes the statistical methodology used to analyze the data and develop the EEMs. Due to issues related to the performance of the gas analyzer at site CA1B and the procedures used to develop speciation profiles for VOC components, the EEM for VOCs is based only on the data from the two Kentucky sites.

For broiler grow-out periods, the EPA used the emissions and process parameter data collected under the NAEMS and SAS statistical software to develop the EEMs. Process data was divided into the following three groups: inventory data (e.g. number of birds and bird weight), ambient data (e.g. ambient temperature, pressure and relative humidity), and confinement data (e.g. building temperature, pressure and relative humidity). All of the process parameters were statistically evaluated to determine if they were predictor variables. In addition, the EPA evaluated whether the predictor variable process data was readily available to the growers, state and local agencies and other interested parties. Based on the results of the EPA’s predictor variable evaluation process, three EEMs were developed using various process parameters. The three EEMs are as follows and are explained below: an EEM based on bird inventory parameters (I EEMs); an EEM based on bird inventory and ambient parameters (IA EEMs) and an EEM based on bird inventory, ambient and confinement parameters (IAC EEMs).

- I EEMs - The input parameters are data that characterize the bird population in the house (i.e., total bird inventory in the house and their average weight). These parameters are typically recorded manually by the grower without the need for an automated monitoring system.
- IA EEMs - The input parameters are the bird inventory, average bird weight and ambient meteorological parameters (i.e., ambient temperature and relative humidity). The ambient data can be obtained by either a monitoring system installed at the farm or from a representative local meteorological station in the National Weather Service (NWS) Automated Surface Observing System (ASOS) network. Recent data from NWS ASOS sites are readily available through the NWS website (http://www.nws.noaa.gov/asos/). Historical data is also available through the National Climate Data Center (NCDC) website (http://www.ncdc.noaa.gov/oa/ncdc.html), regional climate center websites (http://www.wrcc.dri.edu/rcc.html), state climate office websites (http://stateclimate.org/), and some university websites (e.g., http://mesonet.agron.iastate.edu/ASOS/).
- IAC EEMs - The input parameters are the bird inventory, average bird weight, ambient meteorological parameters and confinement parameters (i.e., house temperature, relative humidity and ventilation rate) collected by a monitoring system installed in the house.

For litter decaking and clean-out periods, the EPA developed emissions factors that relate pollutant emissions to the mass of birds raised on the litter since the previous decaking or clean-out activity and the duration of the decaking or clean-out period. The EPA considered applying the regression analyses to develop separate methods for litter decaking and clean-out periods, but rejected this approach due to the relatively small number of emissions and process parameter data values collected during these periods. Also, applying the regression analyses to litter decaking and clean-out periods was further complicated because the data did not fully represent the manner in which the house doors and openings were managed and the specific activities undertaken during these periods while gas and PM sampling were conducted.

2.0 OVERVIEW OF BROILER INDUSTRY

Broiler production is the raising of chickens of either sex for meat. A broiler is a young chicken that is characterized as having tender meat, flexible breastbone cartilage and soft, pliable smooth-textured skin. Section 2.1 describes the typical business structure and the size and scale of broiler operations. Section 2.2 explains the production cycle, outlining the practices of growing hatched chicks to market weight, followed by a description of typical confinement houses in Section 2.3. Section 2.4 describes typical manure management practices. Section 2.5 provides a brief overview of the emissions from broiler production.

2.1 Industry Overview

Broiler production is a highly vertically-integrated industry, wherein a common owner or parent company is involved in several phases of the supply chain. For example, a parent company, or integrator, typically operates or contracts every aspect of the broiler production process (e.g., hatcheries, production houses, slaughterhouses, meat packing plants, feed production facilities and food distributors).

For broiler production operations, the integrator typically provides the birds, feed, medicines, transportation and technical support, under contract, to growers who provide the labor and the production facilities to raise the birds from hatchlings to market weight. The contract grower receives a minimum guaranteed price for the birds moved for market. More than 90 percent of all chickens raised for human consumption in the United States are produced by growers working under contract with integrators (USEPA, 2001). Because of this vertical integration, management strategies at the facility level tend to be more uniform than in other sectors of AFOs.

Based on the information reported in the USDA's 2007 Census of Agriculture (http://www.agcensus.usda.gov/Publications/2007/Full_Report/usv1.pdf), 27,091 broiler operations produced 8.9 billion birds for market in 2007. Larger operations dominate broiler production, based on the 2007 Census data. In 2007, approximately 76 percent of the total broiler operations had a confinement capacity of 90,900 birds or less. However, operations with confinement capacities greater than 90,900 birds (approximately 24 percent of the total number of broiler operations) accounted for approximately 67 percent of the total annual bird production. The EPA estimated the confinement capacity by dividing the 2007 bird sales by the 5.5 flocks raised per year (this value for the typical flock turnover rate was obtained from the USDA National Agriculture Statistics Service). In addition to being dominated by large producers, the broiler industry is concentrated in several states. Alabama, Arkansas and Georgia are the largest broiler producing states followed by Mississippi, North Carolina and Texas. California and Kentucky rank 7th and 14th, respectively, in terms of broiler production.

2.2 Production Cycle

The length of the grow-out period ranges from 28 to 63 days, depending on the size of the bird desired. The grow-out period includes a brooding phase that begins when day-old chicks are placed in a heated section of a broiler house known as the brood chamber. The brood chamber is initially maintained at an elevated temperature (e.g., 85 to 95 °F), which is gradually decreased during the first few weeks of the birds' growth. As the growing birds need floor space, the remainder of the house is opened and the chicks are grown to market weight.

Broilers are produced to meet specific requirements of customers, which can be retail grocery stores, fast-food chains or institutional buyers. For broilers, the typical grow-out period is 49 days, resulting in an average bird weight of 4.5 to 5.5 pounds. The grow-out period may be as short as about 28 days to produce a 2.25 to 2.5 pound bird, commonly referred to as a Cornish game hen. For producing roasters weighing 6 to 8 pounds, the grow-out period is may take as long as 63 days.

Broiler houses are operated on an "all in-all out" basis and require time between flocks when the house is empty litter removal (either decaking or full litter cleanout), cleaning (e.g., pressure washing fans), and repair and maintenance. For broilers, five to six flocks per house per year is typical. However, the number of flocks raised per year is dependent on final bird weight, so is lower for roasters and higher for Cornish game hens. Female broilers grown to lay eggs for replacement stock are called broiler breeders and are usually raised on separate farms. These farms produce only eggs for broiler replacements. A typical laying cycle for hens is about 1 year, after which the hens are sold for slaughter.

2.3 Animal Confinement

The most common type of housing for broilers, roasters and breeding stock is enclosed housing with a compacted soil floor covered with dry bedding. Dry bedding can be sawdust, wood shavings, rice hulls, chopped straw, peanut hulls or other products, depending on availability and cost. The bedding absorbs moisture from the manure excreted by the birds, which forms litter (mixture of bedding and manure). Mechanical ventilation is typically provided using a negative-pressure system, with exhaust fans drawing air out of the house, and fresh air returning through ducts around the perimeter of the roof. The ventilation system uses exhaust fans to maintain acceptable housing conditions year round. Advanced systems use thermostats and timers to control exhaust fans.

2.4 Manure Management

Broiler houses are cleaned between flocks to remove some (i.e., decaking) or all of the accumulated litter. In decaking operations, the upper layer of cake (i.e., the compacted mixture of bedding and manure) that typically accumulates on the house floor near waterers and feeders is removed from the house. The litter remaining after decaking may be "top dressed" with an inch or so of new bedding material before the new flock is placed in the house. When the broiler house is completely cleaned out, the litter is typically removed using a front-end loader. After all litter and organic matter (e.g., feathers adhering to building surfaces) is removed, the house is disinfected.

Litter removed from the house is either immediately applied to cropland and/or pastureland or it is stored for later land application. Water quality concerns have led to the increased use of storage structures known as litter sheds, which are typically partially enclosed pole type structures, to store the cake. Water quality concerns also have prompted the recommendation that cake not stored in litter sheds be placed in well-drained areas and covered to prevent contaminated runoff and leaching. Litter sheds generally are sized only to provide capacity for cake storage because of cost. Thus, because of the larger volume of litter involved with a total facility clean-out, litter is often stored in temporary outdoor stockpiles when manure storage containment structures are at capacity, and/or immediate land application is not possible.

Broiler operations may add litter amendments, such as alum or sodium bisulfate, between the flocks to acidify the litter and reduce NH_3 levels in the houses. However, amendments were not used on the houses monitored as part of the NAEMS.

2.5 Emissions from Broiler Operations

There are three primary sources of emissions associated with broiler operations: (1) the bird confinement house, (2) manure storage and (3) manure land application site. The NAEMS measured emissions from the confinement house and manure storage facility but did not measure emissions resulting from manure land application.

Gaseous emissions (NH_3, H_2S and VOC) from broiler confinement houses are predominately generated by microbial decomposition of bird manure and other materials (e.g., bedding, waste feed) that accumulate on the house floor. Ammonia and VOC emissions are generated under aerobic or anaerobic conditions while an anaerobic environment (e.g., around bird watering stations in confinement houses) is necessary to form H_2S. Emissions of PM from bird confinement houses are primarily due to the entrainment of dry materials (e.g., feed, litter and feathers) caused by movement of birds and personnel in the confinement house.

3.0 NAEMS MONITORING SITES

This section describes the broiler operations monitored under the NAEMS. Section 3.1 explains the site selection criteria and an overview of the sites selected for monitoring. Section 3.2 describes the facility design and animal management practices followed at each site. Section 3.3 summarizes the instrumentation, measurement methods and sampling frequency specified in the site monitoring plans (SMPs).

3.1 Site Selection

Three broiler farms were selected for the NAEMS based on factors specified in the Agreement. In general, these factors focused on the farm's location, configuration, relative size, participation in the Agreement and whether it was representative of the broiler industry. Two houses were monitored at the California farm, designated as CA1B, and a single house was monitored at each of the Kentucky sites. Table 3-1 provides an overview of the sites and their characteristics, based on the information contained in the Quality Assurance Project Plans (QAPPs), SMPs, and site final reports. More detailed descriptions of each site are provided in the following sections.

Table 3-1. NAEMS Broiler Sites Information

Parameter	Site			
	CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3
Site type	Litter on Floor			
House ventilation type	Mechanically ventilated (MV) (tunnel)			
House capacity (no. of birds per flock)	21,000[a]		24,400 (summer) 25,800 (winter)	
Bird type	60% Cobb, 40% Ross		100% Cobb (mixed sex)	
Average animal residence time, days	47		53	
Average bird weight	2.63 kg (5.8 lb)		2.75 kg (6.1 lb)	
Frequency of full litter clean-out	After three flocks		Annually	
Decaking	After each flock		After each flock	
No. of buildings at site	16		8	24
Year of construction	1960s/2002		1992	1991
Ridgeline orientation	East-West		North-South	
House width	12.2 m (40 ft)		13.1 (43 ft)	
House length	125 m (410 ft)		155.5 m (510 ft)	
House area	1,524 m^2 (16,400 ft^2)		2037 m^2 (21,930 ft^2)	
House spacing	12.2 m (40 ft)		18.3 m (60 ft)	
Ridge height	4.2 m (13.8 ft)		5.2 m (17.2 ft)	
Sidewall height	2.3 m (7.5 ft)		2.1 m (7 ft)	
No. of air inlets	60 sidewall/2 tunnel		52 sidewall	

Table 3-1. NAEMS Broiler Sites Information

Parameter	**Site**			
	CA1B H10	**CA1B H12**	**KY1B-1 H5**	**KY1B-2 H3**
Type of inlet	Baffled eave inlet, 0.18 x 1.32 m (0.6 x 4.3 ft)		Box air inlets 0.15 x 0.66 m (0.5 x 2.17 ft)	
Inlet control basis	Static pressure		Automatic (based on air flow rate)	
No. of ventilation fans	12		14	
Largest fan diameter	1.22 m (48 in)		1.22 m (48 in)	
Smallest fan diameter	0.91 m (36 in)		0.91 m (36 in)	
No. of large fans	10		10	
No. of small fans	2[b]		4	
Spacing between large fans	0.2 m (8 in)		0.2 m (8 in)	
Spacing between small fans	125 m (410 ft)[c]		36.6 m (120 ft)[d]	
No. of ventilation stages	17		12	13
Fan manufacturer	Chore-Time (48 in), Aerotech (36 in)		CanArm	Euroemme
Controls vendor	Chore-Time (48 in), Aerotech (36 in)		Chore-Time	Rotem
Artificial heating	LP Radiant brooders (14), 12.3 kW (42,000 Btu/h)		Pancake brooders (26), 8.78 kW (30,000 Btu/h)	
	LP heaters (3), 52.7 kW (180,000 Btu/h)		Space furnaces (3), 65.9 kW (225,000 Btu/h)	
Summer cooling	Tunnel/evaporative pads		Tunnel/evaporative pads	
Brooding section	East half of house		South half of house	
Monitoring Period	Sept. 27, 2007- Oct. 21, 2009		Feb. 14, 2006 – March 14, 2007	Feb. 20, 2006 – March 5, 2007
Length of monitoring (days)	756		394	379

[a] The NAEMS documentation for site CA1B did not indicate a difference in summer and winter bird placements.

[b] One of the small fans was inactive during the study.

[c] The small fans are located at opposite ends of each house.

[d] The small fans are located along one sidewall of each house.

3.2 Description of Sites Monitored

The NAEMS Monitoring Protocol specified that two broiler sites be monitored as part of the study, one on the west coast and the other in the Southeast to reflect the potential impact of climatic differences and geographical density of broiler production. Furthermore, the NAEMS Monitoring Protocol specified that the houses monitored should be mechanically ventilated with litter-on-the-floor manure handling systems. Final site selection was based on factors outlined in the NAEMS Monitoring Protocol and site-specific factors including facility age, size, design and operation practices and feed and bird genetics.

Both the California and Kentucky sites are representative of the broiler industry in the following aspects: the confinement house design (mechanically ventilated, tunnel), animal management practices (pancake brooder along with space heaters and half-house brooding), and the litter management and handling practices (decaking of houses between flocks with periodic full litter clean-outs).

3.2.1 Site CA1B

The California farm (CA1B) is a 16-house broiler ranch in Stanislaus County, California. Figure 3-1 shows the overall layout of the site, with the two monitored houses (Houses 10 and 12) highlighted. The houses are 125 m (410 ft) long x 12.2 m (40 ft) wide arranged in an east-to-west orientation and are spaced 12.2 m (40 ft) apart. The house roofs have a 4:12 slope with sidewall heights of 2.3 m (7.5 ft).

Each house contains 21,000 birds (per flock) for a total farm capacity of 336,000 birds. Six to seven flocks of birds are raised in each house every year, and all houses are operated on the same grow-out and litter clean-out cycles. The birds housed at the facility over the course of the NAEMS were a 60/40 split between Cobb and Ross genetic varieties and were raised from approximately 0.05 to 2.41 kg (1.1 to 5.3 lb) with an average grow-out period of 47 days. The birds were concentrated in the east (front) end of the houses during the first 10 days of each brooding phase of the grow-out period.

Birds were fed a pelleted diet consisting of corn, soybeans, protein, and poultry fat. Four feed rations were used, specially formulated for weeks 1 and 2, weeks 3 and 4, week 5, and week 6. Feed was delivered to the birds by auger and water consumption was recorded by an automatic water meter. The house lights were turned off for several hours each night. A standby generator supplied power for critical systems during power outages.

Ventilation air entered the house through pressure-adjusted, baffled air inlets at the house eaves (Figure 3-2). The building air was withdrawn from the house using 10, 122-cm (48-inch) diameter belted exhaust fans located in banks of five on both the north and south sidewalls (Figure 3-3). The fans within each bank were spaced 20 cm (8 inches) apart. In addition, a single 91-cm (36-inch) diameter belted exhaust fan was located on the west wall at the back of the house. The fan operation in each house was configured into 8 stages to provide temperature control over the grow-out period. Each house was equipped with six sensors to monitor temperature.

During cooler weather, 14 radiant brood heaters [12.3 kW (42,000 Btu/hr) each] heated the front (east) half of the house, while three liquid propane heaters [52.7 kW (180,000 Btu/hr) each] heated the rest of the house. During warmer conditions, evaporative pads located at the east ends of the houses provided supplemental cooling (Figure 3-4). The evaporative pads were made of a paper product and were 1.2 m (3.9 ft) high, 0.2 m (7.9 inches) deep and 0.3 m (11.8 inches) wide.

Between each flock, the top 20 to 25 percent of the litter was removed from the entire length of the house (i.e., decaking) using a commercial poultry litter removal machine. After decaking, the remaining litter at the front (east end) of the house was moved to the back (west end) of the house and 34.4 m^3 (1,214.8 ft^3) of rice hulls were placed in the front of the house. After three flocks, all litter from the houses was removed (i.e., full litter clean-out). Litter removed from the houses during decaking and full litter clean-out activities was placed in short-term storage piles for two to three days before being taken off site to a fertilizer plant.

Other potential emissions sources near site CA1B were a chick hatchery located approximately 1.6 km (0.99 miles) west of the farm, a 10-house broiler farm located approximately 1.2 km (0.75 miles) to the north-northwest, and a large dairy located approximately 0.8 km (0.5 miles) to the northwest.

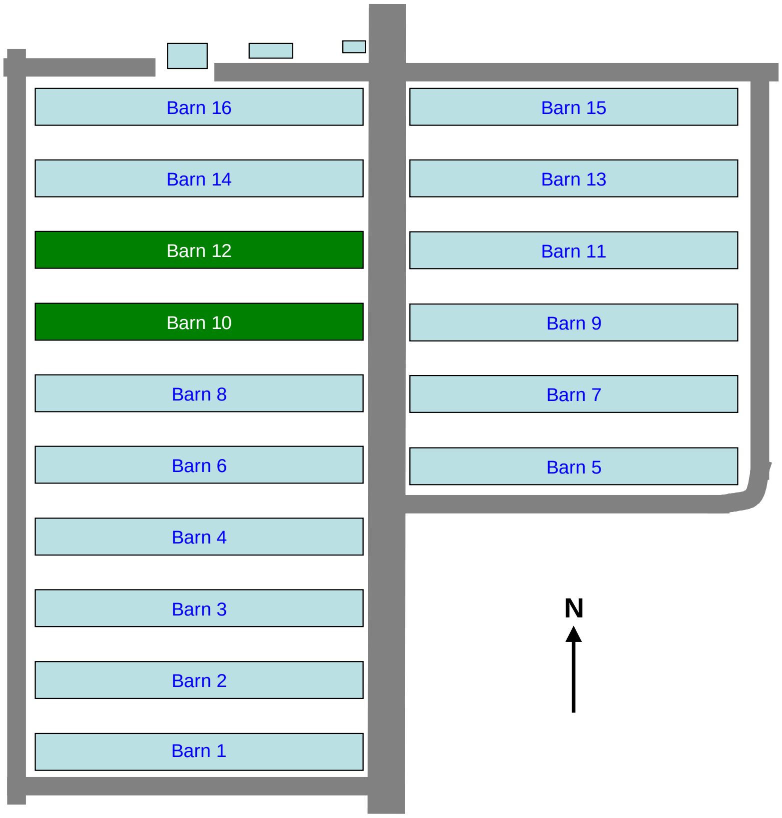


Figure 3-1. California Broiler Site Layout

Figure 3-2. Example House Air Inlet

Figure 3-3. Bank of 122-cm (48-inch) Fans (left, view from inside of house) and (right, view from outside of house)

Figure 3-4. Evaporative Cooling Pads

3.2.2 Sites KY1B-1 and KY1B-2

The two broiler farms, designated as KY1B-1 and KY1B-2, are located in western Kentucky. The KY1B-1 farm has 8 broiler houses and has a total maximum winter capacity of 206,400 birds. The KY1B-2 farm has 24 broiler houses and a total maximum winter capacity of 619,200 birds. Figure 3-5 shows the location of the monitored facilities within Kentucky. The aerial photographs in Figure 3-6 show the locations of the monitored houses at each site.

One broiler confinement house at each farm (designated as KY1B-1 House 5 and KY1B-2 House 3) was monitored. Built in the early 1990s, the two houses each measured 13.1 m x 155.5 m (43 ft x 510 ft). The birds housed during the monitoring period were Cobb-Cobb straight-run (mixed sex) broilers. During the winter, the houses were stocked with an initial placement of 25,800 birds. The initial placement during the summer was 24,400 birds. Typically, the birds were grown to 53 days of market age and an average bird weight of 2.75 kg (6.1 lb).

Each house had insulated drop ceilings, 26 box air inlets [15 x 66 cm (6 x 26 inch)] along each sidewall (see Figure 3-7), 26 pancake brood heaters [8.8 kW (30,000 Btu/hr) each], three space furnaces [65.9 kW (225,000 Btu/hr) each], four 91-cm (36-inch) diameter sidewall exhaust fans spaced approximately 36.6 m (120 ft) apart, and 10, 123-cm (48-inch) diameter tunnel fans. A single 91-cm (36-inch) fan (SW1) used for minimum ventilation was located in the brooding end of each house. Two evaporative cooling pads (24-m (80-ft) sections) were located in the opposite end of the houses from the tunnel fans. The houses were also equipped with foggers for additional cooling, if needed. Rice hulls were used as litter bedding in both houses. Each house was decaked and topped off with fresh litter after every flock, with a full litter clean-out occurring once per year.

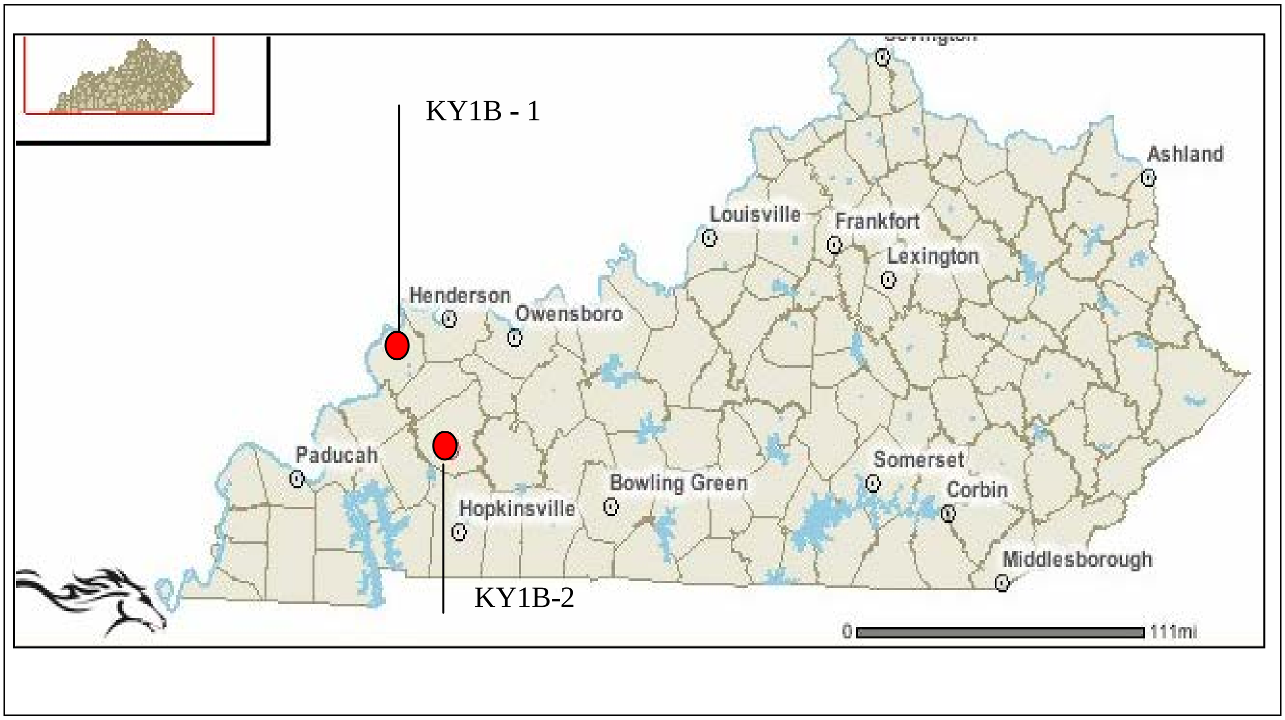


Figure 3-5. Locations of Kentucky Measurement Sites

Figure 3-6. Aerial Photographs of Kentucky Monitoring Sites

Figure 3-7. Tunnel Fans and Box Air Inlets

3.3 Site Monitoring Plans

This section provides a summary of the monitoring conducted at each of the broiler sites. Detailed descriptions of the monitoring program, including monitoring equipment specifications and calibration procedures and frequencies, are provided in Appendix A (QAPPs), Appendix B (SMPs), Appendix C [standard operating procedures (SOPs)], and Appendix D (final site reports).

3.3.1 Site CA1B Monitoring Plan

Figure 3-8 shows the configuration of the house monitoring equipment. Installation and preliminary testing of the monitoring equipment was conducted from May 29, 2007 through September 27, 2007. Monitoring of emissions and process parameters began on September 27, 2007 and was completed on October 21, 2009. Table 3-2 lists the sampling locations by analyte.

The on-farm instrument shelter (OFIS) was positioned between houses 10 and 12 at the far west end houses, with a north/south orientation to minimize interference with vehicle traffic along the driveway west of the houses. The OFIS was positioned somewhat off-center in between the houses to leave enough space on one side for vehicle access.

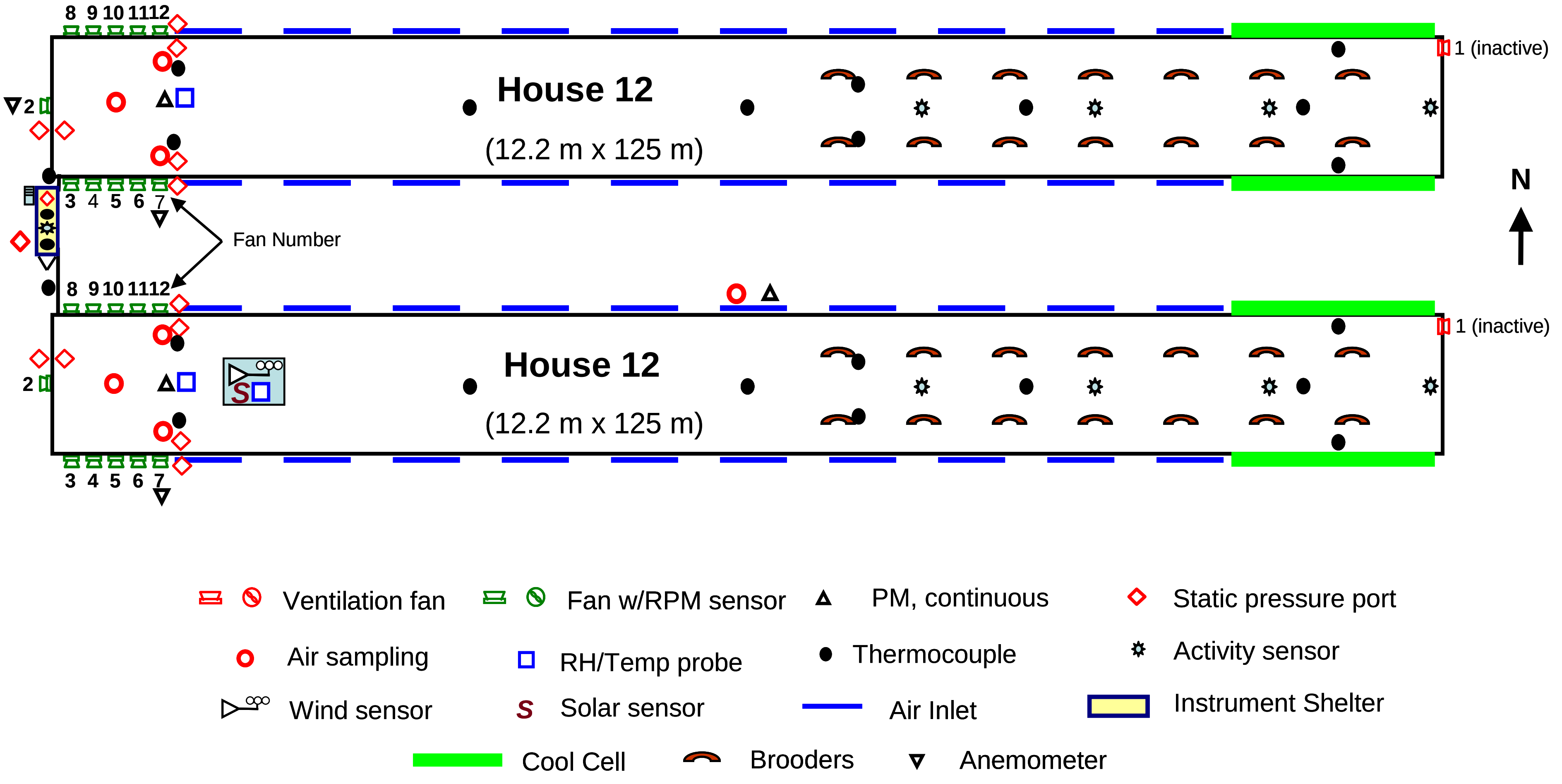


Figure 3-8. Overhead View of Sensor and Air Sampling Locations

Table 3-2. Analyte Sampling Locations at Site CA1B

Analyte	Sampling Location[a]
Gases (continuous measurements for NH_3, H_2S and CO_2)	GSL-A: Directly in front of the inlet of fan 2, along a line connecting fans 5 and 10
	GSL-B: 1 m E of fan 12 and 3 m from N wall
	GSL-C: 1 m E of fan 7 and 3 m from S wall
	INLET: In front of the 5th ventilation inlet from the E end of barn 10 on N sidewall
PM (continuous measurements for $PM_{2.5}$, PM_{10} and TSP)	TEOM: Located 2 m in front of Fan 7
	INLET: Beta-Gage in front of the 5th ventilation inlet from the E end of barn 10 on N sidewall
VOC (grab samples)	1 m E of fan 7 and 3 m from S wall, at fan hub level (GSL-C)

[a] Gas sampling probes were located at fan hub height, suspended from the ceiling. GSL = Gas sampling location.

3.3.1.1 Gas Sampling

A custom-designed gas sampling system (GSS) collected air samples for continuous gas measurements from multiple gas sampling probes located in and near the monitored houses. Each probe was connected to the GSS with Teflon tubing. Tubular raceways between the OFIS and the monitored houses protected the sampling lines and data signal cables. The sampling lines were wrapped with insulation and heated inside the raceways and at other locations vulnerable to cold air to prevent condensation inside the tubes.

The house exhaust emissions were measured using three gas sampling probes (A, B and C) placed in the west end of each house near the exhaust fans at a height equal to the fan hubs (Figure 3-8). Gas sampling probe A was located in front of the inlet of fan 2 and between fans 5 and 10. Two sampling probes (B and C) were located three meters from each sidewall in a cross-sectional plane approximately 1 meter east of fans 7 and 12. Incoming air for both houses was sampled near the air inlet of House 12 at approximately the midpoint (lengthwise) of the house. Other than the exhaust from other houses, the occasional two- to three-day stockpile of litter just outside the far end of the houses was the only on-farm emissions source that could contribute to the concentrations on the inlet air for Houses 10 and 12.

Each exhaust location was sampled and measured continuously for 10 minutes. The inlet air location was monitored for 20 minutes twice daily. After approximately four months of data collection, the gas concentration data were evaluated at each sampling location to determine whether equilibrium occurred within the sampling periods. A statistical analysis confirmed that 10 minutes was sufficient for the exhaust GSLs, but that 30 minutes was required for the house inlet. Consequently, the sampling period for the inlet air was increased from 20 minutes to 30 minutes. Additional detail on the collection method is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP G1). At each sampling location, the gas was analyzed for NH_3, H_2S, non-methane hydrocarbons (NMHC) and CO_2 and the gas analyzer provided concentration readings every second. The average concentration values were recorded every 15 and 60 seconds.

One set of gas analyzers in the OFIS measured gas concentrations as the GSS sequenced through all of the GSLs. A personal computer collected all site monitoring data using a data acquisition and control program (AirDAC). AirDAC averaged the signals (after conversion to engineering units) over 15-second and 60-second intervals and recorded the means into two separate computer files. All real-time data were displayed in tabular and graphic forms for on-site or remote viewing. Measurement alarms, data collection notifications, data files, graphs and statistics of the daily data sets and modified configuration and field note files were automatically emailed to the site investigator and engineer and to the Purdue Agricultural Air Quality Laboratory after midnight each night.

3.3.1.2 PM Sampling

A tapered element oscillating microbalance (TEOM) was placed in each house approximately 6 meters (19.7 ft) in front of fan 7. A Beta Gauge attenuation PM monitor continuously measured the PM concentration of the ambient air. The Beta Gauge was enclosed in a protective outdoor enclosure and was located at the air inlet of House 10. The PM_{10} size-cut heads on the TEOM and Beta Gauge were replaced with $PM_{2.5}$ heads for two, two-week periods over the course of the study, and with TSP heads for one week every 8 weeks (beginning with the first week of data collection).

As shown in Table 3-3, $PM_{2.5}$ emissions were measured in February and July of 2008 and January and September of 2009 continuously for 12 to 18 days each time. The TSP concentrations were measured continuously for six 7- to 14-day periods. Emissions of PM_{10} were measured continuously at all other times. Additional detail on the collection method is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP P1).

Table 3-3. PM Sampling Schedule

Time and Day (mm/dd/yy)		Test Duration (days)		
Start	**Stop**	**PM_{10}**	**TSP**	**$PM_{2.5}$**
9/28/07	12/10/07	73.6	NS	NS
12/10/07	12/19/07	NS	8.9	NS
12/19/07	2/1/08	44.0	NS	NS
2/1/08	2/19/08	NS	NS	18.1
2/19/08	2/20/08	NS	NS	0.3[a]
2/19/08	2/20/08	0.3[b]	NS	NS
2/20/08	5/15/08	85.7	NS	NS
5/15/08	5/28/08	NS	12.8	NS
5/28/08	7/9/08	42.0	NS	NS
7/9/08	7/25/08	NS	NS	16.0
7/25/08	11/17/08	115.1	NS	NS
11/17/08	11/24/08	NS	7.1	NS
11/24/08	1/5/09	41.9	NS	NS
1/5/09	1/20/09	NS	NS	15.0
1/20/09	4/9/09	79.0	NS	NS
4/9/09	4/20/09	NS	11.0	NS
4/20/09	6/25/09	66.1	NS	NS
6/25/09	7/8/09	NS	12.9	NS
7/8/09	9/26/09	80.1	NS	NS
9/26/09	10/7/09	NS	NS	10.9
10/7/09	10/21/09	NS	14.1	NS
10/21/09	10/22/09	0.4	NS	NS
Totals		628.3	66.7	60.3

NS = Not sampled.

[a] For this sampling episode, ambient concentration data were not collected.

[b] For this sampling episode, only ambient concentration data were collected.

3.3.1.3 VOC Sampling

An initial characterization study of VOCs was conducted during the first quarter after site setup at site CA1B. While NMHC were continuously monitored using photoacoustic infrared spectroscopy along with building air-flow rate, periodic grab samples of VOCs were taken at the primary representative exhaust fan location (as defined in the SMPs) of Houses 10 and 12. The purpose of the VOC grab sampling was to obtain data to speciate the NMHC measurements.

During the initial study, three sampling methods were evaluated to determine which method would be used for the remainder of the broiler study: sorbent tubes and Silcosteel canisters for general VOCs, and all-glass bubblers for amines. Each sorbent tube or canister sample was evaluated using gas chromatography – mass spectrometry (GC-MS); amines collected in bubblers were analyzed by ion chromatography (IC). The results of this initial study were used to identify the top 20 analytes by mass. After consulting to determine which of these analytes were present in sufficient quantities to warrant further monitoring, the EPA and the NAEMS researchers determined that canisters would be use to collect periodic VOC samples over the remainder of the broiler monitoring period.

Grab samples of VOCs were collected at fan 7 in Houses 10 and 12 using techniques based on EPA Methods TO-15 and TO-17. Samples were collected using 6-liter (0.2-ft^3) stainless-steel canisters, equipped with 0.64 cm (0.25 in) bellows valves and 207-kPa (30 psi) vacuum gauges. Sampling trains contained flow controllers with 2- to 4-standard cubic centimeters per minute (sccm) (0.12- to 0.24-cubic inches per minute) critical orifices and 7-µm (2.76E-04 in) in-line stainless steel filters. Flow controllers were pre-set to a constant flow rate of 3.4 mL/min (1.2E-04 ft^3/min). Canister sampling was conducted for a 24-hour period, with canister pressures recorded at the beginning and end of each sampling period to calculate total sample volumes. Seven 24-hour sampling episodes were conducted between July 14, 2009 and October 7, 2009, with duplicate samples typically collected at each exhaust location. All canisters were cleaned and passed a quality control inspection before sample collection.

Purdue University’s Trace Contaminant Laboratory analyzed the canister samples. The canisters were pressurized to +207 kPa (30 psi) with ultrapure nitrogen and transferred to sorbent tubes. The pressurized canisters initially yielded sample flows of 50 mL/min (1.8E-03 ft^3/min) during sample transfer to tubes. The canisters were heated when a canister pressure decreased to 13.8 kPa (2 psi) to ensure maximum transfer of nonvolatile components.

Canister samples were analyzed on a thermo-desorption GC-MS, consisting of a GC coupled with a Model 5795 MS detector and equipped with a thermal desorption system and a cooled injection system. The GC-MS passed a leak check prior to analyzing each set of samples. Compounds were separated on a 60 m x 0.32 mm x 1 µm column. The detector utilized the full scan mode covering masses from 27-270 Daltons in 8 scans/second. The MS’s quad hold temperature was 150ºC, and the MS source hold temperature was 230ºC. ChemStation evaluated the analytical results, which manually checked all integrations. This method used an external standard compound for instrument monitoring and quality assurance to avoid losses of low-molecular-weight analytes that would occur when purging solvent used with internal standard(s). All thermal desorption system tubes were cleaned with a conditioning system for 3.5 hour at 350ºC prior to each use.

Response curves were generated at both the beginning and the end of the VOC analysis period. The response curves of all chemical standards reach good linearity as 55 percent of the response curves had $R^2 > 99$ percent and over 98 percent had $R^2 > 95$ percent. Toluene was used as an external standard that was analyzed during each batch of samples to ensure quality. The relative bias and standard deviation of 97 toluene checks were -4.3 percent and 18.8 percent, respectively. The uncertainty of the mean of duplicate field samples was calculated as 27 percent, based on the toluene checks.

3.3.1.4 Building Air Flow

The ventilation air flow for each monitored house was calculated as the sum of the volumetric flow rates for all fans operating over a given time interval. The baseline air flow curves of each type of fan were obtained from the Bioenvironmental and Structural Systems (BESS) Laboratory at the University of Illinois, Urbana-Champaign (Appendix C, SOP A1). Each performance record used to develop the fan curves consisted of air flow measurements (Q1) at several static pressure values (P1), and at relatively constant rotational speeds (N1 = 779 and 550 rpm for small and large fans, respectively). For each fan type, the BESS fan curve was adjusted to the mean speed (N2) of the fan tests (530 and 749 rpm for the large and small fans, respectively). The new, speed-indexed baseline curves were derived using the first ($Q_2 = Q_1(N_2/N_1)$) and second ($\Delta P_2 = \Delta P_1(N_2/N_1)^{0.5}$) fan laws, where Q_2 is the speed-adjusted BESS fan curve at speed N_2. The speed-corrected air flow prediction model is $Q_4 = (a\Delta P_4 + b)\cdot(N_4/N_2)\cdot Q_2$, where ΔP_4 and N_4 are measured fan static pressure and speed.

Rotational speed and operational status of the fans installed in each house were monitored using a magnetic Hall-effect sensors (speed sensor) installed on each fan (except for fan 1 which was inactive). The speed sensors were mounted to detect the rotational speed in revolutions per minute (rpm) of either the fan shaft or the fan pulley. The digital signal from the speed sensor was converted into a frequency measurement with a counter module in the data acquisition system. Additionally, impeller anemometers were installed on the outlet of fans 2 and 7 in House 12 and fan 7 in House 10. The differential static pressure was measured across the north, south and west walls of each house using pressure transducers. The outside port was located against the outside wall near the ventilation fans of the north, south and west walls. Additional detail regarding the air flow calculations is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP A4).

The air flow rate of installed fans was measured using a Fan Assessment Numeration System (FANS). The FANS consists of a housing containing five impeller anemometers mounted horizontally. To measure the flow rate of an individual fan, the housing is centered vertically and horizontally on the exhaust side of the fan to be tested and the anemometer readings provide the average air velocity across a known cross-sectional area. Additional detail on the FANS analyzer is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP A2).

The field data obtained from the FANS were used to develop equations that calculated air flow as a function of differential pressure and fan rotational speed and to assess the uncertainty in air flow predictions. A total of 237 FANS tests with replication were conducted during April and June of 2008 and April, July and September of 2009. Each fan was tested at least once during three or more of the five testing periods. The fan belts had been recently replaced prior to the tests in June 2008. For a given test using the FANS, the model is $Q_4 = (a \cdot \Delta P_3 + b) \cdot (N_3/N_2) \cdot Q_2$, where ΔP_3 and N_3 are the measured fan static pressure and speed during the fan test, and the fan degradation factor $k = a \cdot \Delta P_3 + b$. The values for the coefficients a and b were those that minimized the sum of square differences between Q_4 and Q_3 for all the valid fan tests within a speed regime. Table 3-4 shows the resulting fan models.

Table 3-4. Fan Air Flow Models

Fan Type	Reference Speed (N_2)	Polynomial Coefficients of Q_2=f(ΔP_2) at Speed N_2				Coefficients of k	
		a3	a2	a1	a0	b1	b0
Large	530	2.943E-06	-2.304E-04	4.368E-02	9.412	8.213E-04	0.887
Small	749	1.474E-05	5.108E-04	3.908E-02	5.617	4.196E-03	0.697

3.3.1.5 Meteorological and Confinement Data

At site CA1B, the following meteorological data were continuously recorded: ambient temperature, ambient relative humidity, atmospheric pressure, solar radiation, wind direction, and wind speed. The meteorological instruments (i.e., a capacitance-type relative humidity and temperature probe (RH/T), a pyranometer, and a cup anemometer) were mounted on a 1-meter aluminum tower located on the ridge of House 10 near the OFIS.

To measure the building environmental conditions, RH/T sensors were located at the center of the west end of each house. Type-T thermocouples (TCs) were used to measure temperatures at each sampling point not already monitored with a RH/T probe and were also equally spaced along the center of each house. The TCs were attached to the support posts that ran down the center of the house at 3-meter intervals. Two TCs were located next to the two brooders closest to the OFIS, and two were located at the center of the evaporative pads. A TC was added on April 9, 2009, to monitor the manure temperature in House 12 at floor level.

Thermocouples were also located in the heated raceway between the houses and OFIS. Two TCs were located in the OFIS to measure the temperature of the OFIS and the air-conditioning system. One TC monitored the temperature in the ambient PM monitor enclosure. Additional detail on the collection method is provided in Appendix A (NAEMS QAPP) and Appendix C (SOPs E1 and E2).

3.3.1.6 Animal Husbandry and Building Systems

Infrared motion detectors (activity sensors) were mounted to roof support posts along the center axis of the house to monitor movements of birds and workers. An activity sensor was also used to monitor researcher presence in the OFIS.

The producer recorded data on animal inventory and mortalities manually on a daily basis and provided this information to the NAEMS site personnel. The average mass of the birds between 1 and 47 days old was measured at least weekly during three consecutive cycles of birds. For each measurement period, 25 or 50 birds of each gender (50 or 100 total) were measured in each house and the average mass reported.

The relays that controlled lights, brooders and feeders were monitored in each house using auxiliary contacts in 5V-DC circuits in conjunction with the digital inputs of the data acquisition system.

3.3.1.7 Biomaterials Sampling Methods and Schedule

An independent laboratory, Midwest Laboratories, Omaha, NE, performed all analyses of biomaterials (e.g., litter, bedding). The water provided to the birds in August 2009 was analyzed to evaluate the nitrogen content of the water. Samples of feed and fresh bedding (rice hulls) were collected in duplicate from each house and analyzed for nitrogen and solids. Additional detail regarding the biomaterial sample handling and analyses is provided in Appendix A (NAEMS QAPP) and Appendix C (SOP M1).

On April 15, 2008, the manure mass removed during a full litter clean-out, estimated from the square area and average mass of manure per unit area, was 88,000 kg (97 tons) in House 10 and 79,000 kg (87 tons) in House 12. The total volume of fresh bedding brought into each house on April 18, 2008 after a full litter clean-out was 118 m^3, based on measured litter density.

The estimated volume of litter removed by the decaking procedure was 30 to 45 m^3 (1,059 to 1589 ft^3), based on the volume of manure removed from a house on December 31, 2007, and the average volume of litter removed from multiple houses on January 2, 2008. The amount of bedding used to replenish litter volume after decaking operations was not specified in the final reports submitted to EPA. The density of decaked litter (474 g/m^3, 0.03 lb/ft^3) was determined from a 15.3-liter (0.54-ft^3) sample.

Three types of manure samples were collected: surface litter, decaked litter and litter removed during full clean-out. Surface litter samples were collected over the grow-out period from 16 random locations per house, including 8 samples from the front of the house with relatively fresh litter and 8 from the back of the house with the older litter. The two groups were considered representative of the house litter. At each sampling point, all litter within a 0.6-m radius was brought to the center of the sampling location and mixed thoroughly. Composite samples from the mixtures were analyzed for pH, solids and NH_3. Decaking and complete litter clean-out samples were collected from the blended litter pile before it was removed from the site. A total of 12 samples were collected for each litter decaking and clean-out event and analyzed for ash (after December 2, 2008), nitrogen and solids content.

3.3.2 Sites KY1B-1 and KY1B-2

Figure 3-9 and Figure 3-10 show the schematics of the monitoring plan for the Kentucky sites, and Table 3-5 lists the locations at which the various samples were collected. Equipment was installed by January 06, 2006, and preliminary testing was completed on February 10, 2006. The monitoring periods ran from February 14, 2006, through March 14, 2007, for KY1B-1, and from February 20, 2006, through March 5, 2007, for KY1B-2.

Each broiler house has its own Mobile Air Emissions Monitoring Unit (MAEMU) that contains the air pollutant and fan flow monitoring systems and provides an environmentally-controlled instrument area. Locations of the MAEMU are noted in Figure 3-9 as the “trailer.” Figure 3-10 shows a cross-section view of monitor placement. Heated raceways connected the MAEMU to each house to avoid condensation in the sampling lines during cold weather.

Table 3-5. Analyte Sampling Locations at Sites KY1B-1 and KY1B-2

Analyte	Sampling Location
Gases (continuous measurements for NH_3, H_2S, NMHC, CO_2)	SW1: near the primary minimum ventilation (36-in) sidewall fan (SW1); 1.2 m (4.0 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor
	SW3: fourth sidewall (36-in) exhaust fan (SW3) (non-brooding end); 1.2 m (4.0 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor
	TE: tunnel end (TE); at the center across the house (for example, 6.6 m or 21.5 ft from each sidewall) and 7.3 m (24.0 ft) from the end wall
	A: ambient sample location (A) is between the inlet boxes opposite of the sidewall with the exhaust fans
PM (continuous measurements for $PM_{2.5}$, PM_{10}, TSP)	TEOM: During the brooding period, the TEOMs are placed at SW1 sampling location. When the brood curtain is open, the TEOMs are moved to the TE sampling location.

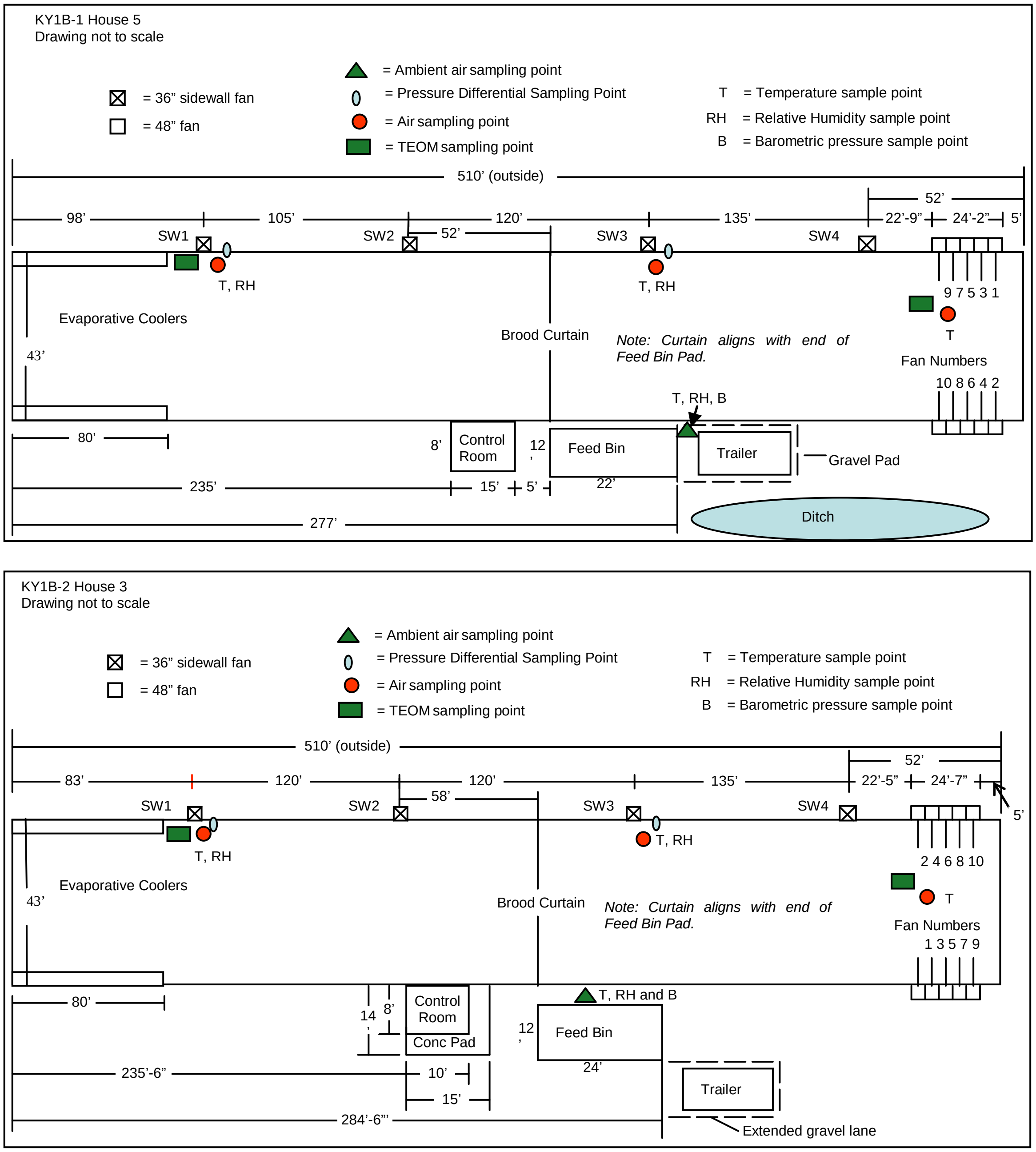


Figure 3-9. Schematic of KY1B-1 (top) and KY1B-2 (bottom)

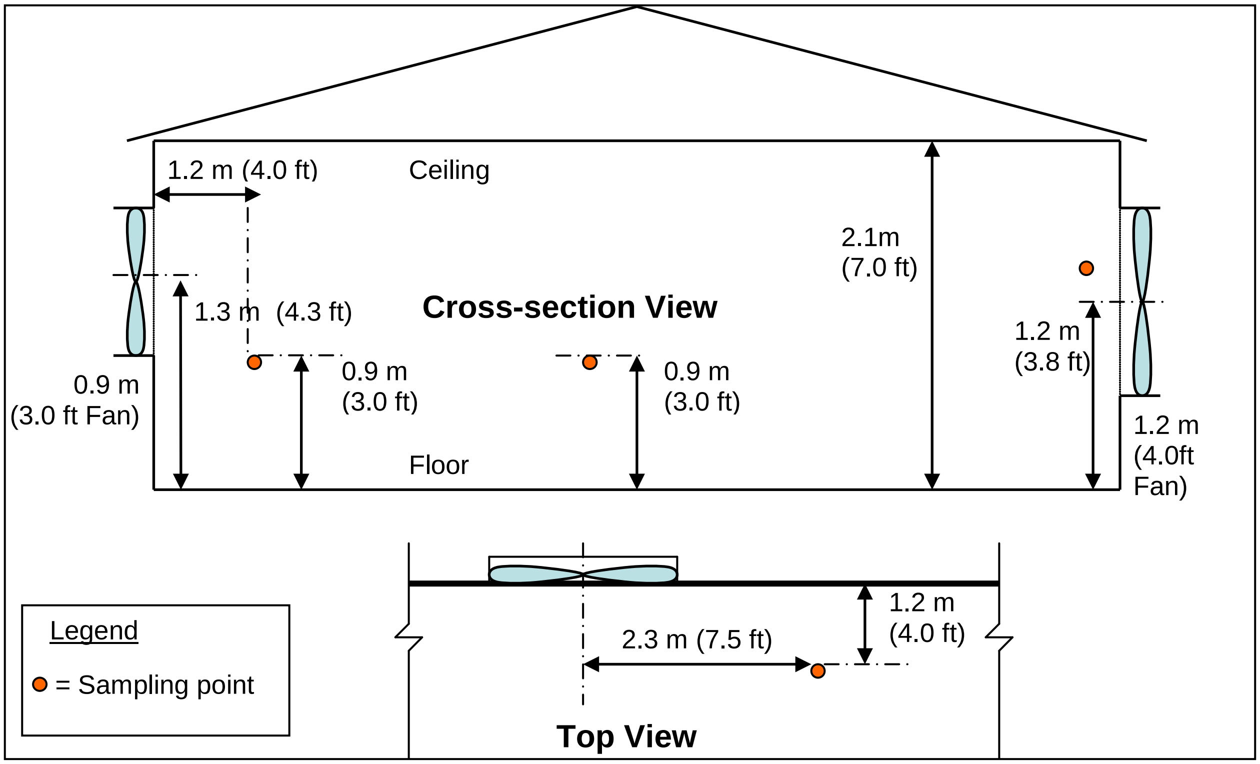


Figure 3-10. Cross-sectional View of Sidewall Sampling Locations

3.3.2.1 Gas Sampling

Individual air samples for both in-house and background locations were collected using a GSS that was designed to collect samples from four locations on a cyclical basis. Gases and PM were sampled when the house ventilation system was in operation. Gaseous emissions were sampled continuously on a 120-second interval (i.e., samples were continuously collected and analyzed every 30 seconds, with every fourth concentration value used to calculate emissions). A real-time data acquisition (DAQ) system program developed with LabView 7 was used to acquire data, automate sampling location control, display real-time data and deliver data and system operation status.

Air samples moving from the broiler house sampling points (representing the exhaust air streams) to the instrument trailer/analyzers were protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable. The samples were pumped into the GSS with pumps on its inlet side, making it a positive-pressure system. Using this approach ensured that the integrity of the gas sample was not compromised if a leak developed at any connection point on the GSS.

Three sampling points were located inside each broiler house at two sidewall fans and at the tunnel end. The fourth sampling point was located outside of the broiler house and was used as the ambient measurement point for background concentration determination. Figure 3-9 shows the location of the sampling points in KY1B-1 and KY1B-2. One sampling location was near the primary minimum ventilation sidewall fan (SW1) used for cold weather ventilation (in the brooding half of the house). The second sampling location was near the third sidewall fan (SW3, nonbrooding end). The third location was at the tunnel end (TE). The ambient sample location (A) was between the inlet boxes opposite of the sidewall with the exhaust fans. The mass of pollutant in the background (inlet) air was subtracted from that in the exhaust air when calculating aerial emissions from the house.

Hydrogen sulfide was measured by ultraviolet (UV) pulsed fluorescence analyzer. Concentrations of NMHC were measured with a methane/nonmethane/total hydrocarbon analyzer using column technology to separate methane and nonmethane from total hydrocarbons and a dual flame ionization detector (FID) to measure each component in the air sample. Concentrations of NH_3 and CO_2 for the ambient (or incoming air) and exhaust air were measured with an advanced photoacoustic multigas analyzer.

Every two hours, air samples from the ambient location were collected and analyzed for 8 minutes. The longer sample analysis time for the ambient point was to account for the longer response time of the instrument when measuring a potentially large step change in gas concentration. The 2-hour interval for the analysis of the ambient concentrations was selected because the ambient conditions remained relatively constant compared to the in-house conditions.

3.3.2.2 PM Sampling

Each of the Kentucky sites was equipped with a TEOM monitor to measure the PM mass concentration of the exhaust air. Three different inlet heads were used on the TEOMs to simultaneously measure TSP, PM_{10} and $PM_{2.5}$ continuously over the study period. The TEOM 1400a is a gravimetric instrument that draws ambient air through a filter at a constant flow rate, continuously weighing the filter and calculating near real-time mass concentrations. The mass concentration was recorded at 1-second intervals and the average readings, which were correlated to the INNOVA 1412 sampling interval, were used for the PM emissions calculation provided in the final report for the Kentucky sites.

Due to concerns that the TEOMs might not function properly under high-velocity conditions near the exhaust fan, an in-house evaluation of the TEOM performance was conducted to determine the optimal placement of the instruments. The first phase of testing consisted of assessing the TEOM performance in air velocities ranging from 1.3 to 6 $m \cdot s^{-1}$ (250 to 1200 feet per minute) and revealed that the TEOM readings are unaffected by the tested air velocity range. In the second phase of testing, the TEOMs were placed near the center of the house. Comparison of TEOM readings taken near the house center versus near the exhaust location revealed that concentrations near the exhaust were generally lower than concentrations near the center of the house. Because velocity showed no impact on the concentration measurement and the goal of the NAEMS was to quantify the emissions going out of the house, the TEOMs were located near the exhaust fan(s).

During the half-house brooding period, the TEOMs were placed near SW1, 0.6 m (2 ft) from the fan in the axial direction. The individual monitors were located at different distances in the radial direction: the TSP TEOM was located 1.1 m (3.5 ft) to the left of the fan, the PM_{10} TEOM was 1.1 m (3.5 ft) to the right of the fan, and the $PM_{2.5}$ TEOM was located 2.2 m (7 ft) to the right of the fan. After the birds were released into the full house (between 10-14 days old), the TEOMs were moved to the tunnel end sampling location: 4.9 m (16 ft) from the tunnel fan in the axial direction. The TSP TEOM was located 11 m (36 ft) from the tunnel end of the house, the PM_{10} TEOM was located 9.8 m (32 ft) from the tunnel end of the house, and the $PM_{2.5}$ TEOM was located 8.5 m (28 ft) from the tunnel end of the house. Figure 3-9 shows the TEOM sampling locations. Additionally, the TEOMs were placed outside the broiler houses to measure the ambient background PM concentrations at KY1B-1 from March 22 to April 21, 2007.

3.3.2.3 VOC Sampling

The NAEMS Monitoring Protocol specified using EPA TO-15 to speciate NMHC emitted from these facilities. Stainless steel canisters were used to collect the air samples from the two broiler houses; a GC-MS method was used to speciate the NMHC compounds. A solid sorbent method (TO-17) was used simultaneously to collect the air samples on glass sorbent tubes. Sample collection and speciation trials were conducted on April 19, 2006, at KY1B-2 (empty house) and on February 6, 2007, at KY1B-1 (with birds in house). The air samples were collected from nine different locations throughout the whole house, including each air sampling location (Figure 3-11). The top 25 compounds were speciated with the TO-15 and TO-17 methods.

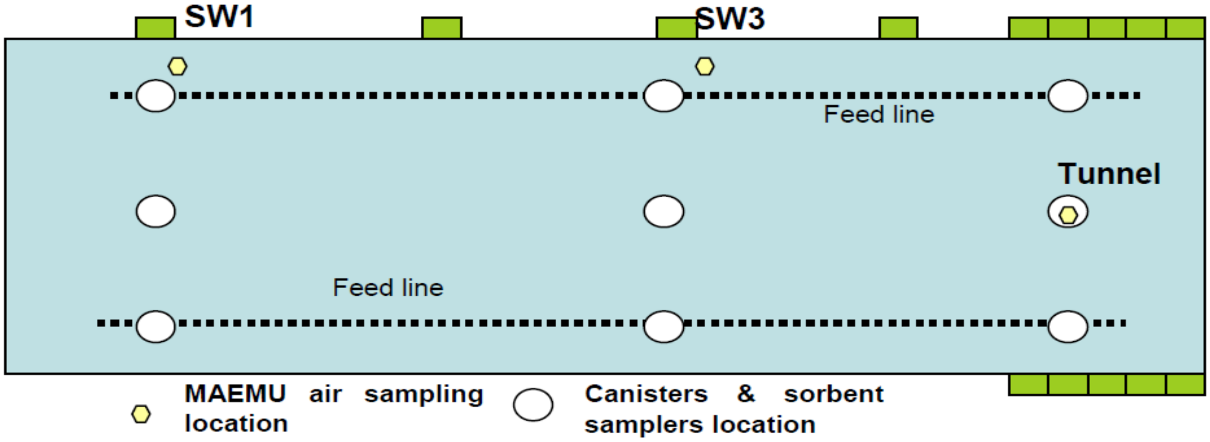


Figure 3-11. Analyte Sampling Locations

3.3.2.4 Building Air Flow

The running time of each fan was monitored continuously using an inductive current switch (with analog output) attached to the power supply cord of each fan motor. The voltage signal from induction current switches attached to the fan power cords were sampled every second and recorded every 30 seconds as the average or duty cycle of the time interval.

Static pressure was measured continuously at SW1 and SW3 locations with a differential pressure transducer. These locations provided building static pressure measurements in both brooding and nonbrooding portions of the production houses.

Ventilation rates of the houses were measured using the following procedure. First, all exhaust fans were calibrated in situ, using a FANS unit to obtain the actual ventilation curves (air flow rate versus static pressure). The FANS measured the total air flow rate of a ventilation fan by integrating the intake velocity field obtained from an array of five propeller anemometers used to perform a real-time traverse of the air flow entering ventilation fans of up to 122 cm (48 in) diameter.

At the beginning of the study, all 14 ventilation fans in each house were calibrated by FANS and fan curves were developed. Three to four fans in each house (at least 20 percent of the total fans) were randomly chosen and calibrated at the beginning of each flock for retesting. If differences in the fan flow rate from the previous calibration were greater than 10 percent, all fans were recalibrated.

Fan ventilation rates (cfm) for each running fan were determined using the building static pressure difference (SP, Pa) and the calibration equation for the fan, as follows:

$$Q_{FAN} = A*(\text{Static pressure, inch})^2 + B*(\text{Static pressure, inch}) + C$$

The parameters A, B and C are fan-specific and were obtained from regression of the FANS calibration data (see Table 3-6 and Table 3-7).

Summing air flows from the individual fans during each monitoring cycle or sampling interval produces the overall house ventilation rate, $Q'_{o.}$ When large spatial variations were noted, the building ventilation rate was broken into representative amounts near each sampling location, typically two values in the broiler house (e.g., $Q'o_1$ and $Q'o_2$).

Table 3-6. Fan Air Flow Models for KY1B-1

Ventilation Rate, cfm = A * (Static Pressure, inch)^2 + B * (Static Pressure, inch) + C												
Fan ID	**September 2005**			**December 1, 2005**			**February 11, 2006**			**April 11, 2006**		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Fan 1	11719	-27449	10948	-125719	239.9	9866.7	-16193	-16591	10708	-16193	-16591	10708
Fan 2	-74375	-12522	10800	-70156	-11629	11127	Not Tested	Not Tested	Not Tested	-52411	-16095	10832
Fan 3	-35469	-21136	9937	43670	-34956	11246	-51604	-13056	10257	-816.07	-20832	9627.9
Fan 4	-53750	-18508	10279	-47062	-14441	10175	Not Tested	Not Tested	Not Tested	59937	-39618	11259
Fan 5	-73750	-61360	17624	-5010469	11666	16847	-145497	-53723	18821	-191642	-41800	17382
Fan 6	102500	-112015	19647	-109817	-54465	17997	-5190.3	-76587	19018	-65045	-71060	18277
Fan 7	-98750	-81440	19707	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-33831	-66266	17584
Fan 8	2578.1	-96907	20675	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-561449	10225	16769
Fan 9	48984	-96008	19035	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	265002	-112655	18225
Fan 10	215885	-132748	21203	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-248939	-26295	17682
Fan 11	-42266	-82438	18652	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	96907	-99875	18616
Fan 12	-26562	-83028	20131	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-48248	69382	18460
Fan 13	109609	-117881	20425	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	306517	-143433	20552
Fan 14	79219	-94836	18649	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	212523	-122196	19134

Table 3-7. Fan Air Flow Models for KY1B-2

Ventilation Rate, cfm = A * (Static Pressure, inch)^2 + B * (Static Pressure, inch) + C												
Fan ID	**July 2005**			**December 5, 2005**			**February 24, 2006**			**May 15, 2006**		
	A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Fan 1	6403.3	-29082	9642.3	-7821.1	-15676	9297.3	-29807	-10340	9111.9	-60966	-8426.1	9398.9
Fan 2	-47858	-14388	9846.4	-114105	9241	8425.6	Not Tested	Not Tested	Not Tested	-40028	-14290	9866.8
Fan 3	42656	-28816	9237.6	21546	-21872	9493.6	43247	-31819	9871.6	-19403	-22317	9747.8
Fan 4	-3342	-24017	10554	8613	-25464	9858.8	Not Tested	Not Tested	Not Tested	47951	-31092	9314.6
Fan 5	253372	-96967	20933	Not Tested	Not Tested	Not Tested	-85076	-9593.1	19509	-78261	-9195.9	19489
Fan 6	-253576	-17841	21085	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-1244.4	-40277	23232
Fan 7	-152966	-26838	18408	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-139947	-9577.2	18517
Fan 8	-44395	-38509	19075	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-114366	-13120	19272
Fan 9	82765	-51069	17839	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-160782	-6965.8	18436
Fan 10	-117396	-17837	17937	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-237136	8013.3	17526
Fan 11	-634085	42869	16708	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-69097	-24168	19206
Fan 12	6932	-30806	22119	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-29634	-18754	21888
Fan 13	-20851	-21422	17939	-66950	-21004	19478	Not Tested	Not Tested	Not Tested	7527	-17373	16694
Fan 14	48860	-41344	17014	-96405	-11609	16430	982.46	-30137	17273	-76565	-38454	20420

Table 3-8. Fan Air Flow Models for KY1B-2 (continued)

Ventilation Rate, cfm = A * (Static Pressure, inch)^2 + B * (Static Pressure, inch) + C												
Fan ID	July 18, 2006			September 28, 2006			December 11, 2006			February 8, 2007		
	A	B	C	A	B	C	A	B	C	A	B	C
Fan 1	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-56437	-6311.5	9349.2
Fan 2	-145370	5525	8548.6	-5730.9	-21492	9959.2	-41252	-13429	9946.1	34189	-24934	10124
Fan 3	-46087	-11251	8220.3	Not Tested	Not Tested	Not Tested	2252.3	-23655	9707.6	-43170	-13533	9322.3
Fan 4	Not Tested	Not Tested	Not Tested	-41312	-13038	8456.6	-1771	-23136	9631.9	49357	-30704	9771.2
Fan 5	Not Tested	Not Tested	Not Tested	-18949	-24356	20541	-66110	-7306.8	19526	Not Tested	Not Tested	Not Tested
Fan 6	90002	-63514	23180	Not Tested	Not Tested	Not Tested	-30536	-24754	22502	Not Tested	Not Tested	Not Tested
Fan 7	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 8	Not Tested	Not Tested	Not Tested	-118262	-8942.8	17835	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 9	3095	-39533	19275	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 10	Not Tested	Not Tested	Not Tested	-210356	16026	16108	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 11	Not Tested	Not Tested	Not Tested	-86591	-21761	19710	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 12	47400	-37407	21819	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 13	-120124	-14919	19103	-89008	-18498	19600	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested
Fan 14	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	Not Tested	-86552	-9773	15676	Not Tested	Not Tested	Not Tested

3.3.2.5 Meteorological and Confinement Data

Ambient and confinement temperature and relative humidity were measured type-T TCs and electronic relative humidity transmitters that were connected to the PC-based DAQ. In addition, portable RH/T loggers were used as back-ups. Ambient air samples were taken near the MAEMU (see Figure 3-9). Building temperature and relative humidity probes were placed adjacent to the SW1, SW3 and TE air sampling points (see Figure 3-9).

3.3.2.6 Animal Husbandry and Building Systems

The study conducted at the Kentucky sites did not track animal activity with infrared motion sensors. The only activity information regarding animal movement in and out of the house was recorded by the producer.

Farm personnel at the Kentucky sites manually recorded the daily animal inventories and mortalities and provided the data to the NAEMS site personnel. Similarly, farm personnel were to provide information regarding the operation of the lights and feeders within the monitored houses; however, this information has not yet been submitted to EPA.

3.3.2.7 Biomaterials Sampling Methods and Schedule

Biomaterial sampling for the Kentucky portion of the study was limited to litter sampling. All litter samples were processed by the Agricultural Waste Management Laboratory in the Department of Agricultural and Biosystems Engineering at Iowa State University.

Litter from the production houses was sampled after the removal of each flock and analyzed for pH, moisture content, NH_3 and total Kjeldahl nitrogen. Analyzed samples, in conjunction with litter mass removed during clean-out, were used to estimate nongaseous nitrogen movement in and out of the house.

Two types of litter samples were collected: total litter and caked litter. For total litter sampling, the broiler house was divided into nonbrooding and brooding zones. Each zone was then subdivided into three sections: sidewall, waterer and feeder and central. Twenty random samples were collected from each section and pooled together to form one composite sample per section (three composite samples per zone). Figure 3-12 illustrates the zone and section for the house and an example sampling scheme to demonstrate the distribution of samples through the zones. Caked litter samples were also collected by taking shovel samples from each load of removed cake and combining them to form two 20-L samples.

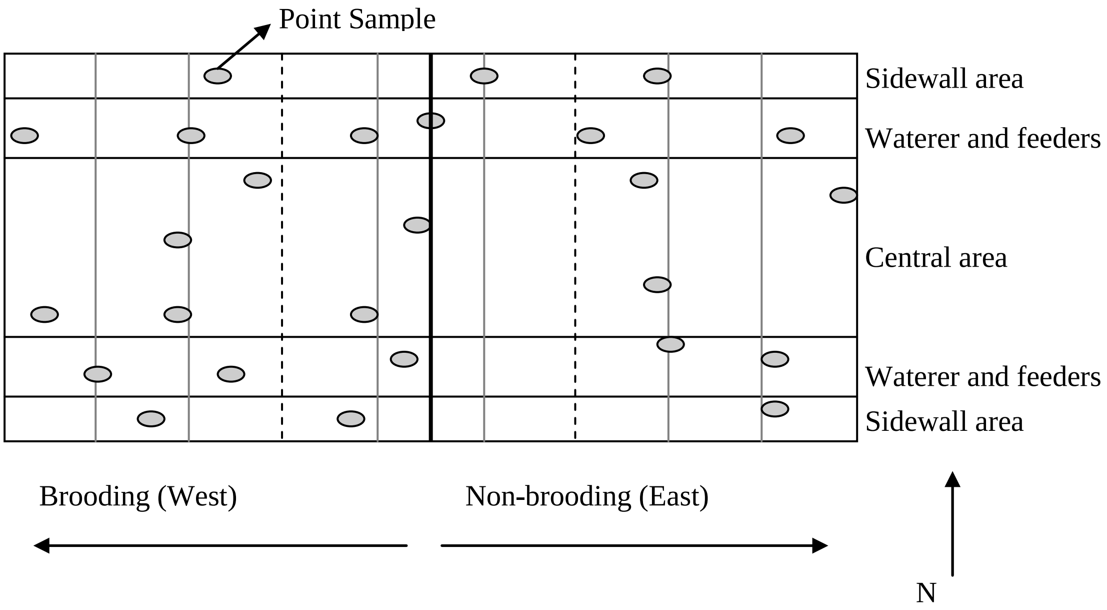


Figure 3-12. Schematic of Litter Sampling Locations

4.0 DATA AVAILABLE FOR EEM DEVELOPMENT

In the Air Compliance Agreement, the EPA committed to developing EEMs for estimating daily and annual emissions from broiler confinement operations using the emissions and process data collected under the NAEMS and any other relevant data and information that are available. Section 4.1 summarizes the NAEMS emissions and process data for broiler confinement operations. Section 4.2 discusses the other relevant data that the EPA has gathered both under a Call for Information (CFI) that was issued by the EPA on January 19, 2011, and through previously-conducted literature searches.

4.1 NAEMS Data

4.1.1 Data Received

The EPA received final reports and data spreadsheets for the CA1B, KY1B-1, and KY1B-2 monitoring sites. In general, the final reports for each site describe the monitoring locations and sampling methods and present the results of the emissions measurements expressed in various units (e.g., annual average emissions in kg NH_3/bird, maximum daily emissions in kg NH_3/bird). For site CA1B, the final report also contained the results of the chemical composition analyses of materials (e.g., nitrogen content of feed) conducted to support the nitrogen mass balance, as well as notes of significant events and modifications to farm practices that occurred over the monitoring period. Appendix D contains the final reports submitted for each monitoring site. The data spreadsheets submitted for each site contains the emissions and process parameter values calculated from continuous measurements. Table 4-1 identifies the information and data submittals for each monitoring site.

Table 4-1. Information and Data Submitted

Site	Description	Submitting Entity
CA1B	Microsoft Excel® spreadsheet containing: daily average values for NH_3, H_2S, PM_{10}, $PM_{2.5}$ and TSP emissions; confinement parameters; meteorological parameters; bird inventory and bird weight and periodic VOC sampling results	Purdue University
	Final report (PDF file)	
KY1B-1 and KY1B-2	Microsoft Excel® spreadsheets containing: 1-second and 30-second sampling data; bird performance data; individual ventilation fan calibration curves and containing daily average data for inventory and weight and pollutant emissions per house and per animal unit	Iowa State University
	Microsoft Excel® spreadsheets containing: daily average values for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOC emissions; building ventilation rate; bird inventory and bird weight	
	Final report (PDF file)	

To increase public involvement and maintain transparency throughout the EEMs development process, the EPA has made information and data relating to the NAEMS available at http://www.epa.gov/airquality/agmonitoring/. This website provides links to background information regarding the Air Compliance Agreement, the NAEMS (including information describing the monitoring sites, site-specific data files and final reports), and the CFI. Additionally, the EPA has included all information received pertaining to the NAEMS in the public docket (EPA Docket ID No. EPA-HQ-OAR-2010-0960), which is available at: http://www.regulations.gov.

Table 4-2 summarizes the emissions and process data elements that were required to be monitored by either the NAEMS Monitoring Protocol, the QAPPs, the SMPs or the SOP documents submitted to the EPA. The NAEMS Monitoring Protocol was developed in a collaborative effort by representatives from the EPA, USDA, AFO industry representatives, agricultural researchers, state and local air quality agencies and environmental organizations. The NAEMS Monitoring Protocol identified the parameters to be monitored during the study and, for some parameters, specific measurement methodologies and frequencies. For those parameters for which either or both the measurement methodology and frequency was not specified, the information was provided in the study's QAPP (Appendix A). Table 4-2 also provides specific information regarding data availability that is based upon the EPA's review of the final reports and data spreadsheets. During its review of the final reports and data spreadsheets, the EPA identified missing emissions and process data. Section 5 summarizes the issues and discrepancies identified by the EPA's review.

The EPA's review of the data spreadsheets also identified negative daily average emissions values for H_2S and PM_{10} for certain days at site CA1B (see Section 5). After discussion with the study's Science Advisor, it was determined the negative values were a result of instrumentation drift, and are considered to be valid values. To avoid possible complications with EEM development (e.g., the EEM predicting negative emissions), the negative values were withheld from the data sets used for EEM development. The amount of measured negative values is low (less than 1.7 percent) compared to the total number of emissions records for H_2S and PM_{10}, which indicates that the steps taken to calibrate and maintain instrumentation and to minimize the influence of other on-site sources on ambient H_2S and PM_{10} emissions were reasonably effective. Because of their relatively small number, excluding the negative values does not compromise the EEM data sets for H_2S and PM_{10}.

The EPA's review of the data spreadsheets also identified daily average emissions and parameter values that were exactly zero. After further review and discussion with the study's Science Advisor, it was determined the values were valid reported values and were used for EEM development.

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
Parameter	Required by the NAEMS Monitoring Protocol	Measurement Methodology	Measurement Frequency	CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
				Data Description	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency
Emissions									
NH$_3$	Yes	Chemiluminescence or photoacoustic infrared	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	Photoacoustic infrared	Logged every 15 & 60 seconds, for 24 months; daily averages provided	Average measured concentration values and average calculated emission rate values	Photoacoustic infrared	Sampled continuously at 120-second intervals for 12 months; daily averages provided
H$_2$S	Yes	Pulsed fluorescence	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	Pulsed fluorescence	Logged every 15 & 60 seconds, for 24 months; daily averages provided	Average calculated emission rate values	UV Pulsed fluorescence	Sampled continuously at 120-second intervals for 12 months; daily averages provided
TSP	Yes	Isokinetic multipoint gravimetric method	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	TEOM for representative exhaust locations in the house, and the TFS FH62-C-14 Beta Monitor for inlet air locations	Logged every 15 & 60 seconds, for six 7- to 14-day periods; Daily average provided	Average calculated emission rate values	TEOM, Reference Method number EQPM-1090-79	Recorded at 300-second intervals for 12 months; daily averages provided
PM$_{10}$	Yes	Real-time measurements using the TEOM at representative exhaust locations in the house and ambient air	24 months with data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	TEOM for representative exhaust locations in the house, and the TFS FH62-C-14 Beta Monitor for inlet air locations	Logged every 15 & 60 seconds. Daily average provided.	Average calculated emission rate values	TEOM, Reference Method number EQPM-1090-79	Recorded at 300-second intervals for 12 months; daily averages provided
PM$_{2.5}$	Yes	Gravimetrically with a federal reference method for PM$_{2.5}$	Measured at least for 1 month per site; data logged every 60 seconds	Average measured concentration values and average calculated emission rate values	TEOM for representative exhaust locations in the house, and the TFS FH62-C-14 Beta Monitor for inlet air locations	Logged every 15 & 60 seconds for February and July, 2008, and January and September, 2009 for 12 to 18 days each time; daily averages provided	Average calculated emission rate values	TEOM, Reference Method number EQPM-1090-79	Recorded at 300-second intervals for 12 months; daily averages provided
CO$_2$	Yes	Photoacoustic infrared or equivalent	24 months with data logged every 60 seconds	Data not available[a]	Photoacoustic infrared	Logged every 15 & 60 seconds, for 24 months;	Average calculated emission rate values	Photoacoustic infrared	Sampled continuously at 120-second intervals for 12 months; daily averages provided

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				**NAEMS Data**					
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**CA1B (Houses 10 and 12)**			**KY1B – 1 House 5 and KY1B – 2 House 3**		
				Data Description	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
Non-methane hydrocarbons (NMHC) emissions (continuous)	Yes	NMHC – dual channel FID analyzer (Method 25A)	24 months with data logged every 60 seconds at one site	Data not available[a]	Photoacoustic infrared	Logged every 15 & 60 seconds, for 24 months; daily averages provided	Average calculated emission rate values	Dual-channel flame ionization detector (FID)	Daily for 12 months
VOC (Characterization Study)	Yes	Total nonmethane hydrocarbons (NMHC) – Dual-channel FID analyzer (Method 25A) VOC - concurrent gas chromatography-mass spectrometry (GC-MS) and GC/FID for TO 15 and other FID-responding compounds	Conducted on 1 day during the first month at the first site	Target VOC compounds for subsequent continuous monitoring and speciation	Canisters, sorbent tubes and glass impingers used to collect VOC samples	One sampling episode using canisters, sorbent tubes and glass impingers, and one sampling episode using sorbent tubes	Target VOC compounds for subsequent continuous monitoring and speciation	EPA TO-15 EPA TP-17	Two sampling events (9 locations in each house)
VOC (grab samples)	Yes	VOC – concurrent GC-MS and GC/FID for TO 15 and other FID-responding compounds.	Continuous for 24 months with data logged every 60 seconds Quarterly samples using selected VOC sampling method at all sites	Concentration and emissions for each day that the VOC samples were taken and the overall averages	Canisters	24 hour canister samples taken every 3 months	Data not collected[b]		
Confinement Parameters									
Bird activity	Yes	Not specified		Data not received[c]	Passive infrared detector	Logged every 15 & 60 seconds for 24 months	Data not collected[b]		
Manure handling	Yes	Not specified		Not applicable (litter periodically removed using manual methods)		End of grow-out periods	Not applicable (litter periodically removed using manual methods)		End of grow-out periods
Lighting	Yes	Not specified		Data not received[c]	Relays for recording on/off status	Logged every 15 & 60 seconds for 24 months	Data not received[c]	Not specified	Not specified
Heating/cooling operation	Yes	Not specified		Data not received[c]	Relays for recording on/off status	Logged every 15 & 60 seconds for 24 months	Data not collected[b]		

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
Floor and manure temperatures	Yes	Not specified		Data not received[c]	Thermocouple	Logged every 15 & 60 seconds for 24 months	Data not collected[b]		
Bird production & mortality (inventory)	Yes	Monitored with producer assistance (Methodology not specified)	Not specified	Daily average number of birds and bird age	Producer records	Daily	Daily average number of birds and bird age	Producer records	Daily
Animal weight gain/loss	Yes	Not specified		Daily average weight	Portable livestock scale	Daily	Daily average weight	Automatic scale	Daily
House ventilation air flow	Yes	Measure fan operational status and static pressure to calculate fan air flow from field-tested fan performance curves and by directly measuring air flow of selected fans using anemometers.	Continuous	Daily average ventilation rate	Measure fan operational status and static pressure to calculate fan air flow from field-tested fan performance curves and by directly measuring selected fan air flows using anemometers	Logged every 30 seconds, for 24 months	Daily average ventilation rate	Measure fan operational status and static pressure to calculate fan air flow from field-tested fan performance curves and by directly measuring selected fan air flows using anemometers	Logged every 30 seconds for 12 months
House temperature	Yes	Not specified		Daily average values	Type T thermocouples	Logged every 15 & 60 seconds for 24 months; daily averages provided	Daily average values	Type T thermocouples	Logged every second
House relative humidity	Yes	Not specified		Daily average values	Capacitance-type RH/T probes	Logged every 15 & 60 seconds for 24 months; daily averages provided	Daily average values	Relative humidity probe	Logged every second
Wind speed	Yes	Not specified		Daily average values	Cup anemometer	Logged every 15 & 60 seconds for 24 months; daily averages provided	Data not collected[b]		
Wind direction	Yes	Not specified		Daily average values.	Cup anemometer	Logged every 15 & 60 seconds for 24 months; daily averages provided	Data not collected[b]		
Solar radiation	Yes	Not specified		Daily average values.	Pyranometer	Logged every 15 & 60 seconds for 24 months; daily averages provided	Data not collected[b]		

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	**Required by the NAEMS Monitoring Protocol**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**	**Data Description**	**Measurement Methodology**	**Measurement Frequency**
House differential static pressure	Yes	Not specified		Daily average values.	Pressure transducer	Logged every 15 & 60 seconds for 24 months; daily averages provide.	30-second average values	Pressure transducer	Logged every second
Ambient temperature at site	Yes	Not specified		Daily average values	Solar radiation shielded capacitance-type RH/T probe	Logged every 15 & 60 seconds for 24 months; daily averages provided	Daily average values	Type T thermocouples	Logged every second
Ambient relative humidity at site	Yes	Not specified		Daily average values	Solar radiation shielded capacitance-type RH/T probe	Logged every 15 & 60 seconds for 24 months daily averages provided	Daily average values	RH probe	Logged every second
Nitrogen Mass Balance									
Water consumption rate	Yes	Monitored with producer assistance (methodology not specified)	Not specified	Data not received[c]	Automatic water meter	Not specified	Daily average values	Producer records	Daily
Water Total Kjeldahl Nitrogen (TKN) content	Yes	Not specified		Data not received[c]	Micro-Kjeldahl/ titrimetric	Not specified	Data not collected[b]		
Feed consumption rate	Yes	Monitored with producer assistance (methodology not specified)	Not specified	Data not received[c]	Not specified	Daily	Data not received[c]	Producer records	Each flock
Feed TKN content	Yes	Not specified		Data not received[d]	Micro-Kjeldahl/ titrimetric	Not specified	Data not received[c]	Producer records	Each flock
Feed sulfur content	Yes	Not specified		Data not collected[b]			Data not collected[b]		
Incoming bedding addition rate	No	Not applicable		Volume of litter (m^3)	Producer estimate	Single value	Data not received[c]	Producer records	Each flock
Incoming bedding TKN content	No	Not applicable		Two daily average values per house (wet weight basis, %)	Micro-Kjeldahl/ titrimetric	4 sampling events over course of study	Daily average value ("as is" and dry matter basis, %); Two values for KY1B-1 and a single value for KY1B-2.	Titration	Taken at least once during the study period after full litter removal

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	Required by the NAEMS Monitoring Protocol	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency
pH of manure and litter (in house)	No	Not applicable		Data not received[b]	Electrochemical pH meter	6 events/yr	16 values taken over 8 sampling events distributed over the grow-out period	Electrochemical pH meter	8 events
Sulfur content of manure and litter (in house)	Yes	Not specified		16 daily average values per house (wet weight basis, %)	Not specified	32 sampling events over course of study	Data not collected[b]		
NH_3 content of manure and litter (in house)	Yes	Not specified		16 daily average values per house (wet weight basis, %)	Kjeldahl/ titrimetric	6 events/yr	16 values taken over 8 sampling events distributed over the grow-out period	Electrochemical pH meter	8 events
Solids content of manure and litter (in house)	No	Not applicable		16 daily average values per house (wet weight basis, %)	Gravimetric	6 events/yr	16 values taken over 8 sampling events distributed over the grow-out period	Gravimetric	8 events
TKN content of manure and litter (decaking)	Yes	Not specified		8 daily average values per house (wet weight basis, %)	Kjeldahl/ titrimetric	3 events over duration of study	6 daily average values per site ("as is" and dry matter basis, %)	Titration	Samples taken after bird removal and just prior to decaking activities; Decaking occurred 6 times during the study period
Solids content of manure and litter (decaking)	No	Not applicable		8 daily average values per house (wet weight basis, %)	Gravimetric		6 daily average values per site ("as is" and dry matter basis, %)	Not specified	
pH of manure and litter (de-caking)	No	Not applicable		Data not received[c]	Electrochemical pH meter		6 daily average values per site	Electrochemical pH meter	
TKN content of manure and litter (cleanout)	Yes	Not specified		Four daily average values per house (wet weight basis, %)	Kjeldahl/ titrimetric	During each full cleanout (2nd or 3rd brood); 3 events in the 1st year, 2-3 events in the 2nd year	One daily average value per site	Titration	During each full litter removal (occurred once per year)
pH of manure and litter (cleanout)	No	Not applicable		Data not received[c]	Electrochemical pH meter		One daily average value per site	Electrochemical pH meter	
Solids content of manure and litter (cleanout)	No	Not applicable		Four daily average values per house (wet weight basis, %)	Gravimetric		One daily average value per site	Not specified	

Table 4-2. NAEMS Emissions and Process Parameter Data Received

Parameter Information				NAEMS Data					
				CA1B (Houses 10 and 12)			KY1B – 1 House 5 and KY1B – 2 House 3		
Parameter	Required by the NAEMS Monitoring Protocol	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency	Data Description	Measurement Methodology	Measurement Frequency
Manure removed	Yes	Monitored with producer assistance (Methodology not specified)	Not Specified	Average estimated mass (metric tons)[e]	Producer estimate	Beginning and end of growth period	Data not collected[b]		
Volume of manure produced	Yes	Monitored with producer assistance (Methodology not specified)	Not Specified	Average estimated mass (metric tons)[e]	Producer estimate	Beginning and end of growth period	Data not collected[b]		

[a] Section 3.6 of the final report (p. 12) states that, due to irreconcilable interferences by water vapor and other gases, the CO_2 and VOC-related gas emissions measured by the INNOVA are not available.

[b] Data not expected. This parameter is not referenced in the QAPP or final report.

[c] The QAPP mentions this parameter was measured; however, these data are not provided in the final report(s).

[d] Section 4.2 of the final report (p. 23) provides the range of feed nitrogen content but does not provide the test values. Also, the report is unclear if the range is for nitrogen or TKN.

[e] Section 3.4 of the final report (p. 11) states that on 4/15/08, the manure mass removed during a complete load-out, estimated from the square area and average mass of manure per unit area, was 88 metric tons in House 10 and 79 metric tons in House 12.

4.1.2 Emissions Levels Reported in the NAEMS Final Reports

The final reports for the California and Kentucky sites indicate that emissions from a broiler confinement house increases over the grow-out period with the lowest emissions occurring at the beginning of the period, when the birds are very small and floor litter is fresh, and the greatest emissions occurring near the end of the grow-out period before the birds are sent to market. Spikes in emissions occur during house litter clean-out periods, which are likely due to increased activity of personnel and cleaning equipment during these periods. The spikes in PM emissions during litter clean-out periods are not as pronounced as gaseous emissions; however, this may be due to the limited number of PM data values available for these periods.

Table 4-3 summarizes the average and maximum emissions cited in the final reports and data spreadsheets for each monitoring site. The average and maximum daily values were reportedly based on all valid monitoring days and include measurements at the beginning, middle and end of the grow-out and full litter clean-out periods (i.e., when the litter in houses is decaked or fully removed from the house between flocks). A valid monitoring day is one in which 75 percent of the hourly average data values used to calculate the daily value were valid measurements. An hourly average is considered valid if 75 percent of the data recorded during that hour were valid. Data were invalidated due to special events (e.g., audits, calibrations, and maintenance), failure of quality control limits (e.g., unreasonably low or high compared with normal ranges combined with supporting evidence that the values are not correct) or when a sample is contaminated. A summary of the major data invalidation events identified for site CA1B is provided in the final site report (see Appendix D). None of the data values submitted to EPA for site CA1B were considered by the EPA to be invalid. For the Kentucky sites, a summary of the major data invalidation events was not provided to the EPA. However, the data spreadsheets submitted to the EPA for the Kentucky sites contained emissions values that were estimated based on a regression analysis, rather than directly measured. The EPA did not use these estimated emissions values in developing the EEMs.

The average daily emissions values obtained during the NAEMS include a small number (less than 1.7 percent) of negative values for H_2S and PM_{10} (see Section 4.1.1). The EPA did not include negative emission values in the development of the EEMs. However, to maintain consistency with the values contained in the final reports, the values shown in Table 4-3 include negative daily emissions values. Section 5 contains data summaries that exclude the negative daily emission values.

For site CA1B, the average and maximum daily emissions data for VOCs were estimated using grab samples that were obtained periodically over the course of the NAEMS; however, continuous measurements were not available due to interference from water vapor encountered in the field by the continuous gas analyzer. Data collection at the Kentucky sites included continuous NMHC sampling. Periodic VOC grab samples were not collected at the Kentucky sites.

Table 4-3. Reported Emission Rates for NAEMS Broiler Houses

Site	Average House Inventory[a] (no. of birds)	Average Market Weight[a] (lbs)	Average Daily Emissions (lb/d-house)[b]					
			NH_3	H_2S	NMHC	PM_{10}	$PM_{2.5}$	TSP
CA1B, H10	21,000	5.81	22.49	0.12	3.92[b]	1.92	0.22	5.84
CA1B, H12	21,000	5.83	19.82	6.87	6.87[b]	1.94	0.27	5.00
KY1B-1, H5	23,000	6.00	26.76	0.11	1.58	2.03	0.20	4.78
KY1B-2, H3	24,500	6.12	27.29	0.12	0.99	2.30	0.21	5.34
			Maximum Daily Emissions (lb/d-house)[b]					
CA1B, H10	21,000	5.81	112.22	0.40	8.68[c]	7.85	7.85	7.85
CA1B, H12	21,000	5.83	77.60	0.40	12.56[c]	7.63	7.63	7.63
KY1B-1, H5	23,000	6.00	98.59	0.57	5.24	9.95	0.89	22.8
KY1B-2, H3	24,500	6.12	78.23	0.41	3.84	9.43	0.85	16.3

[a] The average bird inventory and market weight values were calculated based on the daily values submitted to the EPA.

[b] The emissions (e.g., kg/d-house, mg/d-house) provided in the final reports were converted to lb/d-house to provide a common basis for all pollutants.

[c] The emissions values are based on periodic grab samples of VOC.

4.2 Other Relevant Data

Since 2001, the EPA conducted several literature searches and a CFI to identify data and information that were relevant to support a preliminary investigation into air pollution from large AFOs (see the EPA's *Emissions From Animal Feeding Operations* (draft, August 15, 2001)). The EPA evaluated all of the articles and publications received through its own literature searches and obtained through the CFI to identify data and information that could be useful in developing EEMs for broiler confinement operations. In conducting this evaluation, the EPA retained for further consideration those resources that satisfied each of the following conditions:

- The resource pertained to monitoring conducted on broiler confinement structures at commercial sites.
- The resource contained emissions rates (e.g., mass/time, mass/animal) for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP or VOC, or data to characterize the inputs or outputs necessary to construct a nitrogen mass balance across the confinement house.
- The resource used methods to measure the emissions concentrations, estimate the ventilation flow rate and characterize mass balance parameters that were consistent with the NAEMS procedures.

The EPA excluded data that were related to litter storage piles and land application sites because the Air Compliance Agreement does not cover these processes.

The EPA then evaluated the resources that satisfied the EPA's initial review to determine if the data were appropriate for consideration in either developing the EEMs or assessing the predictive accuracy of the EEMs. Section 4.2.1 summarizes the EPA's CFI and the review of the resources obtained. Section 4.2.2 summarizes the EPA's review of the resources obtained by previous EPA literature searches.

4.2.1 CFI

The EPA issued a CFI on January 19, 2011, seeking peer-reviewed, quality-assured emissions and process data relevant to developing EEMs for animal feeding operations. The CFI was designed to help ensure that the EPA would obtain the broadest range of scientific data available. All data and information received by the EPA is contained in the public docket for the Air Compliance Agreement (EPA Docket ID No. EPA-HQ-OAR-2010-0960) and is available online at http://www.regulations.gov.

In the CFI, the EPA requested emissions and process data for AFOs in the broiler, swine, egg-layer, dairy, beef and turkey industries. Although the EPA is interested in all air pollutants emitted from animal confinement, litter storage and treatment and litter land applications sites associated with AFOs, the CFI specifically requested emissions data and related process information for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOC.

To ensure compatibility with the NAEMS data, the CFI requested that, to the extent possible, the emissions and related process data provided to the EPA be accompanied by documentation that addresses the following parameters:

General information:

- Description of AFO process measured (e.g., animal confinement structure).
- Location of AFO process measured (e.g., physical address, latitude/longitude coordinates of facility).
- Beginning and ending dates of the monitoring period.

Monitoring data:

- Plan for quality assurance and quality control procedures.
- Site-specific monitoring plan.
- Test methods, instrumentation and SOPs used to collect emissions and process data measurements.

- Results of audits conducted on instruments and procedures.
- Field notes and associated documentation collected during the study.
- Emissions data (unanalyzed or analyzed) and associated process data.
- Meteorological data, including average ambient temperature, relative humidity, pressure, wind speed, wind direction and insolation (solar radiation) for each day that the study was conducted.
- Production data (e.g., number of eggs produced per day or quantity of milk produced per day or number of chickens or swine produced).
- Calculations and assumptions used to convert concentration data (e.g., ppmv) into mass emissions (e.g., lb/hr).

Animal confinement structures:

- Dimensions of structures monitored.
- Designed and permitted animal capacity.
- Type, age, number and weight of animals contained in the confinement structure over the duration of the monitoring period.
- Manure management system (e.g., pull-plug pit, scrape).
- Manure removal activities over the duration of the monitoring period.
- Ventilation method (i.e., natural or mechanical).
- Calculations and assumptions used to estimate the ventilation rate of the monitored confinement structure.
- Calibration procedures for instruments (e.g., flow meters, fan relays) used to collect data for calculating ventilation rate of the monitored confinement structure.
- Nitrogen content of process inputs and outputs (e.g., feed, water, bedding, eggs, milk).
- Nitrogen content of manure excreted.
- Description of any control device or work practice used in the monitored structure to reduce emissions.

Manure storage and treatment processes:

- Type, age, number, and weight of animals contributing manure to the storage and treatment process over the monitoring period.
- Dimensions of storage/treatment unit monitored (e.g., storage pile, tank, lagoon).
- Depth of settled solids in storage/treatment unit.
- Temperature, pH and reduction/oxidation potential of manure contained in the storage/treatment unit.

- Moisture, total solids, volatile solids, total Kjeldahl nitrogen and ammoniacal nitrogen content and pH of manure entering storage and treatment process over the monitoring period.

Manure land application sites:

- Type, age, number, and weight of animals contributing manure to the land application site.
- Method used to apply manure (e.g., direct injection, broadcast spreading and frequency of application).
- Area (e.g., acres, square feet) used for manure application over the monitoring period.
- Quantity and moisture content of manure applied.

Table 4-4 lists the articles and publications received by the EPA in response to the CFI that pertained to broiler operations and their possible application for the NAEMS. As shown in the table, most of the articles and publications submitted to the EPA did not contain emissions or process data that met the EPA's initial review criteria (e.g., the measurement methods differed from the NAEMS methods). However, a few resources contained material composition data that could be used to supplement the nitrogen mass balance data collected by the NAEMS.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2000	*Atmospheric Transport and Wet Deposition of Ammonium in North Carolina* - Walker, Aneja, Dickey	This study analyzes transport and deposition of ammonium (NH_4^+) by precipitation using regression analysis.	None	Not applicable	None. Wet deposition is typically conducted by collecting water and analyzing anions. Consequently, this article is not applicable to NAEMS.
2001	*Ammonia Emissions from Animal Feeding Operations* - Arogo, Westerman, Heber, Robarge, Classen	This article provides a compilation of several studies.	Range of poultry confinement emissions factors: 0.5 – 10 g NH_3-N/hr-animal unit (AU) Composite poultry emissions factors: 0.18 – 0.24 kg NH_3-N/yr-animal	Not applicable	None. The article presents ranges of NH_3 emissions factors for livestock operations but the resource does not identify the specific types of poultry or process to which the emissions factors apply.
2002	*Ammonia Losses, Evaluations, and Solutions for Poultry Systems* - Gates, Xin, Wheeler	This study describes an ongoing, multistate effort toward collecting data on emissions rates or emissions factors from selected U.S. poultry houses and the efficacy of certain management practices on emissions rates.	Confinement NH_3 concentrations (ppmv)	Electrochemical sensors (unspecified vendor and model no.)	None. Although the electrochemical sensor was compared to EPA chemiluminescence reference method with good results, the preliminary data presented in this paper are not useful for developing a emission estimating methodology. Additionally, the methodology for deploying the FANS unit to estimate total building air flow was not specified.
			Ventilation flow rate	Relationship between carbon dioxide (CO_2) production and metabolic rate of the birds, and FANS unit	

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2002	*Emission Factors for Broiler Production Operations: A Stochastic Modeling Approach* - Lacey, Redwine, Parnell	This article describes development of linear regressions for NH_3 and PM_{10} from measurement data collected at a commercial-scale broiler houses at a farm in Texas. The article also compares emissions factors developed using the regression equations to other published emissions factors.	PM Emissions Factors (mg/hr-500 kg live weight): Inhalable PM – 5,000; 8,500; 6,218; 4,984; 1,856; and 2,805 Respirable PM – 600, 850, 706, 725, 245, and 394 TSP – 2,214 PM_{10} – 131.5 NH_3 Emissions Factors: 7.4, 8.5, 8.3, 4.2, 2.2, 7.5, 1.9, 6.2, and 8.2 g/hr-500 kg live weight 19.8, 11.2, 8.9, 18.5, and 16.8 mg/hr-bird 0.179, 0.19, 0.2, and 0.02 kg/bird	Confinement NH_3 concentrations: electrochemical sensors (Drager Chip Measurement System) TSP: Hi-vol sampler PM10: Beckman Coulter Multisizer Building flow rate: vane anemometers on fans, scaled-up to whole-house flow rate	None. The NH_3 concentrations were taken at a single location (center of house, 1 meter above the litter surface) rather than at the house exhaust locations. Also, the Coulter particle sizing methodology is not consistent with the federal reference method for measuring PM_{10} emissions.
2002	*The Scientific Basis for Estimating Emissions from Animal Feeding Operations* - Hagenstein, Flocchini	This interim report from the National Academy of Science provides findings regarding identification of the scientific criteria needed to ensure that estimates of air emission rates are accurate, the basis for these criteria in the scientific literature, and the associated uncertainties.	None	Not applicable	None. The report cites studies that developed emissions factors; however, the report does not contain empirical data that could be used to supplement the NAEMS data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2003	*Particulate Matter and Ammonia Emission Factors for Tunnel-Ventilated Broiler Production Houses in the Southern U.S.* - Lacey, Redwine, Parnell	This commercial-scale study measured NH_3 and PM_{10} emission from four tunnel–ventilated broiler production facilities in central TX. The data were used to develop linear regression equations.	Confinement NH_3 concentrations	Electrochemical sensors (Drager Chip Measurement System)	None. Particulate counting by Coulter technique is not equivalent to NAEMS aerodynamic particulate sampling. EPA could not evaluate the comparability of NH_3 measurements because the Drager apparatus used for the study was not specified. Additionally, the daily emissions and flow rate estimates were not explicitly quantified and several of the houses that participated in the study used litter amendments to suppress NH_3 emissions.
			Confinement PM_{10} concentrations	Hi-Vol TSP sampler and Beckman Coulter Multisizer	
			Ventilation flow rate	Vane anemometers and FANS unit	
2003	*Progress Towards the Development of an Integrated Management System for Broiler Chicken Production* - Frost, Parsons, Stacey, Robertson, Welch, Filmer, Fothergill	The article presents previous research conducted to develop a prototype closed-loop, model-based, real time, system for the integrated control of broiler growth and pollutant emissions.	Confinement NH_3 concentrations	Ammonia concentration in the air was measured by converting the ammonia into nitric oxide which was fed to a chemiluminescence nitrogen oxides analyzer.	None. Animal feed was altered in this study when measurements were taken. Because the NAEMS was designed to focus on baseline or uncontrolled emissions, this study is not relevant for EEM development.
2004	*A Comparison of Ammonia Emission Rates from an Agricultural Area Source Using Dispersion Modeling: Gaussian Versus Backward-Lagrangian Stochastic* - Price, Lacey, Shaw, Cole, Todd, Capareda, Parnell	This research-scale study compared the emissions rates generated using the Industrial Source Complex (Guassian) model and the WindTrax (backward Lagrangian Stochastic)	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2004	*Ammonia Emissions from Animal Housing Facilities* - Gay	This article provides background information regarding NH_3 emissions from animal confinement facilities.	NH_3 Emissions Factors (g/bird-d): 0.043 (new bedding) 0.61 (reused litter) NH_3 Emissions Factors (g/bird): 0 – 336 (U.S.) 78 – 174 (European)	Not applicable	None. This article summarizes recent research findings regarding quantification of ammonia emissions from animal confinement in general. However, there is not sufficient information on the duration of the studies and/or the specific measurement technologies used to determine how comparable the results are to the NAEMS data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2005	*CARB Memo: Poultry Emissions VOC Sampling and Analysis Audit* - Goodenow	This memorandum documents an audit of the independent contractor and laboratory responsible for the collection and analysis of VOC emissions samples from a poultry house in Livingston, California.	None	Not applicable	None. The audit does not contain emissions or process data.
2005	*Final Report: Quantification of Gaseous Emissions from California Broiler Production Houses* - Summers, Mattos, Gaffney, FitzGibbon, Duke, Marnatti, Kim, Stabelfeld, Clutter, Ernst, Humbert	This commercial-scale study measured NH_3 and organic compound emissions from a fabricated duct at tunnel-ventilated broiler house in California.	Confinement NH_3 concentrations (ppmv)	BAAQMD Method ST-1B (impinger train w/0.1 N HCl)	While this study does not use measurement methods that are identical to the NAEMS, the data is still relevant and may be useful in assessing the EEMs after they have been developed.
			Confinement total hydrocarbon (THC) concentrations as propane	EPA Method 25A	
			Stack flow rate (dscfm)	CARB Methods 2 and 4	
			C1, C2 and C4 hydrocarbon concentrations	EPA Method 18 (Tedlar bag samples w/GC FID)	The speciated VOC data may be used to supplement the periodic VOC measurements taken under the NAEMS.
			Speciated organic compound concentrations (ppbv)	EPA Method TO-15 (Summa canisters w/GCMS)	
2005	*Nitrogen Emissions from Broilers Measured by Mass Balance Over Eighteen Consecutive Flocks* - Coufal, Chavez, Niemeyer, Carey	This large research-scale evaluated a nitrogen mass balance and partitioning in broiler houses.	Total nitrogen content of birds, feed and litter	Combustion method using LECO FP-428 Nitrogen Determinator	The nitrogen content data may be used to supplement NAEMS mass balance data.
2006	*Dietary Modifications to Reduce Air Emissions from Broiler Chickens* - Powers, Zamzow, Angel, Applegate	This research-scale study investigated the effects of changes to diet on NH_3 emissions.	Ammonia emissions (mg/kg-day)	TEI Model 17C ammonia/NOx chemiluminescence analyzer	Results from the control group in this study may be useful in assessing the EEMs after they have been developed.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2006	*Ammonia Emissions from Twelve U. S. Broiler Chicken Houses* - Wheeler, Casey, Gates, Xin, Zajaczkowski, Topper, Liang, Pescatore	Commercial-scale study of broiler farms in KY and PA to measure NH_3 emissions from house operated under different climatic conditions.	Confinement NH_3 concentrations	Portable electrochemical sensor (Drager Polytron)	None. Several of the houses that participated in the study used litter amendments to suppress NH_3 emissions. The flocks with and without litter treatment were grouped together in this study. Because the NAEMS was designed to focus on baseline or uncontrolled emissions, this study is not relevant for EEM development. Additionally, the results in this study are not explicitly quantified.
			Ventilation flow rate	Estimated using differential static pressure, temperature, relative humidity, and fan operation measurements	
			Bird inventory	Manual records	
			Bird weight	Estimated using regression equations in terms of bird age developed under a different study	
2006	*A Review of Emission Models of Ammonia Released from Broiler Houses* - Liu, Want, Beasley	This paper summarizes the scientific basis of and the major factors that may influence NH_3 emissions from broiler litter. The theoretical principles and the structures of the models are generalized. According to the study, these models improved understanding of NH_3 releases and can be useful to improve the accuracy and simplicity in emissions estimates. The paper also discusses current technical challenges and future direction of developments.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2006	*Quality Assured Measurements of Animal Building Emissions: Odor Concentrations* - Jacobson, Hetchler, Schmidt, Nicolai	This study focuses on the methodology for collecting and analyzing samples for odor concentrations.	None	Not applicable	None. The article addresses odor measurement and does not contain emissions or process data that could be used to supplement the NAEMS data.
2006	*Quality Assured Measurements of Animal Building Emissions: Gas Concentrations* - Heber, Ni, Lim, Tao, Schmidt, Koziel, Beasley, Hoff, Nicolai, Jacobson, Zhang	This study focuses on the methodology of measuring gas concentration and the difficulty in achieving the desired results for livestock houses due to their unique traits.	None	Not applicable	None. The article provides an overview of the emissions monitoring system and instrumentation but does not contain emissions or process data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2007	*Determination of Ammonia Emission Rates From a Tunnel Ventilated Chicken House Using Passive Samplers and a Gaussian Dispersion Model* - Siefert, Scudlark	This study provided NH_3 emissions data from tunnel-ventilated houses.	Mean EF = 0.13 g NH_3–N/bird-day Range of EFs = 0.0053 g NH_3–N /s to 0.037 NH_3–N g/s	Emissions of NH_3 were back-calculated from concentration measurements made using a sampling array (Ogawa passive samplers) positioned downwind of broiler house and Gaussian plume model.	None. The use of different sampling methods (passive vs. active) and modeling limit the applicability of the study for direct comparison or use in the NAEMS.
2007	*Effect of Moisture Content on Ammonia Emissions from Broiler Litter: A Laboratory Study* - Liu, Wang, Beasley, Oviedo, Munilla, Baughman, Williams	The research study evaluated the effect of moisture content on NH_3 emissions from litter samples using dynamic flow-through chambers.	None	Ammonia emissions from litter samples of varying moisture content placed in dynamic flow-through chambers were measured simultaneously using a chemiluminescence analyzer and a boric acid scrubber combined with gas chromatography of the scrubber solution.	None. Because this study used flux chambers to measure ammonia emissions, this study is not relevant for EEM development.
2007	*Modeling Atmospheric Transport and Fate of Ammonia in North Carolina—Part I: Evaluation of Meteorological and Chemical Predictions* - Wu, Krishnan, Zhang, Aneja	This study discusses the application of EPA's Community Multiscale Air Quality (CMAQ) modeling system to study the deposition and fate of NH_3 emissions from activities. Part I of the study describes the model configurations, evaluation protocols, databases and the operational evaluation for meteorological and chemical predictions.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2007	*Modeling Atmospheric Transport and Fate of Ammonia in North Carolina—Part II: Effect of Ammonia Emissions on Fine Particulate Matter Formation* - Wu, Hu, Zhang, Aneja	This study discusses the application of EPA's CMAQ model to study the deposition and fate of NH_3 emissions from agricultural activities. Part II of the study describes the sensitivity simulations applied to various emission scenarios.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2008	*Ammonia Assessment from Agriculture: U.S. Status and Needs* - Aneja, Blunden, James, Schlesinger, Knighton, Gilliam, Jennings, Niyogi, Cole	This article summarizes recent research on agricultural air quality and describes best management practices for reducing NH_3 emissions.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2008	*Auditing and Assessing Air Quality in Concentrated Feeding Operations* - Cole, Todd, Auvermann, Parker	This paper discusses AFO emissions and the current air quality regulations and techniques for measuring and quantifying emissions.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2008	*Commentary: Farming Pollution* - Aneja, Schlesinger, Erisman	This article provides commentary on the U.S. efforts to regulate farms. It provides general information related to agricultural emissions and the state of knowledge of processes and a comparison to of U.S. regulations to European regulations.	None	Not applicable.	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2008	*Comparison of Ammonia Emission Rates from Three Types of Broiler Litters* - Atapattu, Senaratna, Belpagodagamage	This research-scale study compared the emissions of NH_3 from three kinds of broiler bedding: refused tea, sawdust and paddy husk.	Confinement NH_3 emissions	NH_3 emissions volatilized from litter samples in conical flasks were trapped in 100 mL of 0.32 *N* H_3SO_4 solutions. The trap was titrated with 0.1 *N* HCl to determine the NH_3 emissions.	None. The NH_3 concentrations were taken from litter samples analyzed under laboratory conditions. Additionally, data are not available to determine how the concentration measurements made using the titration method compare to the measurements made using the NAEMS methodology (i.e., chemiluminescence analyzer).
2008	*Instrumentation for Evaluating Differences in Ammonia Volatilization from Broiler Litter and Cake* - Miles, Owens, Moore, Rowe	The research-scale study evaluated a chamber acid trap (CAT) technique for measuring NH_3 losses from broiler litter samples.	None	Ammonia concentrations from litter samples contained in 1-liter containers were measured using boric acid traps followed by titration with hydrochloric acid.	None. This study specifically looked at emissions from litter samples. Emissions from litter samples are not directly comparable to emissions from broiler houses. Additionally, no data was provided to relate the litter samples to a specific bird inventory.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2008	*Modeling Ammonia Emissions from Broiler Litter at Laboratory Scale* - Zifei	Laboratory-scale study to develop an NH3 emissions model using broiler litter samples. Emissions were measured using a wind tunnel and a flux chamber.	Confinement NH_3 concentrations	Chemiluminescence gas analyzer	The nitrogen and moisture content and pH of litter may be used to supplement the mass balance data collected under the NAEMS. Regarding the NH3 concentrations, although the measurements were made using a chemiluminescence gas analyzer (which is consistent with the NAEMS), the measurements were taken from litter samples placed in laboratory flux chambers and a wind tunnel. Also, data were not provided to relate the NH3 emission to the size of the litter sample or bird inventory.
			Total ammoniacal nitrogen content of broiler litter (manure and wood shavings)	Extraction with 1.25 N K_2SO_4	
			Total N and total C content of broiler litter (manure and wood shavings)	Thermal conductivity detection (Leco C/N 2000 analyzer)	
			TKN content of broiler litter (manure and wood shavings)	Catalytic digestion (using K_2SO_4, $CuSO_4$, H_2O and pumice) w/H_2SO_4	
			Moisture content of broiler litter (manure and wood shavings)	Gravimetric (before and after drying)	
			pH of broiler litter (manure and wood shavings)	Not specified	
2008	*Winter Broiler Litter Gases and Nitrogen Compounds: Temporal and Spatial Trends* - Miles, Rowe, Owens	Commercial-scale study of two broiler houses in Mississippi. Data specifically relate to spatial/temporal variation in gases emitted from litter at different locations.	NH_3, N_2O and CO flux emission rates	Flux chamber w/photoacoustic multigas analyzer (Innova 1312)	None. Because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
			Total NH_4, NO_3 and TKN content of litter	NH_4 and NO_3: water extraction (QuikChem 8000) TKN: block digestion and distillation/titration (2300 Kjeltec Analyzer)	The nitrogen content data may be used to supplement NAEMS mass balance data.
2009	*Ammonia Emissions and Animal Agriculture* - Gay, Knowlton	This article provides general information regarding AFO emissions and the effects of farming on pollution.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2009	*Does Animal Feeding Operation Pollution Hurt Public Health? A National Longitudinal Study of Health Externalities Identified By Geographic Shifts In Livestock Production* - Sneeringer	This article discusses an epidemiological study that assessed the relationship between livestock farming and infant mortality.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2009	*Effects of Agriculture upon the Air Quality and Climate: Research, Policy, and Regulations* - Aneja, Schlesinger, Erisman	This article describes the state of the science and how research can be improved.	None	Not applicable	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2009	*Efficacy of Urease Inhibitor to Reduce Ammonia Emission from Poultry Houses* - Singh, Casey, King, Pescatore, Gates, Ford	The study addresses the use of urease inhibitors to reduce NH_3 emissions from broiler litter.	None	Flux chambers and a photoacoustic infrared gas analyzer.	None. The litter samples used in the study were subjected to amendments that suppressed NH_3 emissions. Also, because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
2010	*Ammonia Emission Factors from Broiler Litter In Houses, in Storage, and After Land Application* - Moore, Miles, Burns, Pote, Berg, Choi	Commercial-scale study to measure NH_3 emissions from four confinement houses for 1 year and to construct a N mass across the houses.	Confinement NH_3 concentrations	Electrochemical sensors (Drager Polytron)	These data may be used to supplement the NAEMS data.
			Building ventilation rates	Anemometers (R.M. Young) located at fan outlets	
			Bird inventory, final average weight (kg), Final total house bird weight (kg)	Counts of initial chick placement and birds caught for market (methods used to determine bird weight not specified).	These data may be used to supplement the NAEMS data.
			Nitrogen content of birds, feed, bedding and litter	Feed and litter: total N analysis (method not specified); KCl-extractable NH_4 (Moore et al., 1995) Bedding: Elementar Variomax N analyzer (combustion w/thermal conductivity) Birds: Elementar N analyzer	These data may be used to supplement the NAEMS N mass balance data.
			NH_3, N_2O, CH_4 and CO flux measurements from litter on floor	Flux chamber and photoacoustic multigas analyzer (Innova 1412)	None. Because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
			NH_3, N_2O, CH_4 and CO flux measurements from litter storage piles	Flux chamber and photoacoustic multigas analyzer (Innova 1412)	None. The EPA is not assessing emissions from broiler litter storage piles at this time.
			NH_3, N_2O, CH_4 and CO flux measurements from land application site	Lab-scale wind tunnels, phosphoric acid traps and wire anemometers	None. The EPA is not assessing emissions from broiler litter land application sites at this time.

Table 4-4. Review of Broiler Articles Received in Response to EPA's CFI

Year	Title - Author(s)	Brief Description	Relevant Data	Methodology	Possible Application for NAEMS
2010	*Effect of Atmospheric Ammonia on Growth Performance and Immunological Response of Broiler Chickens* - Wang, Meng, Guo, Wang, Wang, Yao, Shan	Experimental study to assess the effects of NH_3 concentrations on growth and immune response of broilers.	None	Not applicable	None. The study subjected birds to varying levels of NH_3 concentrations provided in a controlled environment.
2011	*Comparing Ammonia Emissions from Poultry Barns Using Two Techniques* - Flesch, Harper, Wilson	This commercial-scale study compared the NAEMS NH_3 emissions rates for CA1B to emissions determined using backward Lagrangian Stochastics (bLS)	None	Not applicable	None. The bLS emissions estimates were determined based on upwind and downwind NH_3 concentrations and inverse dispersion modeling rather than direct measurement of confinement concentrations and ventilation flow rate.
2011	*Spatial Contrasts of Seasonal and Intraflock Broiler Litter Trace Gas Emissions, Physical and Chemical Properties* - Miles, Brooks, Sistani	Commercial-scale study of two broiler houses in Mississippi. Data showed the litter chemical/physical properties, and flux values were specific to the litter surface and not necessarily to the broiler house as a whole.	NH_3, N_2O and CO litter flux emission rates	Flux chamber w/photoacoustic multigas analyzer (Innova 1312)	None. Because this study used flux chambers to measure emissions, this study is not relevant for EEM development.
			Litter total N, NH_4 and total carbon content	Max CN analyzer (Elementar)	The litter composition data could be used to supplement the NAEMS N mass balance data.

4.2.2 Previous Literature Searches

Beginning in 2001, the EPA conducted several literature searches using the Agricultural Online Access (AGRICOLA) bibliographic database to identify data and information that were relevant to support a preliminary investigation into air pollution from large AFOs (see the EPA's *Emissions From Animal Feeding Operations* (draft, August 15, 2001)). The EPA also conducted literature searches to support development of the EPA's National Emissions Inventory (NEI) for NH_3 emissions from animal agricultural operations.

Table 4-5 lists additional articles and publications pertaining to broiler operations that the EPA identified through literature searches it conducted prior to the CFI. Articles that were common to both the CFI and previous literature searches are reported in the Table 4-4 only. As result, articles with a publication date after 2002 are not shown in Table 4-5. As shown in the Table 4-5, none of the articles previously obtained by the EPA to support emissions factor development were applicable for EEM development.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1965	*Dust Problems in Poultry Environments*	Grub, Rollo, Howes	None. This study focuses on collecting dust samples and does not provide particle-sizing data for PM_{10} or $PM_{2.5}$. Consequently, these data were not considered for use in EEM development.
1987	*Quantification of Odour Problems Associated with Liquid and Solid Feedlot and Poultry Wastes*	du Toit	None. This study focuses on the methodology for collecting and analyzing samples for odor concentrations. Consequently, these data were not considered for use in EEM development.
1988	*Controlling Ammonia Emission from Poultry Manure Composting Plants*	Bonazzi, et al.	None. This study evaluated emissions of odor and NH_3 and litter characteristics from two composting plants in Italy. The EPA is not assessing emissions from broiler litter composting sites at this time. Consequently, these data were not considered for use in EEM development.
1988	*Concentration and Size Distribution of Airborne Particles in a Broiler House*	Gupta, Sandhu, Harter-Dennis, Khan	None. This study evaluated PM concentrations inside of a broiler house. However, PM emissions from the house were not quantified. Consequently, these data were not considered for EEM development.
1988	*Ammonia Emission from Poultry Housing Systems*	Kroodsma, Scholtens, Huis	None. This study presents European farming practices and did not provide data for bird age, weight or inventory. Consequently, these data were not considered for EEM development.
1988	*Ammonia Emissions from Cattle, Pig and Poultry Wastes Applied to Pasture*	Lockyer, Pain, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1988	*Available Nitrogen in Broiler and Turkey Litter*	Westerman, et al.	None. This study evaluated nitrogen availability in poultry litter under aerobic and anaerobic conditions. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1989	*Poultry Manure Composting: Design Guidelines for Ammonia*	Hansen, Keener, Hoitink	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1989	*Dust and Odour Relationships in Broiler House Air*	Williams	None. According to the author, the dust emissions measured during the study were likely increased due to a separate study that was being conducted at the same time that involved catching and weighing the birds. Consequently, these data were not considered for use in EEM development.
1990	*Empirical Models to Determine Ammonia Concentrations from Broiler Chicken Litter*	Carr, et al.	None. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1990	*Batch Digester Studies on Biogas Production from Cannabis Sativa, Water Hyacinth and Crop Wastes Mixed with Dung and Poultry Litter*	Mallik, et al.	None. The EPA is not assessing the performance of anaerobic digestion of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1991	*Odour Emissions from Broiler Chickens*	Clarkson, Misselbrook	None. This study focuses on the methodology for collecting and analyzing samples for odor. Consequently, these data were not considered for use in EEM development.
1991	*Odor Control from Poultry Manure Composting Plant Using a Soil Filter*	Sweeten, Childers, Cochran, Bowler	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1992	*Effect of Surface-Applied Poultry Waste Source on Infiltration and Runoff*	Daniel, Edwards	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1992	*Gaseous Pollutants Produced by Farm Animal Enterprises*	Tamminga	None. This resource was used to develop emissions factors for broiler operations for the EPA's Emissions From Animal Feeding Operations (draft, August 15, 2001). However, data describing the number, size and weight of the birds associated with the emissions data were not provided. Consequently, these data were not considered for use in EEM development.
1992	*Potential Environmental Effects of Long-Term Land Application of Broiler Litter*	Kingery, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1992	*Physical and Chemical Characteristics of Pine Shavings Poultry Litter*	Koon, et al.	None. This study presents the chemical composition and particle size distribution of litter samples collected over four broiler grow-out periods.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1993	*Nitrogen Transformations in Surface-Applied Poultry Litter: Effect of Litter Physical Characteristics*	Cabrera, Chiang, Merka, Thompson, Pancorbo	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1993	*Testing of Broiler Litter and its Effect on Land Application*	Nordstedt	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1993	*Mineral Levels of Broiler House Litter and Forages and Soils Fertilized with Litter*	Smith, Britton, Enis, Barnes, Lusby	None. The EPA is not currently assessing the mineral concentrations in broiler litter and soils treated with broiler litter, and thus these data were not considered in this study.
1993	*Use of Mineral Amendments to Reduce Ammonia Losses from Dairy-Cattle and Chicken-Manure Slurries*	Termeer, Warman	None. The EPA is not assessing the performance of litter amendments for broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Volatile Fatty Acids as Indicators of Process Imbalance In Anaerobic Digestors*	Ahring, et al.	None. The EPA is not assessing the performance of anaerobic digestion of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Chemical and Microbiological Characteristics of Poultry Processing By-Products, Waste and Poultry Carcasses During Lactic Acid Fermentation*	Cai, Pancorbo, Barnhart	None. The EPA is not assessing waste composition during composting at this time. Thus these data were not considered for use in EEM development.
1994	*Stabilization of Poultry Processing By-Products and Waste and Poultry Carcasses Through Lactic Acid Fermentation*	Cai, Pancorbo,Merka, Sander, Barnhart	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Land Application of Livestock and Poultry Manure*	Hammond, Segars, Gould	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1994	*Impact of Long-Term Land Application of Broiler Litter on Environmentally Related Soil Properties*	Kingery, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1994	*Changes in Physical and Chemical Characteristics of Poultry Litter Due to Rotary Tilling*	Koon, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1994	*Losses and Transformation of Nitrogen During Composting of Poultry Manure with Different Amendments: An Incubation Experiment*	Mahimairaja, et al.	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1994	*Poultry Waste Management: Agricultural and Environmental Issues*	Sims, Wolf	None. This article reviews general information regarding issues related to poultry waste. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1994a	*Nitrogen Mineralization and Ammonia Volatilization from Fractionated Poultry Litter*	Cabrera, et al.	None. This study evaluates mineralization of nitrogen in poultry litter and the effects of water content on mineralization, NH_3 volatilization and respiration. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1994b	*Ammonia Volatilization and Carbon Dioxide Emission from Poultry Litter: Effects of Fractionation and Storage Time*	Cabrera, et al.	None. The EPA is not assessing emissions from broiler litter storage sites at this time. Consequently, these data were not considered for use in EEM development.
1995a	*Poultry Manure Management: Environmentally Sound Options*	Moore, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1995b	*Effect of Chemical Amendments on Ammonia Volatilization from Poultry Litter*	Moore, et al.	None. The EPA is not assessing the performance of litter amendments for broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1995	*Measuring Air-Borne Microbial Contamination of Broiler Cabinets*	Berrang, Cox, Baily	None. This study compares methods for measuring airborne bacteria. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
1995	*Exposure to Excessive Carbon Dioxide: Risk Factor for Early Poultry Mortality*	Donaldson, Christensen, Garlich, and McMurtry	None. The EPA is not assessing the effects of post-hatch stressors on newly hatched turkeys at this time. Consequently, these data were not considered for use in EEM development.
1995	*Ammonia Quick Test and Ammonia Dosimeter Tubes for Determining Ammonia Levels in Broiler Facilities*	Skewes, Harmon	None. The study measured NH_3 concentrations above the litter surface over a short period (10 hours). However, the concentration data were not converted to a mass emissions rate. Also, the data for the bird inventory were not provided in this article. Consequently, these data were not considered for use in EEM development.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1995	*Addition of Different Sources and Levels of Amino Acids and Sugars to Broiler Litter Before Deep-Stacking*	Wang, et al.	None. The EPA is not assessing the use of additives in broiler manure at this time. Consequently, these data were not considered for use in EEM development.
1996	*Trace Element characterization of Composted Poultry Manure*	Ihnat, Fernandes	None. The EPA is not assessing emissions from composting of broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1996	*Changes During Processing in the Organic Matter of Composted and Air-Dried Poultry Manure*	Mondini, et al.	None. The EPA is not assessing the effects of manure drying and composting on emissions at this time. Consequently, these data were not considered for use in EEM development.
1997	*Land Application of Poultry Lagoon Effluent*	Aldrich, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1997	*A Farm-Scale Study on the Use of Clinoptilolite Zeolite and De-Odorase® for Reducing Odour and Ammonia Emissions from Broiler Houses*	Amon, Dobeic, Sneath, Phillips, Misselbrook, Pain	None. The EPA is not assessing the performance of litter amendments for broiler litter at this time. Consequently, these data were not considered for use in EEM development.
1997	*Mineralizable Nitrogen in Broiler Litter: I. Effect of Selected Litter Chemical Characteristics*	Gordillo, Cabrera	None. This study assessed the kinetics of nitrogen mineralization in broiler litter samples to evaluate the supply of nitrogen to land application sites. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1997	*Reduction of Poultry Ventilation Fan Output Due to Shutters*	Simmons, Lott	None. This study evaluates the effects of fan shutters on air flow rates of poultry house fans. Emissions and the overall ventilation flow rate data for the house were not provided. Consequently, these data were not considered for use in EEM development.
1997	*Concentrations and Emission Rates of Aerial Ammonia, Nitrous Oxide, Methane, Carbon Dioxide, Dust and Endotoxin in UK Broiler and Layer Houses*	Wathes, Holden, Sneath, White, Phillips	None. Emissions in this study were measured over a very short sampling period (24 hours during summer and winter). Consequently, these data were not considered for use in EEM development.
1998	*Nitrogen: Some Practical Solutions for the Poultry Industry*	Chambers, Smith	None. This article discusses general options for reducing nitrogen emissions in the poultry industry. The article does not contain emissions or process data that could be used to supplement the NAEMS data.

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
1998	*Litter Production and Nutrients from Commercial Broiler Chickens*	Patterson, Lorenz, Weaver	This study analyzed the moisture, total nitrogen, ammoniacal nitrogen, phosphorous pentoxide and potassium oxide content of broiler litter samples and the crude protein, total phosphorous, and total potassium content of feed. The nitrogen content data could be used to supplement NAEMS mass balance data.
1998	*Field-Scale Nitrogen and Phosphorus Losses From Hayfields Receiving Fresh and Composted Broiler Litter*	Vervoort, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.
1998	*Aerial Emissions from Poultry Production*	Wathes	None, This article discusses the potential control mechanisms for pollutants from broiler operations. Emissions values presented were from other articles and the article does not provide descriptions of monitoring methodologies used to measure emissions.
1998	*Estimating Ammonia Emission Factors in Europe: Summary of the Work of the UNECE Ammonia Expert Panel*	Van der Hoek	None. This resource was used to develop emissions factors for broiler operations for the EPA's Emissions From Animal Feeding Operations (draft, August 15, 2001). However, the resource does not provide the underlying data (e.g., daily values for bird inventory, bird mass, pollutant emissions) for the emissions factors cited. Consequently, these data were not considered for use in EEM development.
1998	*Concentrations and Emissions of Ammonia in Livestock Buildings in Northern Europe*	Groot Koerkamp, Metz, Uenk, Phillips, Holden, Sneath, Short, White, Hartung, Seedorf, Schroder, Linkert, Pederson, Takai, Johnsen, Wathes	None. This resource was used to develop emissions factors for broiler operations for the EPA's *Emissions From Animal Feeding Operations* (draft, August 15, 2001). However, data describing the number, size and weight of the birds associated with the emissions data were not provided. Consequently, these data were not considered for use in EEM development.
1999	*In Situ Measurement of Ammonia Volatilization from Broiler Litter Using an Enclosed Air Chamber*	Brewer, Costello	None. The study measured NH_3 emissions from litter using flux chambers. The article does not contain emissions or process data that could be used to supplement the NAEMS data.
2002	*Efficient Feed Nutrient Utilization to Reduce Pollutants In Poultry and Swine Manure*	Nahm	None. The EPA is not assessing the effects of dietary changes on emissions at this time, and this study evaluates outcomes not addressed by the NAEMS (such as odor and manure characteristics).

Table 4-5. Review of Broiler Articles Obtained by Previous EPA Literature Searches

Date	Title	Author	Possible Application for NAEMS
2002	*Continuous Monitoring of Ammonia, Hydrogen Sulfide and Dust Emissions From Swine, Dairy and Poultry Barns*	Schmidt, Jacobson, Janni	None. This study does not contain broiler data.
NA	*Ammonia Emissions from Field Applications of Poultry Litter*	Meisinger, et al.	None. The EPA is not assessing emissions from broiler litter land application sites at this time. Consequently, these data were not considered for use in EEM development.

5.0 NAEMS DATA PREPARATION

This section provides an overview of the data assessment procedures followed by the NAEMS in collecting the emissions and process parameter data from the broiler monitoring sites and the procedures followed by the EPA in preparing the data for use in development of EEMs for broiler confinement operations.

Section 5.1 discusses the Quality Assurance/Quality Control (QA/QC) procedures outlined in the NAEMS QAPP and implemented by the researchers to ensure collection of high-quality emissions and process data. Section 5.2 summarizes the steps the EPA followed to process and review the data submitted to the EPA prior to developing the broiler EEMs. Section 5.3 compares the design and operating parameters and reported emissions of each site.

5.1 NAEMS Data Assessments

5.1.1 QA/QC Procedures

The NAEMS followed strict QA/QC procedures throughout the data collection and preliminary data analyses processes of the NAEMS. The investigators developed QAPPs, SOPs for sampling systems and monitoring instruments and site-specific monitoring plans and provided extensive training for on-site operators and producers. Appendix A contains the QAPPs, Appendix B contains the SMPs for each monitoring site and Appendix C contains the SOPs.

Monitoring instruments underwent initial and periodic calibration, bias and precision checks and were corrected if they failed the QC checks. The frequency of each check/calibration event was dependent on the type of instrument and on the site investigator. For example, the NH_3 gas analyzer was checked with calibration gases weekly or semi-weekly for the Kentucky sites, while the calibration checks were conducted every two months at site CA1B. The investigators also implemented external system audits conducted by independent personnel and maintained supporting documentation (e.g., field logs, instrument calibration records).

All of the monitoring sites were equipped with data acquisition (DAQ) systems that allowed on-site operators, and other authorized personnel via high-speed Internet connection, to view the measured data and parameter values daily through real-time computer displays. The DAQ systems also generated email notifications for project personnel when monitored parameter values were outside of preset ranges.

The NAEMS also used control charts extensively in QA/QC procedures to assess data quality and measurement variability and to evaluate long-term trends in the instrument/equipment performance. The control charts provided a graphical means of determining whether the measured parameters were within acceptable upper and lower control limits. Data values outside the control limits triggered corrective actions by site operators to maintain data quality. The control charts were generated on site using Microsoft ® Excel templates to provide a real-time assessment of the data quality.

Measurement data recorded at each site were uploaded to the respective researchers (Purdue University for site CA1B and Iowa State University for the Kentucky sites) each day for review and evaluation. The researchers used custom-designed software to apply flags to measurement data that were considered invalid or outliers and to calculate emissions rates for the monitored houses. The researchers used the Calculation of Air Pollutant Emissions from Confined Animal Buildings (CAPECAB) program for site CA1B and the Mobile Air Emissions Monitoring Unit (MAEMU v1.2) program for the Kentucky sites.

5.1.2 Data Validation

In general, the researchers invalidated measurement data (e.g., concentration, differential static pressure, temperature) if the data values were:

- Unreasonably low or high when compared to normal ranges if there was supporting evidence that the data value is not correct (e.g., unresponsive relative humidity sensor inside a house producing a reading of less than 10 percent).
- Obtained during system installation, testing or maintenance during which uncorrectable errors might be introduced.
- Obtained when a sensor or instrument was proven to be malfunctioning (e.g., unstable).
- Obtained during calibration or precision check of a sensor or instrument and before the sensor or instrument reached equilibrium after the check.
- Obtained when the data acquisition and control hardware and/or software were not functioning correctly.

Data that the researchers deemed invalid were retained in the preprocessed data sets. However, the EPA did not use the flagged data to calculate pollutant emissions rates.

For averaged data, data were invalidated to avoid errors introduced into calculated mean values due to partial-data days (e.g., only a few hours of valid data) that would result in biased time weights:

- Hourly averages were invalidated if less than 75 percent of the data recorded during that hour were valid.

- Daily means were invalidated if less than 75 percent of the hourly average data recorded during that day were valid.
- Monthly averages were invalidated if less than 75 percent of the individual days recorded during that month were valid.
- Average daily means (ADM) were invalidated if less than 75 percent of the daily average data recorded during all measurement days were valid.

5.1.3 Data Completeness

Consistent with the EPA's *Guidance for Quality Assurance Project Plans* (EPA QA/G-5), data completeness is the measure of the amount of valid data obtained from a measurement system, compared with the amount of data that was expected to be obtained under normal conditions. Data completeness is expressed as the percentage of valid data obtained from the measurement system. For data to be considered valid, they must meet all the acceptance criteria. The researchers calculated data completeness during data processing.

The goal of the NAEMS was to continuously monitor emissions and process parameters over a long period to characterize uncontrolled emissions from broiler confinement houses. The long monitoring period was intended to capture the variations in pollutant emissions due to the bird grow-out and litter clean-out cycles, and diurnal and seasonal variations. Emissions and process parameters were monitored at site CA1B from September 27, 2007, to October 21, 2009, and at site KY1B-1 from February 14, 2006, to March 14, 2007, and at site KY1B-2 from February 20, 2006, to March 5, 2007.

Table 5-1 presents the total number of days that the monitoring instrumentation systems were operational and the number of valid emissions days submitted to EPA for each site. According to the criteria established in the NAEMS QAPPs, a valid day for a pollutant or process parameter was one in which more than 75 percent of the measurement values recorded were valid (i.e., the data passed all QA checks). The NAEMS also established an overall completeness goal of 75 percent for the number of valid days of data that were recorded versus the number of scheduled sampling days. Table 5-2 presents the data completeness percentages for each site by pollutant. In the development of EEMs, the EPA considered all valid data days regardless of whether the NAEMS completeness goal was achieved.

Table 5-1. Reported Number of Valid Emissions Days for Required Data from NAEMS Broiler Operations

Site	Monitoring Period	Total Monitoring Days[a]						Number of Valid Emissions Days[a]					
		NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NMHC	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NMHC
CA1B, H10	9/27/2007 – 10/21/2009	756	756	628	60	67	756	467	592	352	53	37	NA[b]
CA1B, H12	9/27/2007 – 10/21/2009	756	756	628	60	67	756	466	590	376	43	39	NA[b]
KY1B-1, H5	2/14/2006 – 3/14/2007	394	394	394	394	394	394	381	342	295	279	304	268
KY1B-2, H3	2/20/2006 – 3/5/2007	379	379	379	379	379	379	337	274	301	299	298	203

[a] In the final report for the Kentucky sites, the number of total monitoring days and valid emissions days were prorated to represent a monitoring period of 365 days. The values shown in the table are the actual number of days.
[b] Not available. The final report for the CA1B site states that the NMHC data were questionable due to irreconcilable interferences caused by water and other gases.

Table 5-2. Data Completeness for Daily Emissions Data from NAEMS Broiler Operations

Site	Data Completeness (%)					
	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NMHC
CA1B, H10	61.8	78.3	56.1	88.3	55.2	NA[a]
CA1B, H12	61.6	78.0	59.9	71.7	58.2	NA[a]
KY1B-1, H5	96.7	86.0	74.9	70.8	77.0	68.5
KY1B-2, H3	88.9	71.2	79.4	78.9	80.8	55.1

[a] Not available. The final report for the CA1B site states that the NMHC data were questionable due to irreconcilable interferences caused by water and other gases.

At site CA1B, the completeness goal of 75 percent was achieved only for H_2S (at Houses 10 and 12) and $PM_{2.5}$ (only at House 10). The completeness goal was not met for NH_3, PM_{10} and TSP emissions by either house at site CA1B due to delays in receiving monitoring equipment at the beginning of the study and calibration and maintenance issues with the gas analyzer.

At site CA1B, a single instrument (TEOM) and different inlet sampling heads were used to measure PM_{10}, $PM_{2.5}$ and TSP emissions. Because a single instrument was used, each PM component was sampled on an intermittent schedule. The goal of the NAEMS over the study period was to collect emissions data for seven weeks out of every eight weeks for $PM_{10;}$ two weeks of summertime data and two weeks of wintertime data for $PM_{2.5}$; and data for one week out of every eight weeks for TSP.

Table 5-3 shows the operating times for the TEOM instrument and the total number of measurement days at each particle size. The number of valid PM emissions days was limited due to TEOM failures. Emissions of $PM_{2.5}$ were sampled in periods ranging from 12 to 18 days in February and July 2008 and in January and September 2009, with the goal of obtaining data under both cold (winter) and hot (summer) conditions. For TSP, sampling was conducted during six measurement events, each lasting from 7 to 14 days. Emissions of PM_{10} were measured at all other times over the course of the monitoring study at site CA1B. The length of the monitoring period for each PM size cut was varied, where possible, to accommodate the completeness requirements. For example, TSP sampling was allowed to run for up to two weeks to meet the 75 percent completeness requirement of 5.25 emissions days. However, if this requirement was not met by the end of the two-week period, the TEOM was reconfigured for the next particle size cut to be monitored.

Table 5-3. Particulate Matter Monitoring Schedule for CA1B

Date		Test Duration (days)		
Start	**Stop**	**PM_{10}**	**TSP**	**$PM_{2.5}$**
9/28/07	12/10/07	73.6	NS	
12/10/07	12/19/07	NS	8.9	NS
12/19/07	2/1/08	44	NS	
2/1/08	2/19/08	NS		18.1
2/19/08	2/20/08	NS		0.3[a]
2/19/08	2/20/08	0.3[b]	NS	
2/20/08	5/15/08	85.7	NS	
5/15/08	5/28/08	NS	12.8	NS
5/28/08	7/9/08	42	NS	
7/9/08	7/25/08	NS		16
7/25/08	11/17/08	115.1	NS	
11/17/08	11/24/08	NS	7.1	
11/24/08	1/5/09	41.9	NS	
1/5/09	1/20/09	NS		15
1/20/09	4/9/09	79	NS	
4/9/09	4/20/09	NS	11	NS
4/20/09	6/25/09	66.1	NS	
6/25/09	7/8/09	NS	12.9	NS
7/8/09	9/26/09	80.1	NS	
9/26/09	10/7/09	NS		10.9
10/7/09	10/21/09	NS	14.1	NS
10/21/09	10/22/09	0.4	NS	
	Totals	628.3	66.7	60.3

NS - Not sampled.

[a] Ambient data were not collected during this sampling period.

[b] Only ambient data were collected during this sampling period.

At the Kentucky sites, the completeness goal of 75 percent was achieved for all pollutants except for H_2S (at KY1B-2 H3), PM_{10} (at KY1B-1 H5) and $PM_{2.5}$ (at KY1B-1 H5). The final report for the Kentucky sites did not provide explanations for the missing data days.

5.2 EPA Assessments

5.2.1 Data Processing

The data collected under the NAEMS were provided to the EPA in the form of final site reports (pdf format) and Microsoft Excel® spreadsheets that contained the emissions and process data. For site CA1B, separate worksheets were used to present the daily values for each pollutant. In addition, the data within each worksheet were further divided into tables that presented the daily values and summary statistics (i.e., number of data points, averages, standard deviations, minimums and maximums) for each month of the study period.

To facilitate analyses of the emissions and process data for site CA1B, the EPA reformatted and converted the files to a Microsoft Access® database containing all of the data elements provided by the investigators in the summary spreadsheets. To reformat the spreadsheets received, the EPA removed the summary statistics and the blank spaces between data tables that presented the data for each month. Merged cells were removed and the data headers for each month were consolidated and rearranged, as necessary, to create an input file for uploading into Microsoft Access®. The EPA performed QA checks to verify that the conversion from spreadsheets to database tables was performed correctly and that data were not lost or transposed in the conversion. Additionally, the EPA randomly selected three dates during the study period and compared all of the values contained in the database on those dates to the original spreadsheets to ensure the data were properly transferred to the new file format.

The EPA reformatted and converted the spreadsheets submitted for the Kentucky sites to Microsoft Access® data tables. The EPA performed QA checks of the uploaded Kentucky data and then the Kentucky data were combined with the data for site CA1B to create a comprehensive database of the NAEMS broiler data.

5.2.2 Data QA

The EPA developed a comprehensive list of the emissions and confinement operating parameter, meteorological condition and mass balance data that were expected to be submitted to the EPA based on the EPA's review of the QAPPs, SOPs and SMPs. As the final reports and data spreadsheets were received, the EPA compared the information received to the comprehensive list to identify missing information. After determining whether the data submittals to the EPA were complete and identifying missing data elements, the EPA verified that the units of measurement for the emissions and supporting data were consistent between the final reports and spreadsheet data files. In addition, the EPA assessed whether the units of measurement and the magnitude of emissions were consistent across the monitoring sites. The EPA prepared and provided summaries of the missing data elements to the researchers.

The EPA's review identified that a small number (less than 1.7 percent) of the daily average emissions for H_2S and PM_{10} at site CA1B were reported as negative values. After discussion with the study's Scientific Advisor, it was determined the negative emission values occurred due to drift in the instrument readings between calibrations. The EPA included the negatives values when graphing the data to visualize emission trends but did not include the negative values when developing EEMs for broiler houses, to avoid possible complications with EEM development (e.g., the EEM predicting negative emissions) the negative values were withheld from the data sets used for EEM development. The EPA's review also identified a few instances (less than 2 percent) of zero emission values (i.e., instances where the ambient and confinement concentrations were the same). However, because the zero values were not the result of instrument drift, the EPA included the zero emissions values in the data sets used in the development of the EEMs for broiler confinement houses.

As specified in the QAPPs developed for the CA1B and Kentucky sites, the daily emissions values submitted to the EPA did not include measurements that were considered to be outliers by the NAEMS researchers. However, the EPA compared the emissions values calculated for each day of the grow-out, decaking and litter clean-out periods for each flock to the average daily emissions for all flocks to identify anomalies in the reported data. Daily emissions values that were higher or lower than ± two standard deviations and ± twice the average flock emission for that day were noted for further evaluation. For these values, the EPA prepared graphical overlays of the pollutant emissions and the average ambient and confinement parameter values (e.g., air temperature, house temperature, ventilation flow rate) recorded for that day to determine if the anomalous emission value could be attributed to an irregular condition (e.g., an abnormally high ambient temperature or house ventilation flow rate). This analysis identified several anomalies (e.g., spikes in NH_3 emissions during litter clean-out periods); however, the analysis suggested that other activities (e.g., high/low ventilation rates) could account for these anomalies. Additionally, the field note summaries in the final reports for the CA1B and Kentucky sites did not suggest abnormal conditions that would warrant excluding the emissions values from EEM development.

5.2.3 Data Completeness Assessment

The EPA assessed the data completeness of the average daily emissions values to verify the completeness calculations presented in the final reports. Based upon its analysis, the EPA confirms that the completeness goal of 75 percent was achieved at site CA1B only for H_2S (at Houses 10 and 12) and $PM_{2.5}$ (only at House 10) and was not achieved for $PM_{2.5}$ at KY1B-1 H5. Additionally, the EPA looked at the seasonal distribution of the data to determine if any pollutant was under-represented during a particular season (see Table 5-4 and Table 5-5). The NAEMS QAPP for barn sources defined the seasons as follows:

- Spring: March 1 through May 31.
- Summer: June 1 through August 31.
- Fall: September 1 through November 30.
- Winter: December 1 through February 28.

Table 5-4. Number of Valid Emissions Days in the Spring and Summer

Site	Spring					Summer				
	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
CA1B, H10	160	161	76	0[a]	8	130	169	104	15	10
CA1B, H12	160	160	113	0[a]	15	129	167	90	15	12
KY1B-1, H5	103	103	87	89	89	90	54	55	46	63
KY1B-2, H3	89	49	67	67	67	87	64	79	79	79

[a] Per the study design, $PM_{2.5}$ data was not scheduled for collection during the spring and fall.

Table 5-5. Number of Valid Emissions Days in the Fall and Winter

Site	Fall					Winter				
	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
CA1B, H12	49	88	78	0[a]	5	128	175	95	28	7
CA1B, H10	51	89	88	10	12	126	173	84	28	7
KY1B-1, H5	87	87	69	57	69	98	98	90	94	94
KY1B-2, H3	88	84	77	75	77	72	94	81	79	77

[a] Per the study design, $PM_{2.5}$ data was not scheduled for collection during the spring and fall.

For site CA1B, the least number of days of valid NH_3 and H_2S emissions were collected during the fall, most likely a function of the partial fall seasons captured at the start and end of the study. The seasonal distributions of PM_{10} and TSP emissions days were relatively consistent. Emissions data for $PM_{2.5}$ were collected during the summer and winter for both houses and only for House 10 in the fall.

At the Kentucky sites, the seasonal distributions of the emissions data were relatively consistent across pollutants. However, the amount of H_2S emissions data collected was somewhat lower during the spring at site KY1B-2 H3 and during the summer at both Kentucky sites. For PM_{10}, less data were collected during the summer at site KY1B-1 H5. Fewer $PM_{2.5}$ data values were collected during the summer and fall at site KY1B-1 H5 and fewer TSP data were collected during the fall at site KY1B-1 H5.

5.3 Comparison of Broiler Monitoring Sites

Table 5-6 shows the NAEMS data available for the grow-out and litter removal periods at each site. The EPA developed comparative statistics and graphs of emissions data for each site to determine if there were any notable differences or data anomalies among the sites at the process, location or emissions level. Each of these comparisons is discussed in more detail in the following sections. Based upon this assessment, the EPA determined that the NAEMS data are appropriate and consistent with the requirements of the Air Compliance Agreement.

Table 5-6. NAEMS Data for Broiler Confinement Operations

Process Description		NAEMS Data
Confinement	**Period**	
Broiler on litter, mechanically ventilated (tunnel) houses	Grow-out	CA1B (Houses 10 and 12), KY1B-1 H5 and KY1B-2 H3
	Decaking	
	Full litter clean-out	

5.3.1 Process-Level Comparison

Table 5-7 summarizes the design and operating parameters for the CA1B and Kentucky sites. All of the broiler confinement houses monitored under the NAEMS are comparable at the process level. All sites use mechanically-ventilated tunnel houses with litter (rice hulls) on the floor and periodically conducted decaking and full litter clean-out operations. In each of the houses, birds are raised to an approximate final weight of 5 to 6 pounds over the grow-out periods covered by the study.

The houses differed in the types of birds raised and length of the litter clean-out periods. The flocks at site CA1B comprised a 60/40 percent mix of Cobb and Ross broilers while the flocks at the Kentucky sites were all Cobb broilers. The differences in growth rate, feed conversion and emissions due to bird type are expected to be negligible. Regarding duration of the litter clean-out periods, the clean-out operations at the Kentucky sites tended to last an average of 8 days longer than at site CA1B (see Table 5-8). This apparent difference could be caused by a longer idle period (i.e., the period after litter has been cleaned out but before a new flock is placed in the house) for the Kentucky houses compared to the CA1B site.

Additionally, the Kentucky sites conducted full litter clean-outs once per year, while the CA1B houses cleaned out litter after three consecutive grow-out periods. Table 5-9 specifies the dates of the litter clean-outs for each broiler confinement house during the study and the type of clean-out activity performed.

Table 5-7. Design and Operating Parameters of the NAEMS Broiler Sites

Monitoring Site		House Capacity (no. of birds)	Bird Type	Final Bird Weight[a] (kg)		Design	Ventilation Type
				Average	Range		
CA1B	H10	21,000[b]	60 percent Cobb, 40 percent Ross	2.64	2.48 – 2.75	Litter (rice hulls) on floor	Mechanical (tunnel)
	H12			2.65	2.55 – 2.76		
KY1B-1	H5	25,800 (summer) 24,400 (winter)	100 percent Cobb[c]	2.74	2.53 – 2.89		
KY1B-2	H3			2.78	2.47 – 2.97		

[a] Bird weight at the end of the grow-out period.

[b] The CA1B site did not vary stocking numbers during the year.

[c] Described in the final report text as “Cobb-Cobb-straight-run (mixed sex).”

Table 5-8. Duration of Grow-out and Clean-out Periods

Monitoring Site		Grow-Out Periods			Clean-Out Periods					
					Decaking			Full Litter Clean-Out		
		Frequency	Average (days)	Range (days)	Frequency	Average Duration (days)	Range of Duration (days)	Frequency	Average Duration (days)	Range of Duration (days)
CA1B	H10	~ 7 flocks per year	47	45 - 49	~ 5 time per year	7.75	6 – 11	Every third flock (~2 times per year)	12.6	6 – 21
	H12	~ 7 flocks per year	47	45 - 49	~ 5 time per year	7.25	3 – 11	Every third flock (~2 times per year)	12.8	6 – 23
KY1B-1	H5	~ 6 flocks per year	51	50 - 54	~4 times per year	15.5	12 – 22	Once per year	25	NA[a]
KY1B-2	H3	~ 6 flocks per year	52	50 - 54	~4 times per year	22	15 – 41	Once per year	9	NA[a]

[a] Not applicable. Only one full litter clean-out event was monitored during the study.

Table 5-9. Summary of Flock and Litter Clean-out Operations

Monitoring Site		Flock	Start and End Dates	Season[a]	Type of Litter[b]	Type of Clean-Out[c]
CA1B	H10	1[d]	9/20/07 - 11/3/07	F	Built-up litter	Full litter
		2	11/15/07 - 12/31/07	F/W	New bedding	Decake
		3	1/7/08 - 2/21/08	W	Built-up litter	Decake
		4	2/28/08 - 4/15/08	Sp	Built-up litter	Full litter
		5	4/22/08 - 6/6/08	Sp	New bedding	Decake
		6	6/14/08 - 8/1/08	Su	Built-up litter	Decake
		7	8/11/08 - 9/27/08	Su/F	Built-up litter	Full litter
		8	10/20/08 - 12/4/08	F	New bedding	Decake
		9	12/12/08 - 1/28/09	W	Built-up litter	Decake
		10	2/9/09 - 3/27/09	W/Sp	Built-up litter	Full litter
		11	4/10/09 - 5/27/09	Sp	New bedding	Decake
		12	6/5/09 - 7/21/09	Su	Built-up litter	Decake
		13	7/30/09 - 9/14/09	Su	Built-up litter	Full litter
		14[d]	9/26/09 - 11/10/09	F	New bedding	NA[e]
	H12	1[d]	9/20/07 - 11/3/07	F	Built-up litter	Full litter
		2	11/15/07 - 1/1/08	F/W	New bedding	Decake
		3	1/5/08 - 2/21/08	W	Built-up litter	Decake
		4	2/28/08 - 4/15/08	Sp	Built-up litter	Full litter
		5	4/22/08 - 6/6/08	Sp	New bedding	Decake
		6	6/14/08 - 8/1/08	Su	Built-up litter	Decake
		7	8/11/08 - 9/26/08	Su/F	Built-up litter	Full litter
		8	10/20/08 - 12/4/08	F	New bedding	Decake
		9	12/12/08 - 1/28/09	W	Built-up litter	Decake
		10	2/9/09 - 3/27/09	W/Sp	Built-up litter	Full litter
		11	4/10/09 - 5/27/09	Sp	New bedding	Decake
		12	6/4/09 - 7/21/09	Su	Built-up litter	Decake
		13	7/30/09 -9/14/09	Su	Built-up litter	Full litter
		14[d]	9/26/09 - 11/10/09	F	New bedding	NA[e]
KY1B-1	H5	1	2/14/20 - 4/4/06	W/Sp	Built-up litter	Decake
		2	4/21/06 - 6/9/06	Sp	Built-up litter	Decake
		3	6/22/06 - 8/10/06	Su	Built-up litter	Full litter
		4	9/5/06 - 10/25/06	F	New bedding	Decake
		5	11/17/06 - 1/9/07	F/W	Built-up litter	Decake
		6	1/22/07 - 3/14/07	W	Built-up litter	NA[e]
KY1B-2	H3	1	2/20/06 - 4/10/06	W/Sp	Built-up litter	Decake

Table 5-9. Summary of Flock and Litter Clean-out Operations

Monitoring Site		Flock	Start and End Dates	Season[a]	Type of Litter[b]	Type of Clean-Out[c]
		2	5/22/06 - 7/11/06	Su	Built-up litter	Decake
		3	7/28/06 - 9/19/06	Su	Built-up litter	Decake
		4	10/5/06 - 11/27/06	F	Built-up litter	Decake
		5	12/14/06 - 2/2/07	W	Built-up litter	Full litter
		6[d]	2/12/07 - 3/5/07	W	New bedding	NA[e]

[a] Season of the year: Su = Summer, Sp = Spring, F = Fall, W = Winter.

[b] Denotes the type of litter on which the flock was raised. Built-up litter is litter that was decaked after removing the previous flock and partially replenished with fresh bedding (typically, 20 – 25 percent of the bedding material is new). New bedding is the complete replenishment of bedding material after full litter clean-out operations.

[c] Clean-out process occurs after the flock has been removed from the confinement house.

[d] Partial data.

[e] Clean-out occurred after study period concluded. No data were collected.

5.3.2 Comparison of Local Meteorological Conditions

Table 5-10 summarizes the site-specific ambient and confinement conditions for each site. Ambient temperature and relative humidity are the same for both CA1B broiler houses because a single sampling point was used to represent the ambient conditions for both houses. The minimum ambient temperature at the Kentucky farms tended to be lower than at the CA1B site, but the average ambient temperatures are very similar to those at CA1B. Ambient relative humidity conditions are very similar for all the broiler sites, as are temperature and relative humidity conditions in the broiler houses.

Table 5-10. Site-Specific Ambient and Confinement Conditions

Monitoring Site		Ambient				Confinement			
		Temperature (°C)		Relative Humidity (%)		Temperature (°C)		Relative Humidity (%)	
		Average	Range	Average	Range	Average	Range	Average	Range
CA1B	H10	16.69	3.30 - 31.10	61.53	32.70 - 94.90	24.99	11.40 - 32.60	57.66	35.70 - 89.20
	H12					24.99	10.80 - 33.70	55.48	36.60 - 88.10
KY1B-1 H5		13.02	-9.94 - 29.78	71.82	37.44 - 97.46	23.03	10.25 - 30.27	58.24	29.41 - 80.24
KY1B-2 H3		13.37	-6.96 - 29.94	72.97	37.8 - 97.43	24.09	8.04 - 31.92	59.7	33.49 - 83.10

5.3.3 Emissions-Level Comparison

Table 5-11, Table 5-12, Table 5-13, Table 5-14 and Table 5-15 summarize the emissions values from each of the broiler confinement houses monitored during the NAEMS, for each phase of production. The data presented in the tables include all non-negative, daily average values.

As shown in Table 5-11, the average and range of daily emissions for all periods (i.e., grow-out, decaking and full litter clean-out) are comparable across the three monitoring sites, although the average NH_3 and PM_{10} emissions tended to be slightly higher for sites KY1B-1 H5 and KY1B-2 H3 than site CA1B.

Table 5-12 presents the emissions for grow-out periods in terms of pollutant mass per day. The average NH_3 emissions were somewhat higher at the Kentucky sites. Emissions of H_2S and PM_{10} were also higher at KY1B-2 H3. Table 5-13 presents the emissions for grow-out periods in terms of pollutant mass per day per bird. The average per-bird emissions rates for all pollutants were comparable across the monitoring sites, although $PM_{2.5}$ emissions at the KY1B-1 H5 were slightly higher than the other sites.

Table 5-14 and Table 5-15 show the emissions for decaking and full litter clean-out periods. For both types of clean-out activities, NH_3 emissions tended to be higher at site KY1B-1 H5 than the other broiler houses. Emissions of H_2S during decaking periods tended to be higher at site CA1B while H_2S during litter clean-out periods were higher at site KY1B-2 H3. The Kentucky sites tended to have higher PM_{10} emissions during decaking and litter clean-out periods.

The average emissions for gaseous pollutants during the grow-out period are higher than during the decaking or full litter clean-out periods, as fresh manure is constantly deposited by the birds to contribute to the chemical reactions responsible for the emissions. Although PM emissions data during the clean-out periods are limited (the TEOMs at site CA1B were removed to prevent damage by the cleaning operations), the available data show that PM emissions also tend to be higher during grow-out periods. This difference is likely attributable to contributions from bird feathers and dander and the agitation of the litter by the birds.

With the exception of PM_{10}, all pollutant emissions during full litter clean-out periods were lower than during decaking periods. Decaking events are expected to have higher emissions than full litter clean-out events because of litter remaining in the house continues to contribute to gaseous emissions.

Table 5-11. Average Daily Emissions for All Periods

Pollutant	Parameter	Site[a]			
		CA1B (H10)	**CA1B (H12)**	**KY1B-1 H5**	**KY1B-2 H3**
NH_3 (g/d)	No. of values	467	466	378	336
	Average	10,197.05	8,950.20	12,136.80	12,376.33
	Range	0 – 50,900	0 – 35,200	0 – 44,721.02	0 – 35,484.91
H_2S (g/d)	No. of values	583	580	342	291
	Average	53.72	51.24	47.84	53.5
	Range	0 - 181.00	0 - 181.00	0 - 259.46	0 - 186.34
PM_{10} (g/d)	No. of values	349	375	301	304
	Average	880.67	881.64	919.7	1,043.47
	Range	0 - 3,560.00	1.2 - 3,460.00	0 - 4,513.85	0 – 4,146.87
$PM_{2.5}$ (g/d)	No. of values	53	43	286	300
	Average	98.8	124.41	89.61	97.32
	Range	1.3 - 243.00	45.1 - 235.00	0 - 405.16	0 - 383.82
TSP (g/d)	No. of values	37	39	315	330
	Average	2,652.16	2,269.77	2,166.50	2,421.74
	Range	0 - 4,760.00	0 - 6,220.00	0 - 10,340.87	0 – 7,472.53

[a] The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

Table 5-12. Average Daily Emissions During Grow-Out Periods (mass per day)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	**CA1B (H12)**	**KY1B-1 H5**	**KY1B-2 H3**
NH_3 (g/d)	No. of values	390	389	299	246
	Average	11,072.25	9,719.26	12,230.00	14,562.90
	Range	56.0 – 35,900	71.0 – 29,700	332.65 – 28,587.85	143.24 – 35,484.91
H_2S (g/d)	No. of values	511	509	276	216
	Average	59.79	56.97	56.84	69.56
	Range	0.0 – 181.00	0.0 – 181.00	1.41 – 259.46	1.36 – 186.34
PM_{10} (g/d)	No. of values	335	366	299	243
	Average	919.88	903.11	969.94	1,234.79
	Range	9.8 – 3,560	3.1 – 3,460	20.9 – 4,513.85	24.56 – 4,146.87
$PM_{2.5}$ (g/d)	No. of values	53	43	290	256
	Average	98.80	124.41	95.11	113.56
	Range	0 – 243	0 – 235	2.55 – 405.16	3.89 – 383.82
TSP (g/d)	No. of values	37	39	215	166
	Average	2,652.16	2,269.77	2,347.02	2,830.54
	Range	0 – 4,760	0 – 6,220	43.53 – 10,340.87	44.47 – 7472.53

[a] The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

Table 5-13. Average Daily Emissions During Grow-Out Periods (mass per day per bird)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d-bird)	No. of values	386	390	299	246
	Average	1.37	1.22	1.19	1.31
	Range	0.01 – 42.20	0.01 – 39.90	0.03 – 3.35	0.01 – 3.27
H_2S (g/d-bird)	No. of values	511	509	276	216
	Average	3.02E-03	2.89E-03	2.52E-03	2.84E-03
	Range	3.06E-6 – 2.07E-02	5.47E-05 - 1.18E-02	5.47E-05 – 1.18E-02	5.57E-05 – 7.80E-03
PM_{10} (g/d-bird)	No. of values	335	366	299	243
	Average	4.46E-02	4.37E-02	4.33E-02	5.05E-02
	Range	4.61E-04 – 1.17E-01	3.39E-04 – 1.68E-01	8.01E-04 – 2.07E-01	9.83E-04 – 1.74E-01
$PM_{2.5}$ (g/d-bird)	No. of values	53	43	290	256
	Average	4.78E-03	6.00E-03	4.30E-03	4.66E-03
	Range	6.74E-05 – 1.19E-02	2.15E-03 – 1.14E-02	1.29E-04 – 1.86E-02	1.08E-04 – 1.53E-02
TSP (g/d-bird)	No. of values	37	39	215	166
	Average	1.28E-01	1.09E-01	1.05E-01	1.16E-01
	Range	6.80E-02 – 2.28E-01	1.61E-04 – 2.98E-01	1.74E-03 – 4.22E-01	1.82E-03 – 3.09E-01

[a] The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

Table 5-14. Average Daily Emissions During Decaking Periods (mass per day)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d)	No. of values	51	48	58	82
	Average	7,534.51	6,208.75	12,675.34	6,773.21
	Range	0 – 50,900	0 – 35,200	0 – 44,721.02	0 – 34,974.74
H_2S (g/d)	No. of values	55	52	57	67
	Average	18.21	15.1	12.09	6.9
	Range	0 – 98.60	0 – 68.0	0 – 76.44	0 – 56.39
PM_{10} (g/d)	No. of values	6	4	11	45
	Average	4.5	3.98	24.79	22.92
	Range	0 .10 – 11.8	1.50 – 8.9	0 – 55.36	0 – 171.52
$PM_{2.5}$ (g/d)	No. of values	b		19	45
	Average			17.24	12.39
	Range			0 – 40.33	0 – 153.18
TSP (g/d)	No. of values	b		20	41
	Average			85.02	41.34
	Range			0 – 361.23	0 – 321.37

[a] The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than confinement concentration).

[b] Emissions data for this pollutant were not collected during decaking periods.

Table 5-15. Average Daily Emissions During Full Litter Clean-Out Periods (mass per day)

Pollutant	Parameter	Site[a]			
		CA1B (H10)	CA1B (H12)	KY1B-1 H5	KY1B-2 H3
NH_3 (g/d)	No. of values	30	30	21	8
	Average	3,459.60	3,390.07	9,322.43	2,571.25
	Range	57.0 – 23,100	17.0 – 24,000	0 – 30,569.63	129.78 – 10,024.84
H_2S (g/d)	No. of values	23	23	8	8
	Average	5.36	7.23	4.62	10.16
	Range	0.06 – 31.30	0.05 – 63.50	0.84 – 20.01	1.81 – 30.72
PM_{10} (g/d)	No. of values	9	5	5	3
	Average	9.66	12.86	24.86	23.13
	Range	0 - 30.50	1.20 – 35.80	0 - 71.29	7.18 – 55.72
$PM_{2.5}$ (g/d)	No. of values	b		1	3
	Average			0	6.83
	Range			0	0 – 13.76
TSP (g/d)	No. of values	b		5	3
	Average			21.86	69.97
	Range			0 – 61.12	10.83 – 161.71

[a] The daily emissions values presented in the table do not include negative data points (i.e., measurements where the ambient concentration was greater than the confinement concentration).

[b] Emissions data for this pollutant were not collected during litter clean-out periods.

6.0 MEASURED EMISSIONS FROM BROILER OPERATIONS

The EPA prepared graphs of the NAEMS daily emissions values to identify general and seasonal trends or cycles in pollutant emissions over the monitoring period. Section 6.1 describes the data processing steps used to prepare the graphs of daily emissions values. Sections 6.2 through 6.6 present the daily and seasonal graphs and discuss any trends seen for NH_3, H_2S, PM_{10}, $PM_{2.5}$, TSP and VOC emissions, respectively. For the trend discussions, the EPA related the emissions trends identified for specific process operations based upon its review of the field note summaries in the final reports for the monitoring sites and its general understanding of broiler operations.

In general, the emissions of all pollutants from broiler confinement houses tend to:

- Increase over the grow-out period with the lowest emissions rate occurring at the beginning of the period (when the birds are small and floor bedding is fresh) and the highest emissions rate occurring near the end of the grow-out period before the birds are sent to market.
- Decrease during the decaking and full litter clean-out periods when the houses are empty.

6.1 Data Processing

This section describes the processing steps used by the EPA in preparing the emissions graphs. The graphs prepared by EPA include all of the valid measurements submitted to the EPA.

6.1.1 Daily Emissions Graphs

For the graphs of daily emissions, the emissions values were highlighted to designate whether the emissions values were associated with the grow-out, decaking or full litter clean-out periods. Unshaded values on the daily emissions figures correspond to grow-out periods. Light shading depicts the decaking periods (i.e., partial litter removal and replenishment with fresh bedding) and darker shading indicates full litter clean-out periods (i.e., complete removal of litter).

6.1.2 Seasonal Emissions Graphs

For this analysis, the EPA assigned each of the flocks monitored under the NAEMS a season using the same designations as specified in the NAEMS QAPP:

- Spring - March through May.

- Summer - June through August.
- Fall - September through November.
- Winter - December through February.

Table 6-1 provides the average duration of the grow-out, decaking and full litter clean-out periods, along with the range of values in brackets. To simplify the seasonal assignments, if the grow-out period of the flock overlapped with another season by less than 15 days, the EPA assigned the flock to the season that had the majority of days. The EPA assigned flocks that overlapped the next season by more than 15 days as mixed-season flocks (e.g., Fall/Winter). Table 6-2 contains the start and end dates for each flock grow-out period and the seasonal designation assigned by EPA.

Table 6-1. Average Flock Duration by Site

Site	Average Duration and Range of Period (days) [min, max]			
	Grow-Out	Litter Removal Activity		Total Flock
		Full Litter Clean-Out	Decaking	
CA1B H10	47.00 [45, 49]	12.60 [6, 22]	7.75 [6, 11]	56.69 [52, 70]
CA1B H12	47.21 [45, 49]	12.80 [6, 23]	7.25 [3, 11]	56.69 [51, 70]
KY1B-1 H5	51.17 [50, 54]	25.00	15.50 [12, 22]	72.40 [62, 86]
KY1B-2 H3	52.00 [50, 54]	9.00	22.00 [15, 41]	71.40 [60, 91]

Table 6-2. Flock Classified by Season

Site	Flock	Number of Days	Occupied Start	Occupied End	Season (Occupied)
CA1B H10	1	45	9/20/2007	11/3/2007	Fall
	2	47	11/15/2007	12/31/2007	Fall/Winter
	3	46	1/7/2008	2/21/2008	Winter
	4	48	2/28/2008	4/15/2008	Spring
	5	46	4/22/2008	6/6/2008	Spring
	6	49	6/14/2008	8/1/2008	Summer
	7	48	8/11/2008	9/27/2008	Summer/Fall
	8	46	10/20/2008	12/4/2008	Fall
	9	48	12/12/2008	1/28/2009	Winter
	10	47	2/9/2009	3/27/2009	Winter/Spring
	11	48	4/10/2009	5/27/2009	Spring
	12	47	6/5/2009	7/21/2009	Summer
	13	47	7/30/2009	9/14/2009	Summer
	14	46	9/26/2009	11/10/2009	Fall
CA1B H12	1	45	9/20/2007	11/3/2007	Fall
	2	48	11/15/2007	1/1/2008	Fall/Winter
	3	48	1/5/2008	2/21/2008	Winter

Table 6-2. Flock Classified by Season

Site	Flock	Number of Days	Occupied Start	Occupied End	Season (Occupied)
	4	48	2/28/2008	4/15/2008	Spring
	5	46	4/22/2008	6/6/2008	Spring
	6	49	6/14/2008	8/1/2008	Summer
	7	47	8/11/2008	9/26/2008	Summer/Fall
	8	46	10/20/2008	12/4/2008	Fall
	9	48	12/12/2008	1/28/2009	Winter
	10	47	2/9/2009	3/27/2009	Winter/Spring
	11	48	4/10/2009	5/27/2009	Spring
	12	48	6/4/2009	7/21/2009	Summer
	13	47	7/30/2009	9/14/2009	Summer
	14	46	9/26/2009	11/10/2009	Fall
KY1B-1 H5	1	50	2/14/2006	4/4/2006	Winter/Spring
	2	50	4/21/2006	6/9/2006	Spring
	3	50	6/22/2006	8/10/2006	Summer
	4	51	9/5/2006	10/25/2006	Fall
	5	54	11/17/2006	1/9/2007	Fall/Winter
	6	52	1/22/2007	3/14/2007	Winter
KY1B-2 H3	1	50	2/20/2006	4/10/2006	Winter/Spring
	2	51	5/22/2006	7/11/2006	Summer
	3	54	7/28/2006	9/19/2006	Summer
	4	54	10/5/2006	11/27/2006	Fall
	5	51	12/14/2006	2/2/2007	Winter
	6[a]	22	2/12/2007	3/5/2007	Winter

[a] Values for flock 6 at KY1B-2 H3 represent a partial flock. The study period concluded before the grow-out period ended.

Table 6-3 summarizes the seasonal distribution of flocks monitored during the course of the NAEMS. The table shows that each discrete season (i.e., spring, summer, fall, and winter) is well represented by the NAEMS data. Although most of the flocks monitored during the NAEMS occurred during a single season, the study also collected data for each transitional period with the exception of spring to summer.

Table 6-3. Flock Distribution by Season

Season	Number of Flocks
Spring	7
Spring/Summer	0
Summer	9
Summer/Fall	2
Fall	8
Fall/Winter	3
Winter	7
Winter/Spring	4

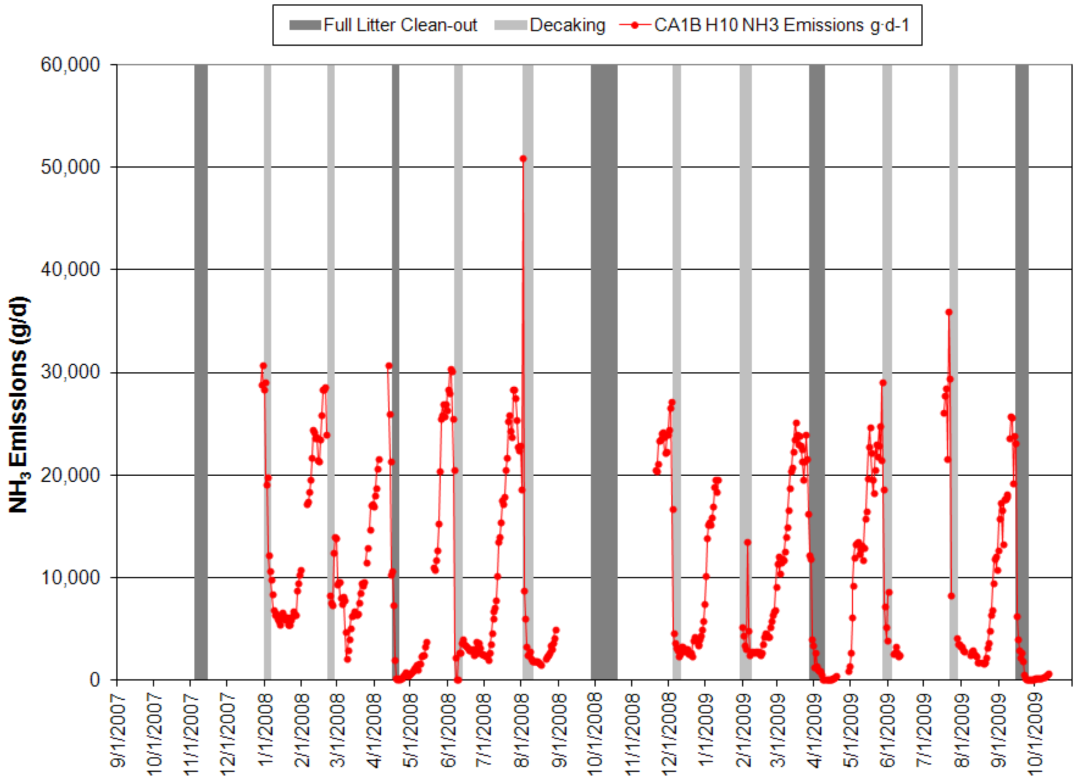
To derive the values used in the seasonal graphs, the overall average emissions for each day of each flock was calculated. For example, the EPA determined the data point for the first day of a summer flock by averaging the emissions values for Day 1 for all flocks grown during the summer season.

6.2 NH_3 Emissions

6.2.1 General Trends

Figure 6-1and Figure 6-2 present the daily NH_3 emission rates calculated over the study period for the CA1B houses and the Kentucky sites, respectively. As reflected in these plots, the daily NH_3 emissions rate generally increased over the grow-out period and decreased during the decaking and full litter clean-out periods. These figures also show spikes and dips in emissions during these litter removal periods that are likely due to increased personnel and equipment activity associated with removing litter, disinfecting the house and replenishing or replacing bedding. Low emissions values during litter removal periods reflect the house sitting idle after cleaning before the next flock of birds arrives. The figures also indicate variation in the emissions levels at the beginning of flock placement and the early stages of the grow-out period. The relationship of this variance with litter condition (i.e., fresh bedding versus decaked litter) is discussed in Section 7.

The decrease in NH_3 emissions early in the grow-out periods shown in the graphs is likely due to management practices of the confinement space. Typically, the birds are confined to a portion of the house (e.g., using a dividing curtain) for the first few weeks of the grow-out period. As they grow larger, the full house is opened up, allowing emissions to diffuse across a larger volume.



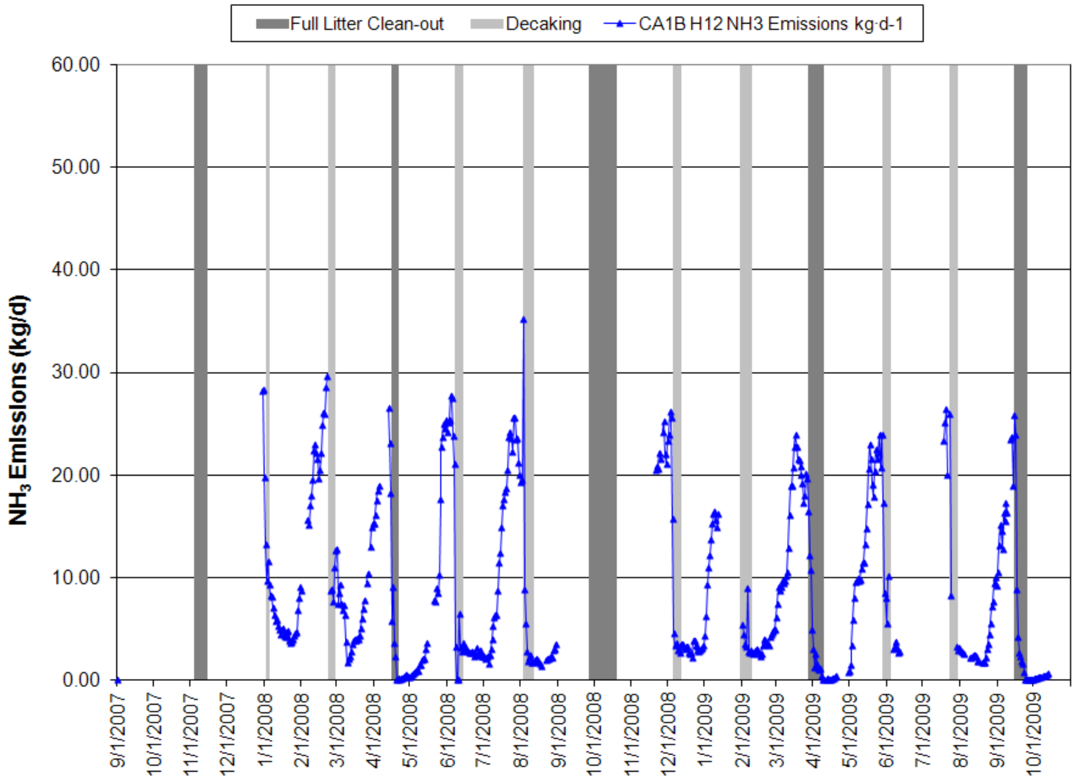
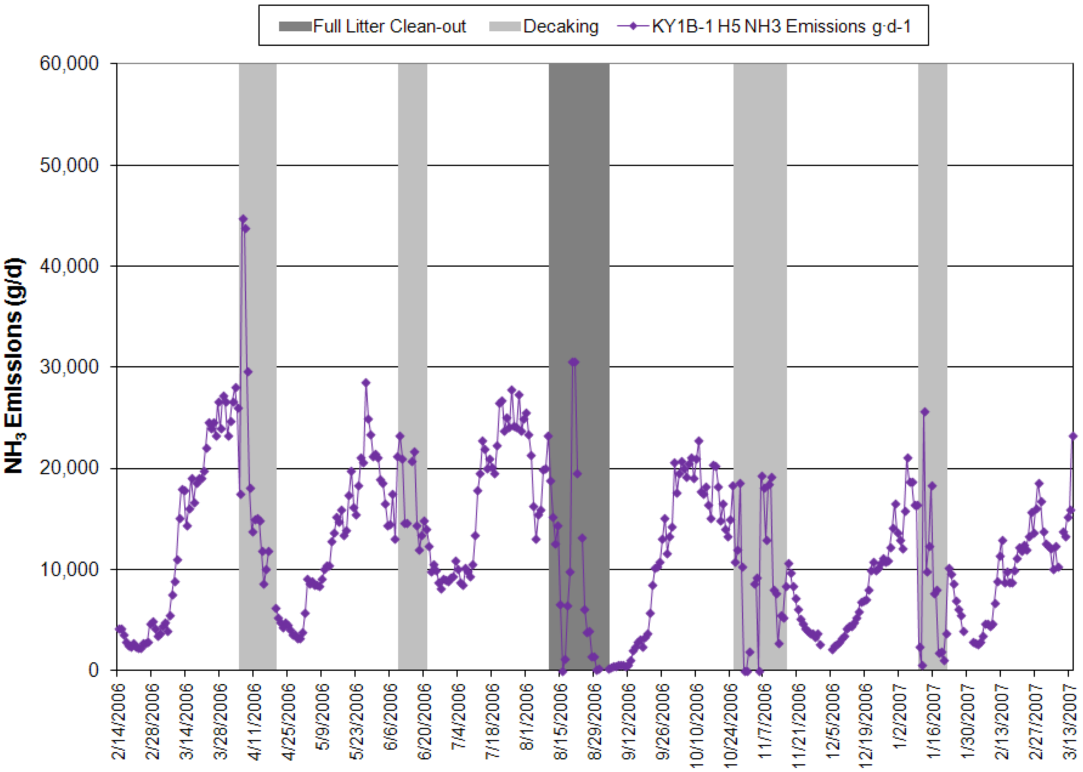


Figure 6-1. NH$_3$ Emission Rates from the CA1B Broiler Houses



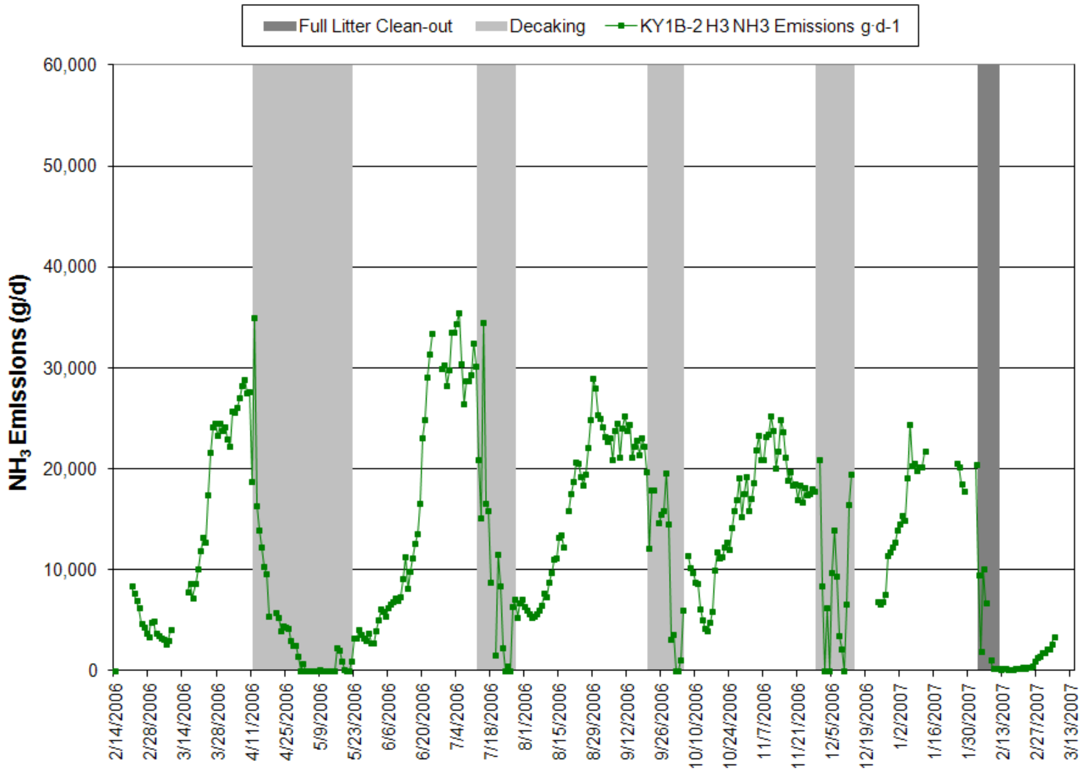


Figure 6-2. NH$_3$ Emission Rates from the Kentucky Broiler Houses

6.2.2 Seasonal Trends

Figure 6-3 presents the daily NH_3 emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6-4, Figure 6-5. Figure 6-6 and Figure 6-7 present the same data shown in Figure 6-3, grouped by season and transitional periods between seasons. The black line on the figures represents the average NH_3 emissions for all flocks.

Based on the seasonal plots, NH_3 emissions from the grow-out, decaking and full litter clean-out periods tend to be higher than the average during the summer months and lower than average during the winter months. The plots for the seasonal classification (Figure 6-5. and Figure 6-6) also indicate NH_3 emissions in the fall season are slightly above average for most of the flock. Furthermore, the average emissions rates for the four seasons suggest that spring is representative of the average emissions rate across all the houses. The graphs show that summer flocks also tended to have the highest NH_3 emissions towards the end of the grow-out and litter removal periods. The only exception is the first monitored flock from KY1B-1 H5 that occurred in the transitional period from winter to spring (WI/SP).

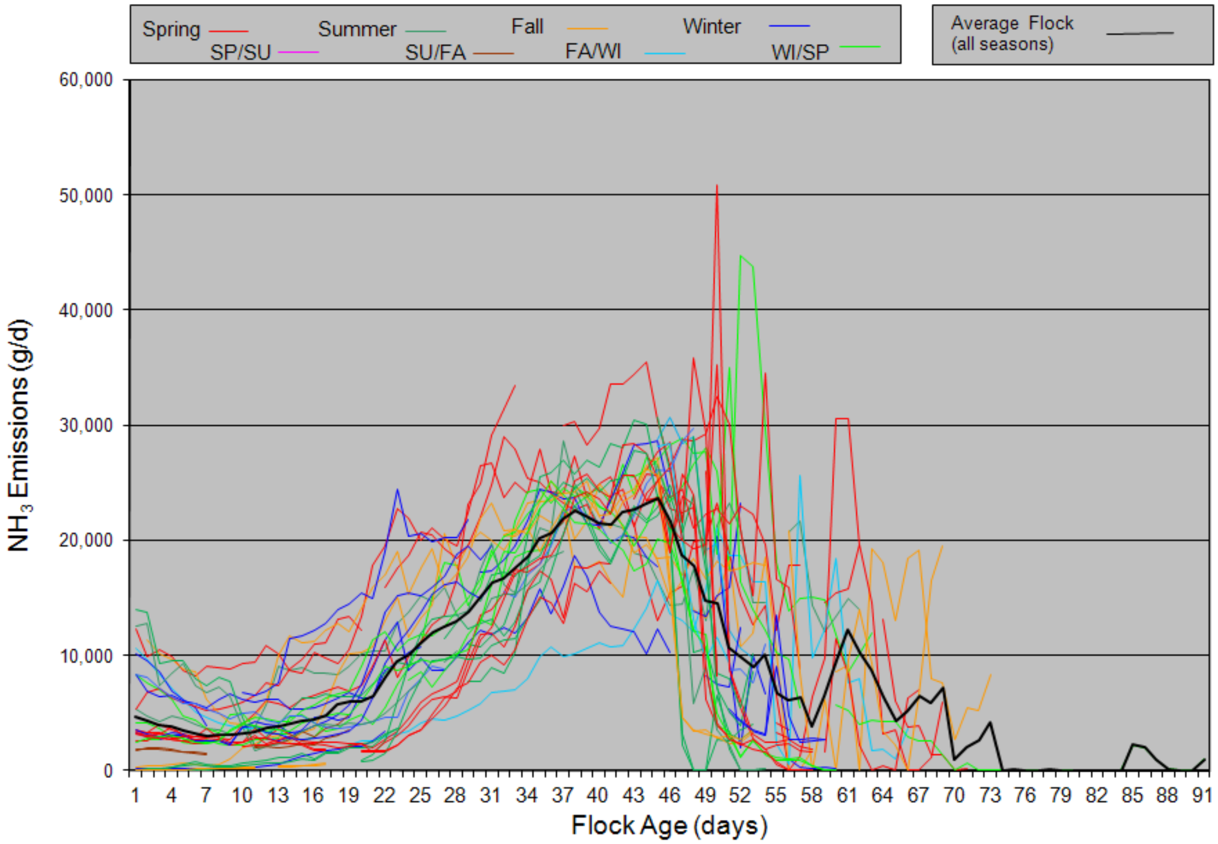
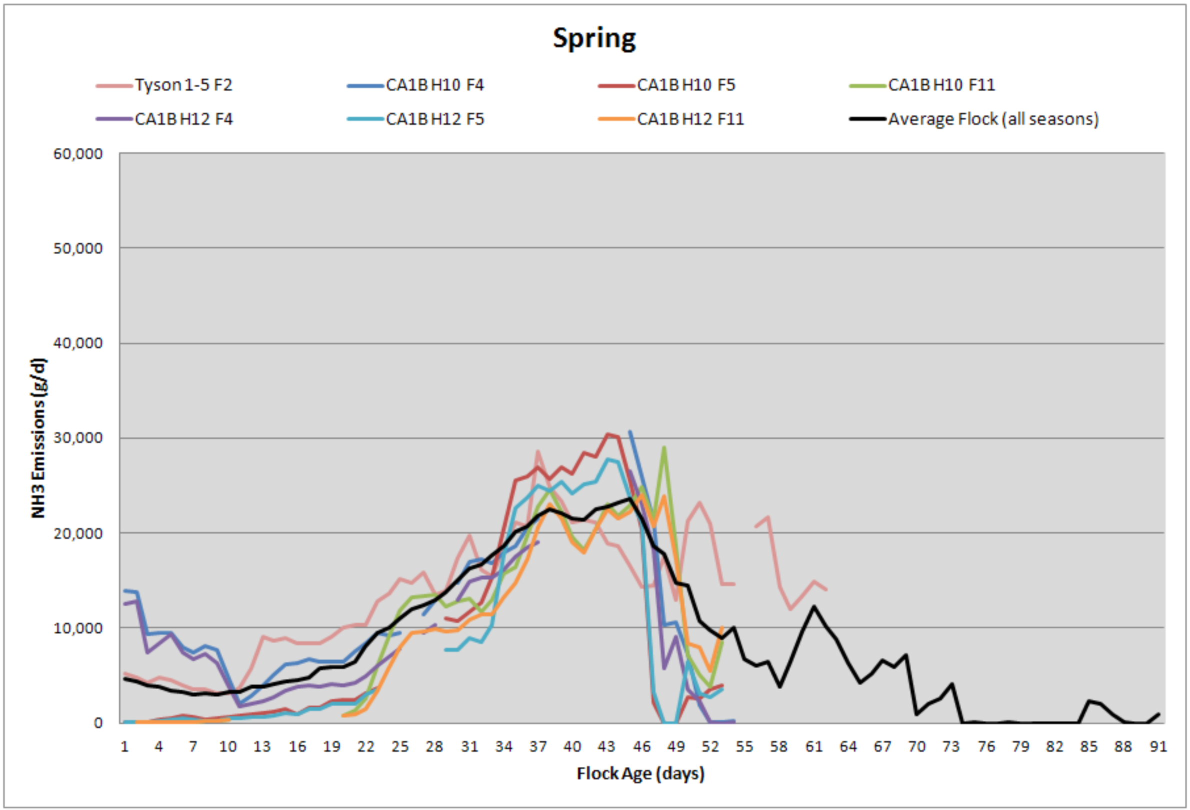


Figure 6-3. NH_3 Emissions by Flock, Color Coded by Season



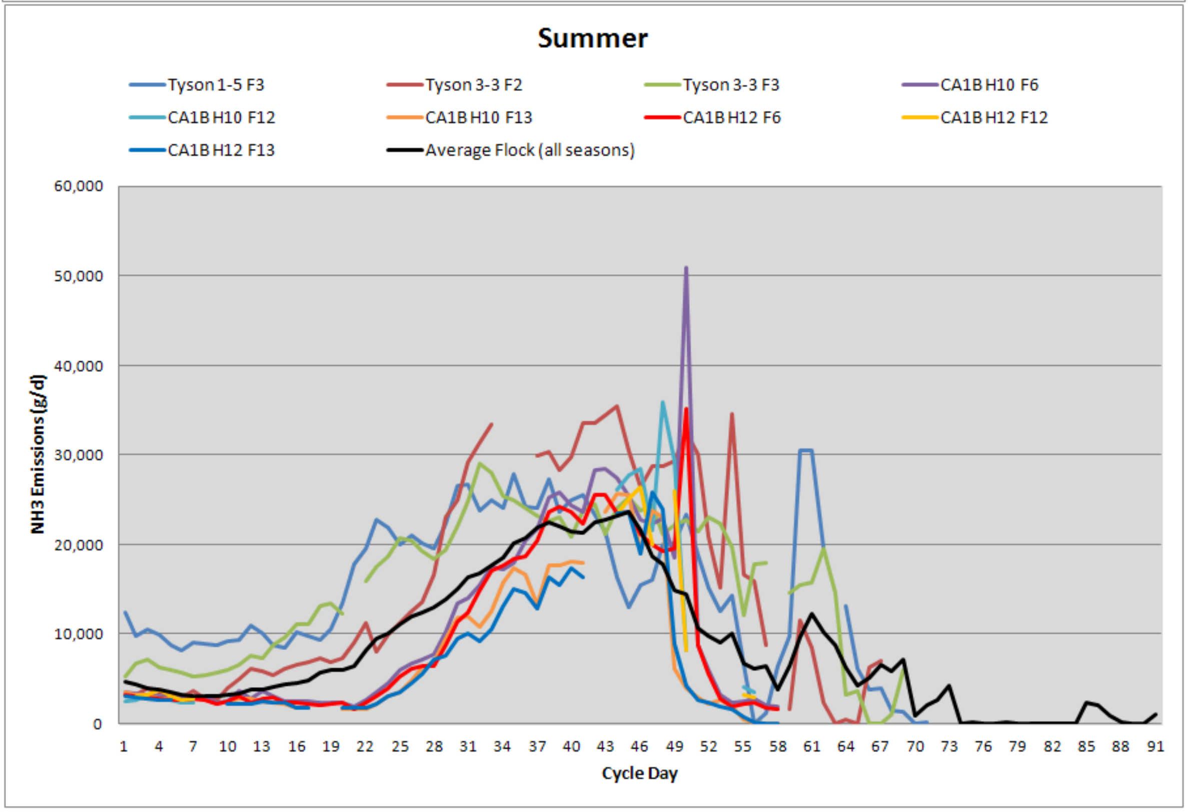
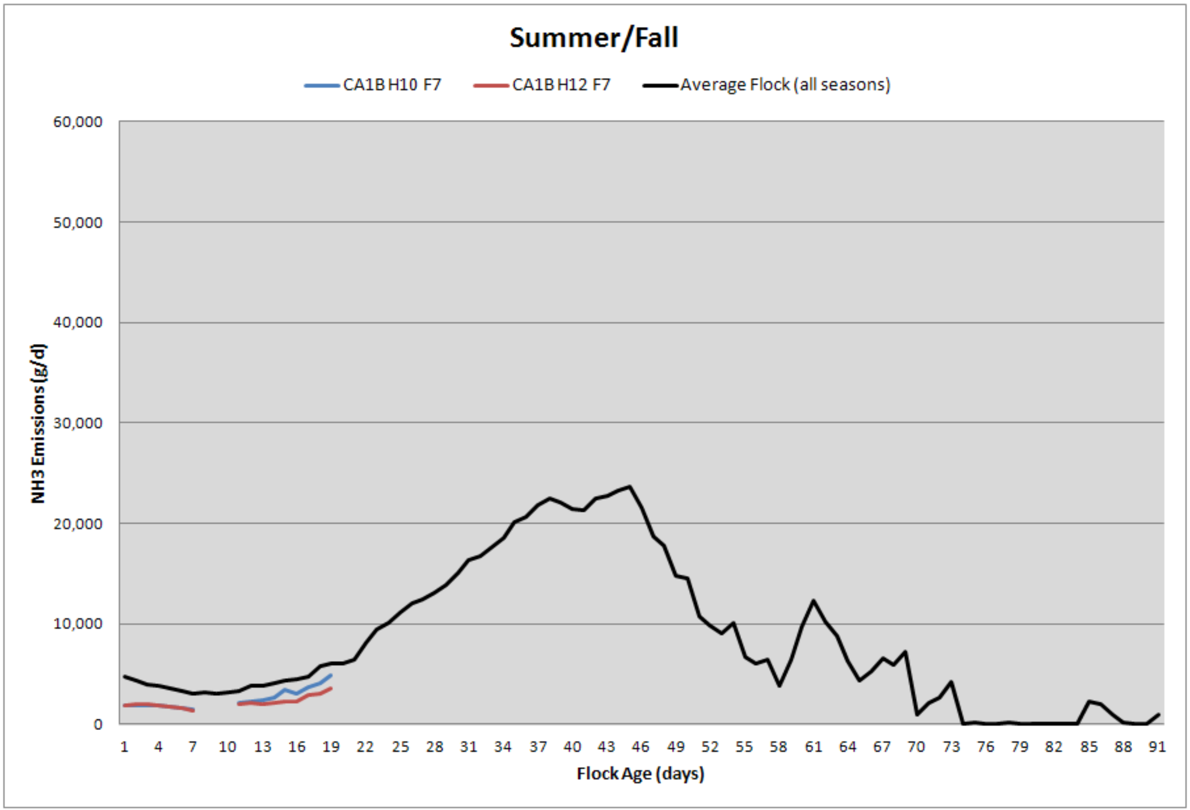


Figure 6-4. NH_3 Emissions from the Broiler Sites for Spring and Summer



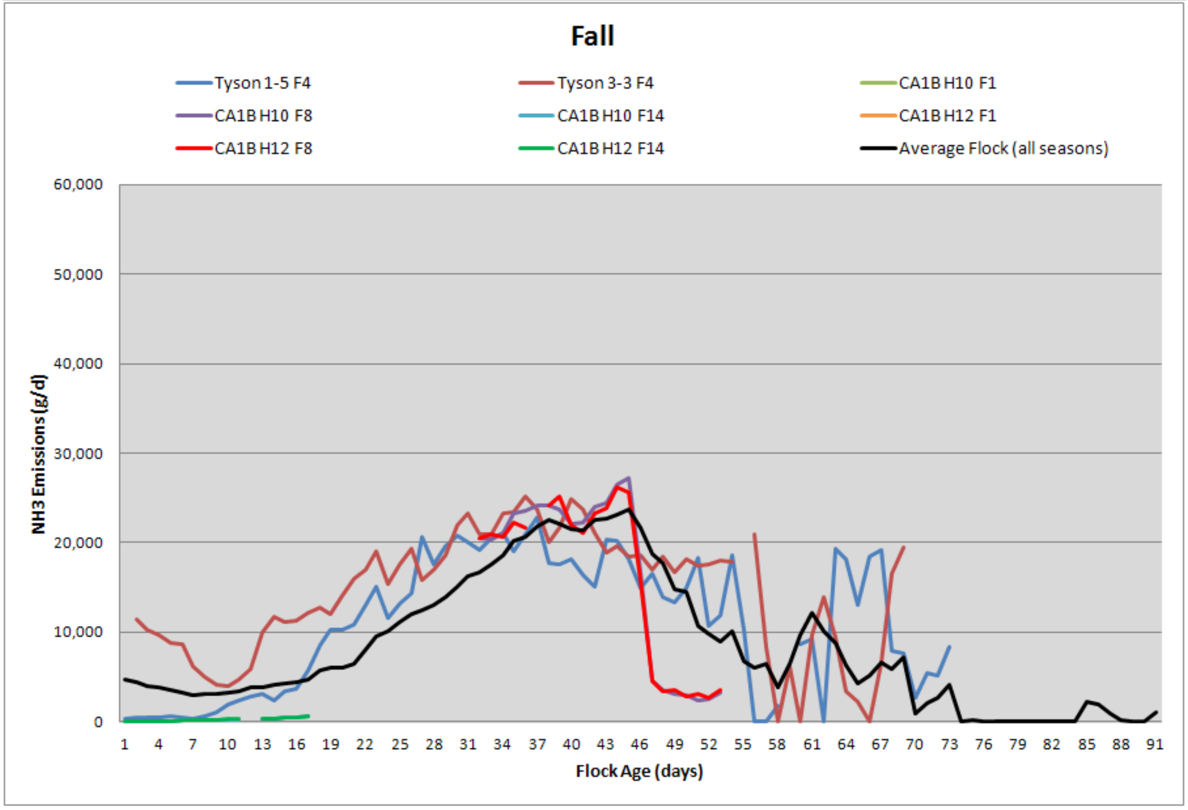


Figure 6-5. NH_3 Emissions from the Broiler Sites for Summer/Fall and Fall

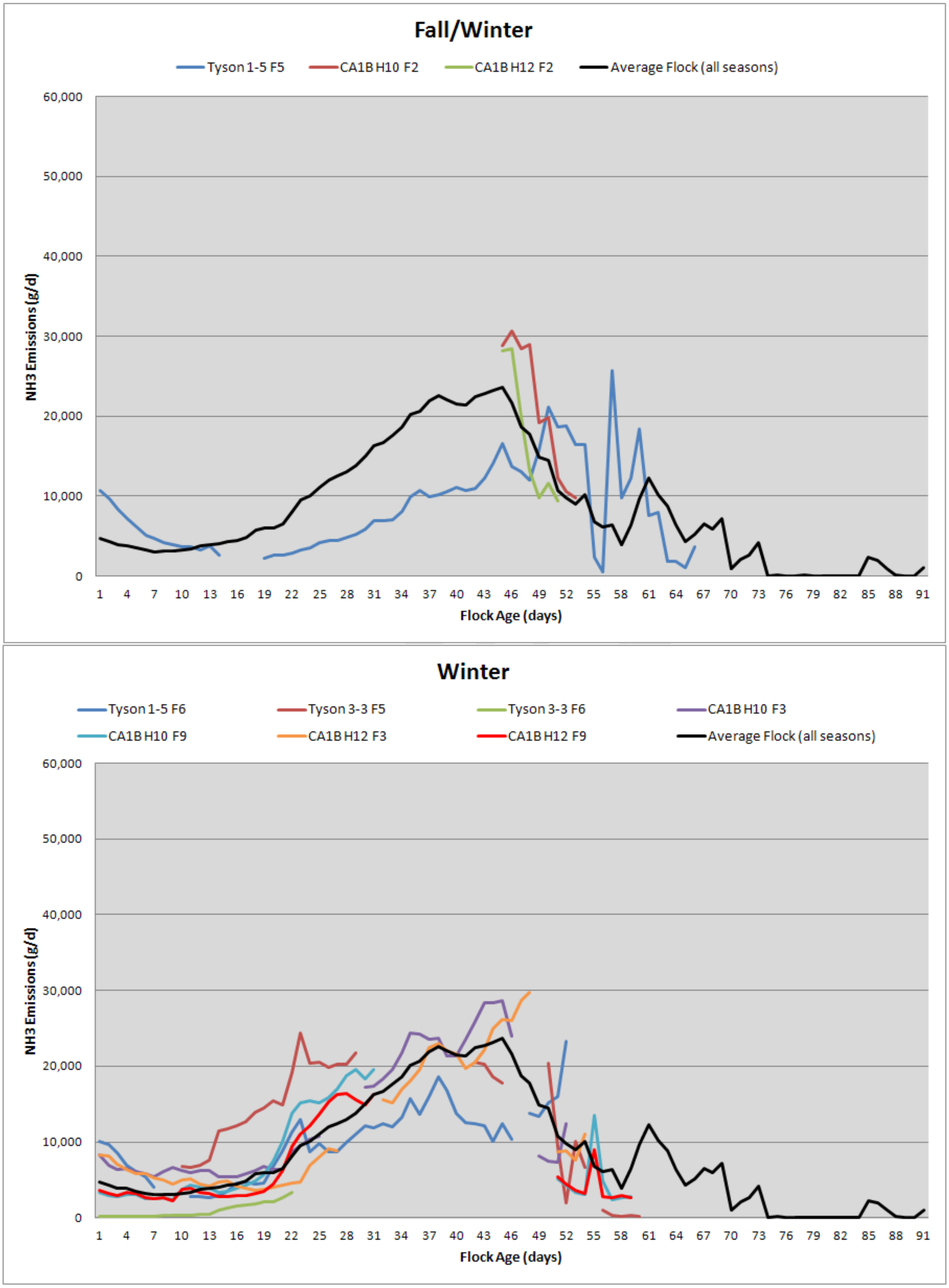


Figure 6-6. NH_3 Emissions from the Broiler Sites for Fall/Winter and Winter

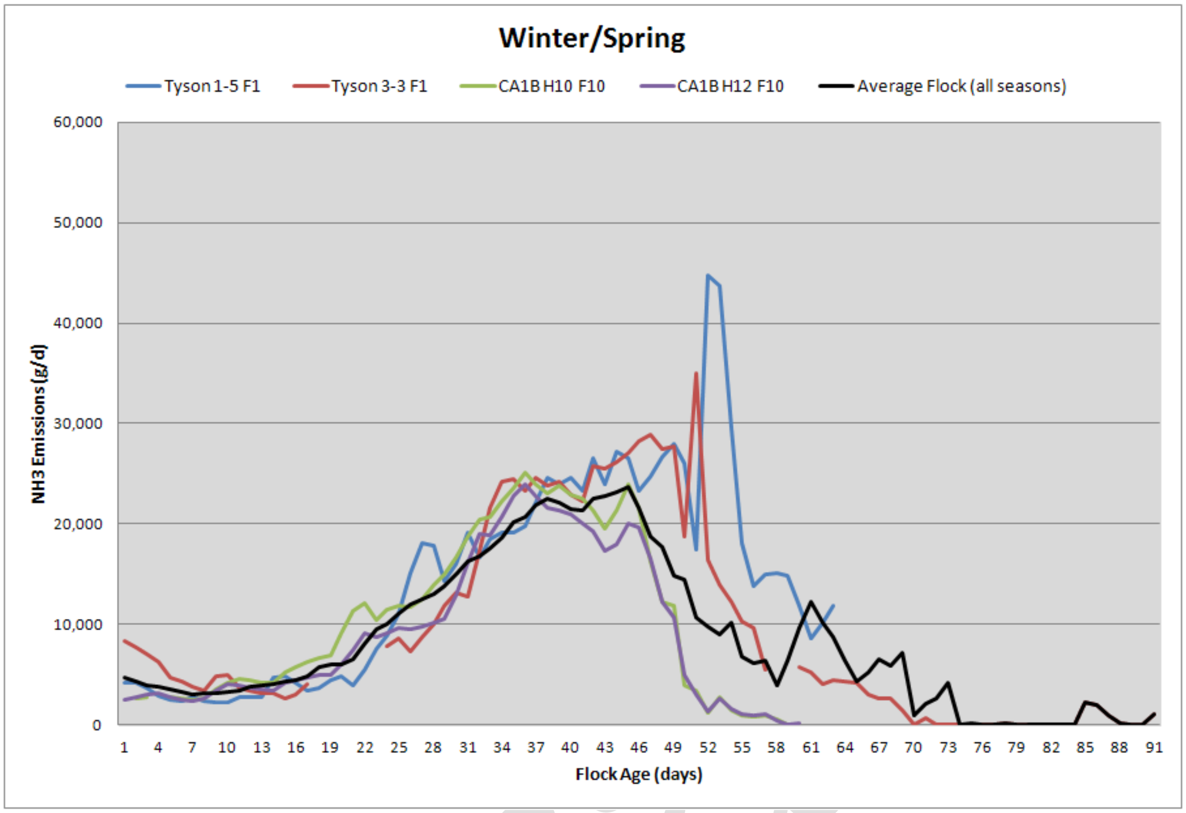
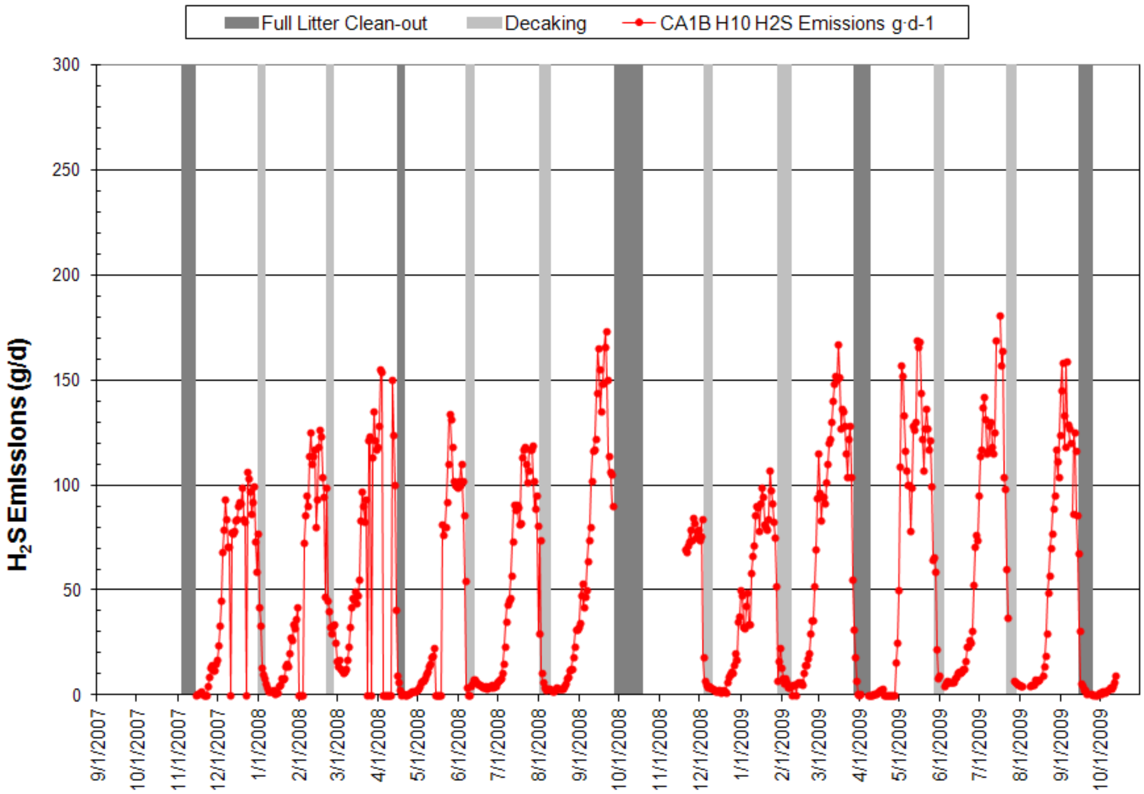


Figure 6-7. NH_3 Emissions from the Broiler Sites for Winter/Spring

6.3 H_2S Emissions

6.3.1 General Trends

Figure 6-8 and Figure 6-9 present the daily H_2S emission values calculated over the study period for the CA1B and Kentucky sites. The H_2S emissions follow the same general trend as NH_3 emissions (i.e., increasing emissions with bird age, with emissions dropping after birds are removed from the house). Figure 6-9 also shows that the H_2S emissions rates tended to spike at site KY1B-1 H5.



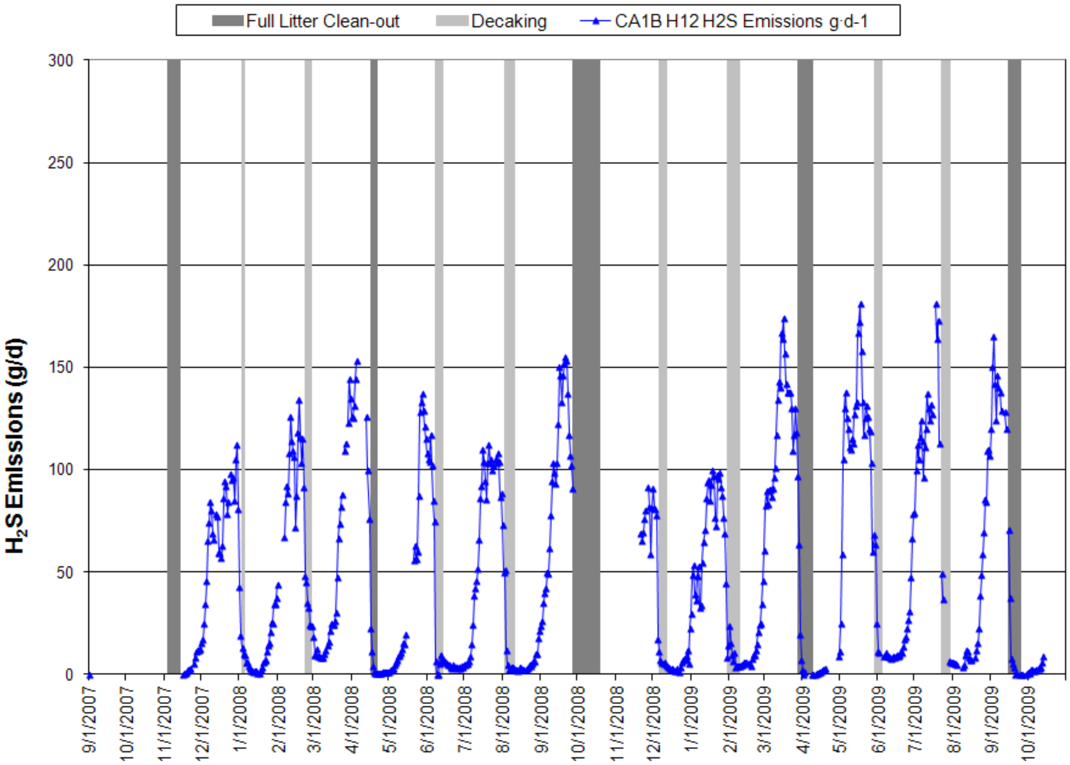
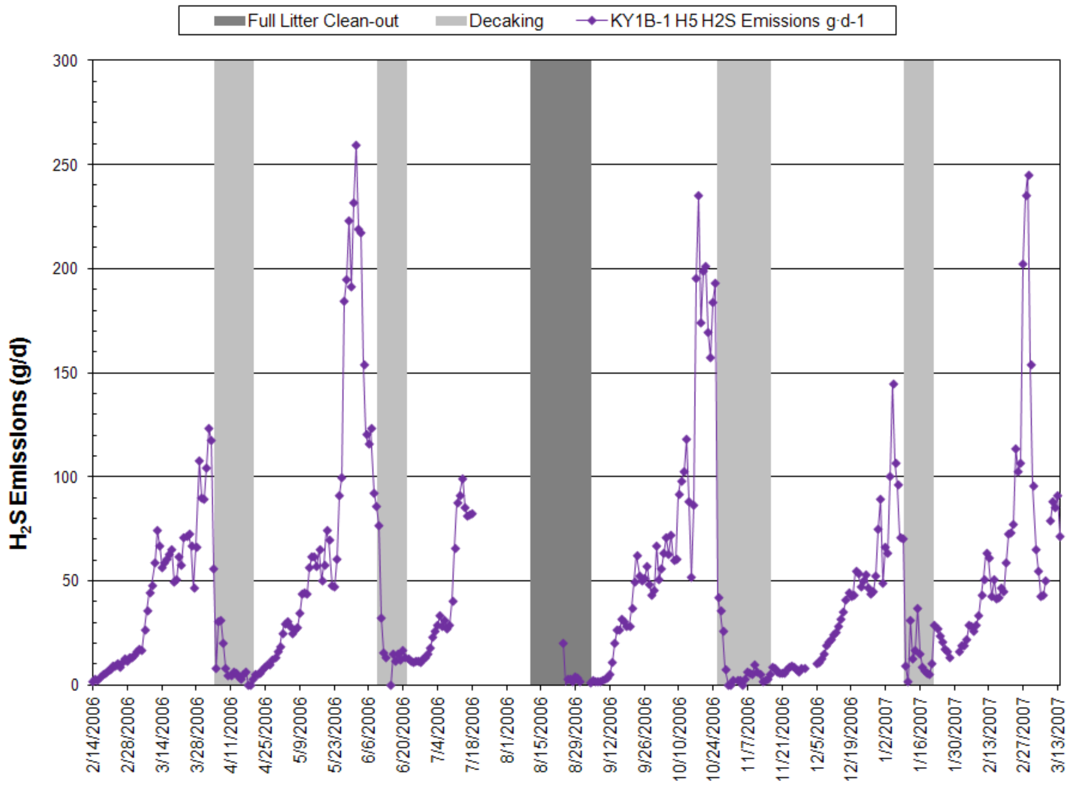


Figure 6-8. H_2S Emissions from the CA1B Broiler Houses



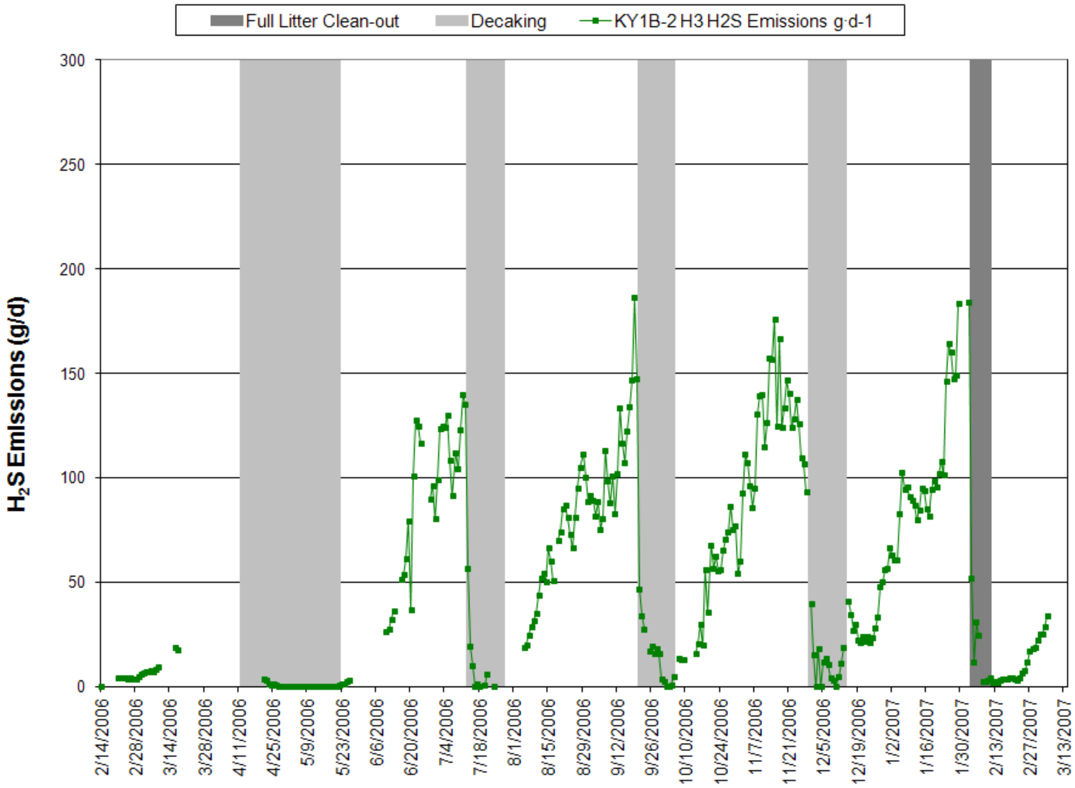


Figure 6-9. H_2S Emissions from the Kentucky Broiler Sites

6.3.2 Seasonal Trends

Figure 6-10 presents the daily H_2S emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6-11, Figure 6-12, Figure 6-13 and Figure 6-14 present the same data shown in Figure 6-10, grouped by season and transitional period. The black line on the figures represents the average emissions for all flocks.

In general, emissions were slightly higher than average during grow-out periods in the spring and slightly higher during litter removal periods in the summer and fall. Figure 6-10 also shows that the variation in daily emissions rates from the overall average (black line) was minimal, with a few exceptions later in the period (days 35 through 55). As shown in Figure 6-11 and Figure 6-12, these late period anomalies occurred at KY1B-1 H5. The anomalies of two of these flocks from the summer (flock 3) and fall (flock 4) are largely explained by the change in emissions during litter removal activities. The anomalies of the remaining two flocks in the spring (flock 2) and winter (flock 6) that peak near day 40 appear to be due to higher ventilation rates for the house. Figure 6-12, Figure 6-13 and Figure 6-14 also show flocks raised during the transition between seasons had emissions near the overall average.

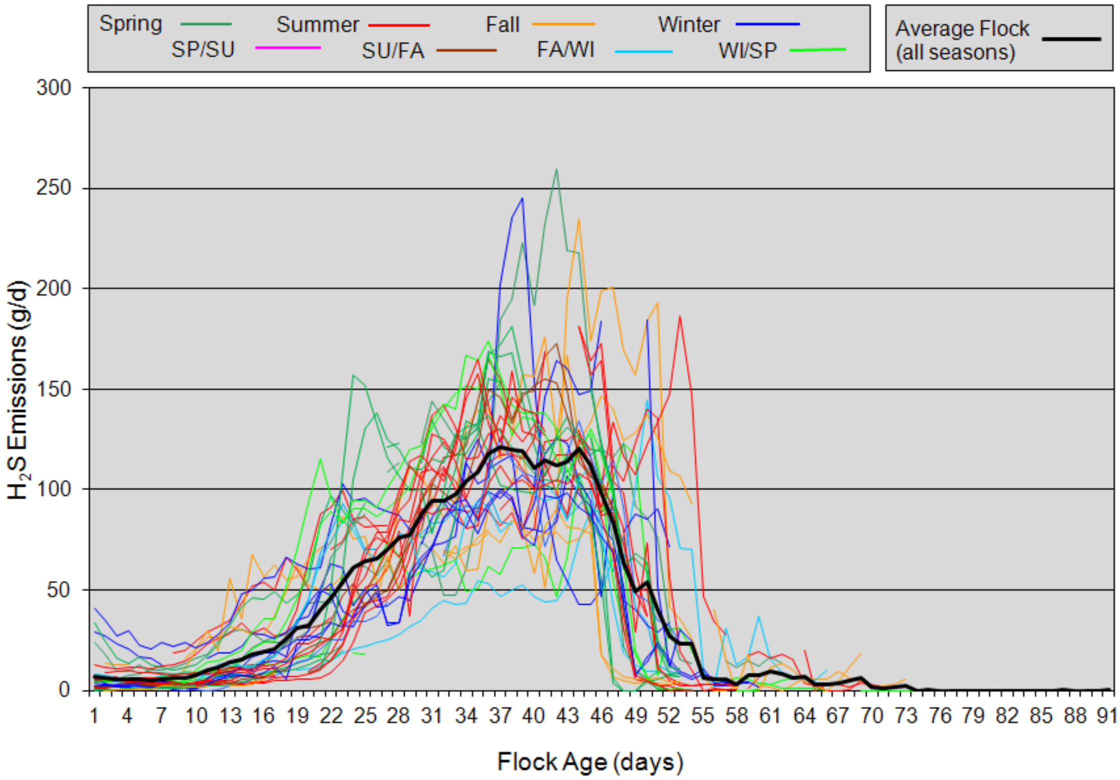


Figure 6-10. H_2S Emissions by Flock, Color Coded by Season

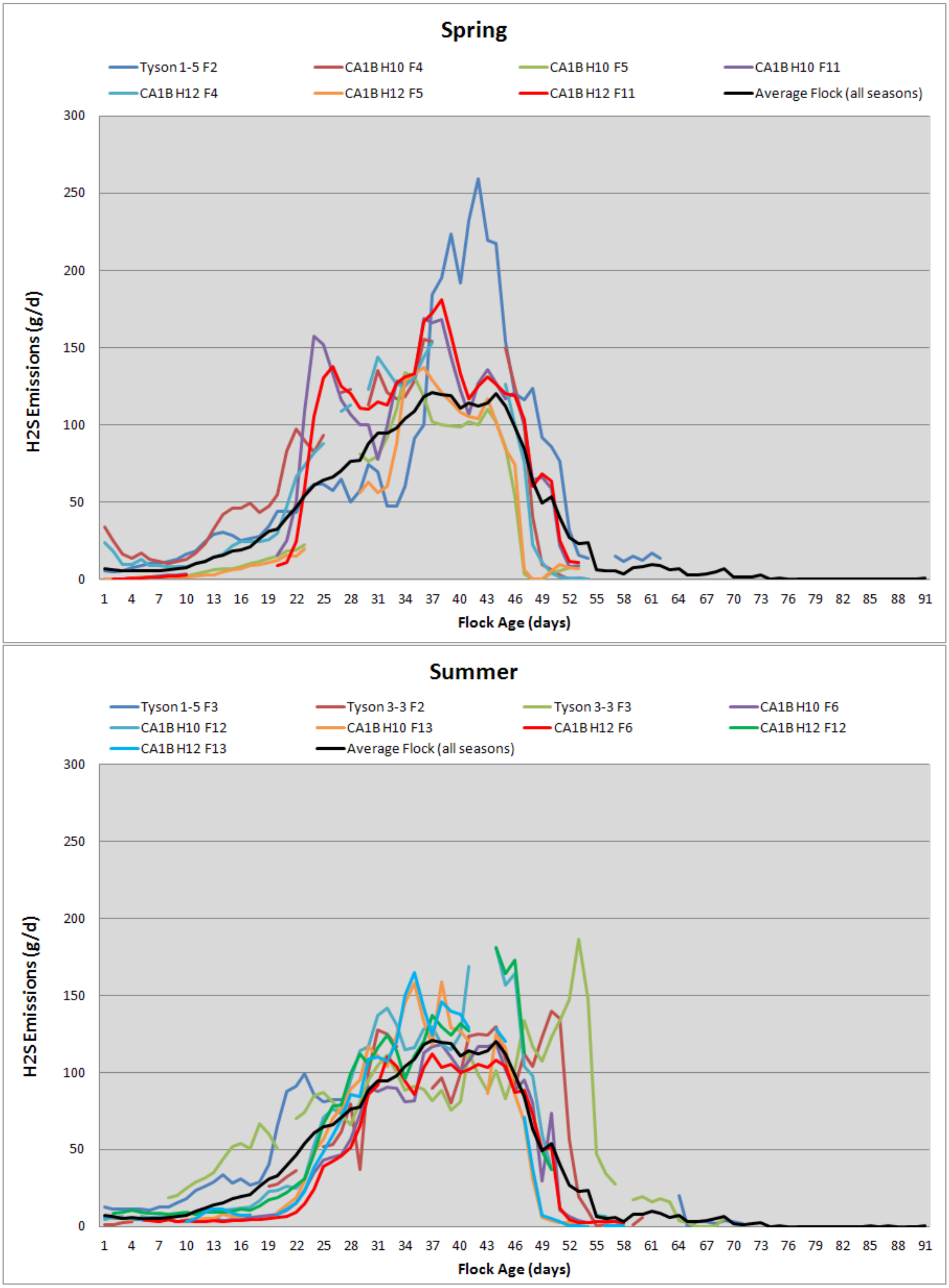


Figure 6-11. H_2S Emissions from the Broiler Sites for Spring and Summer

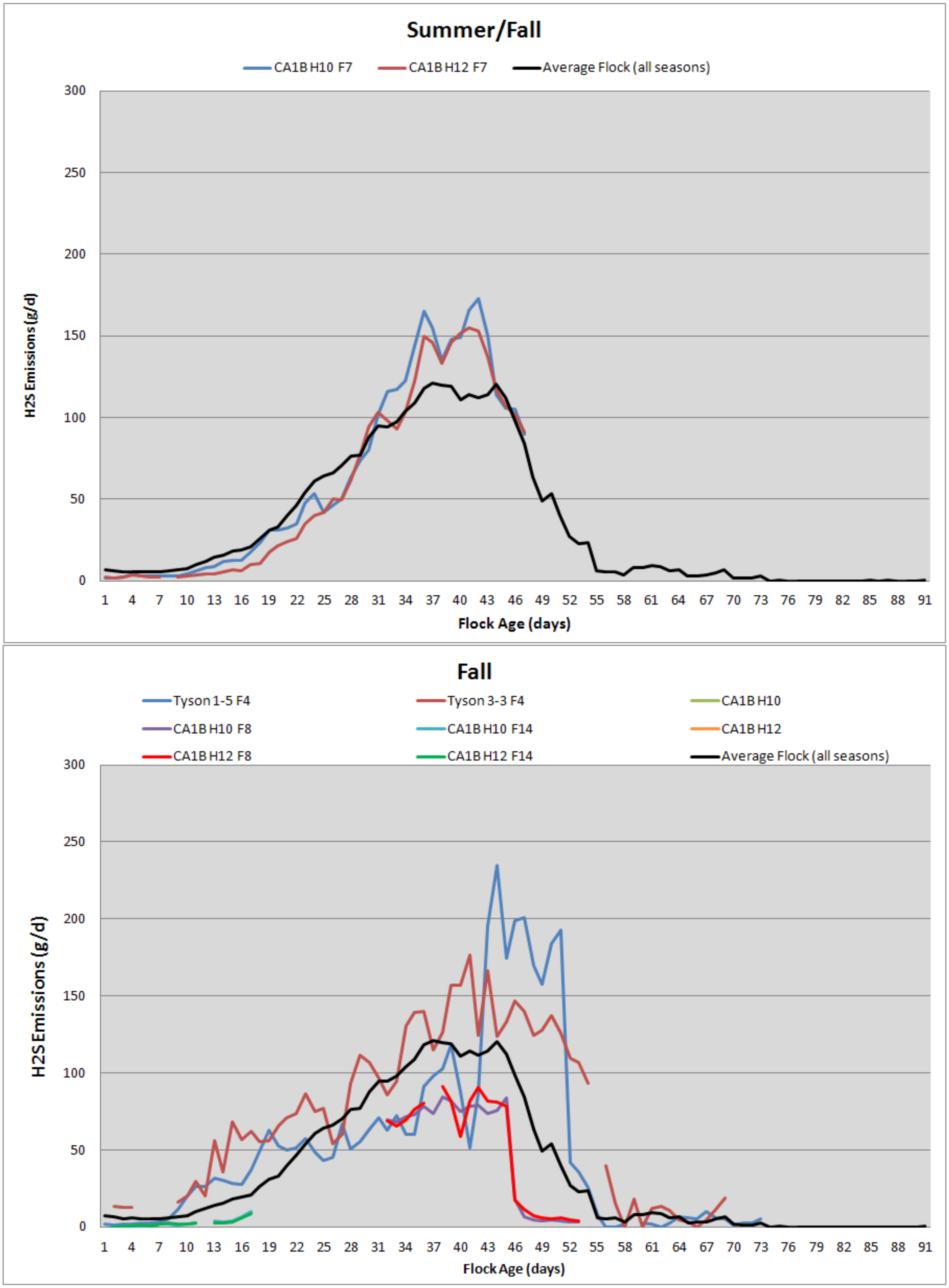
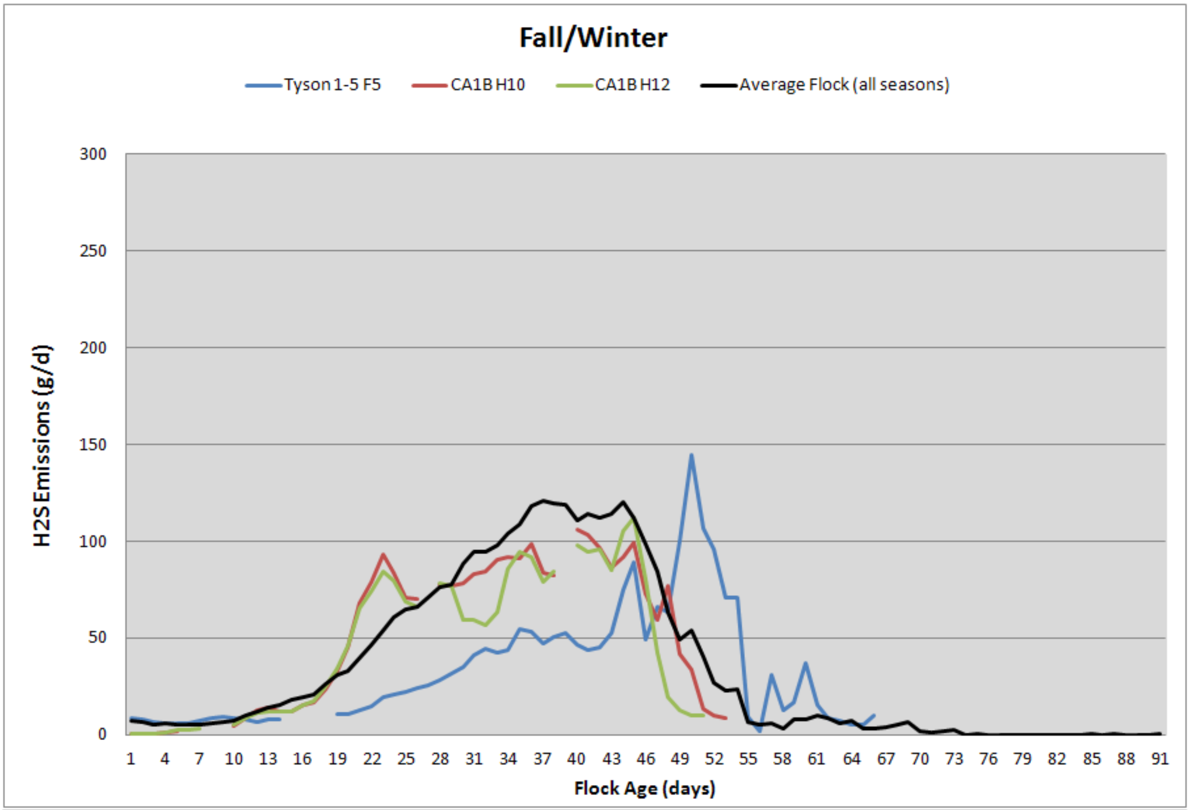


Figure 6-12. H_2S Emissions from the Broiler Sites for Summer/Fall and Fall



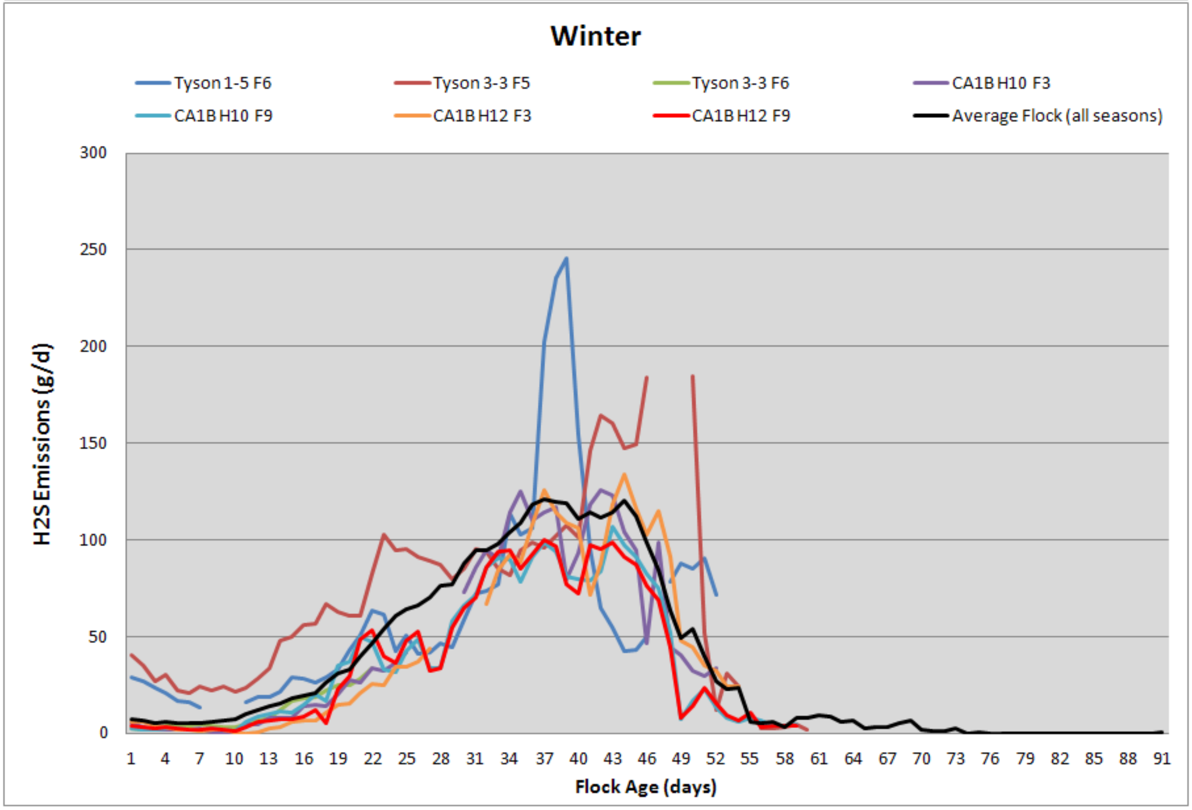


Figure 6-13. H_2S Emissions from the Broiler Sites for Fall/Winter and Winter

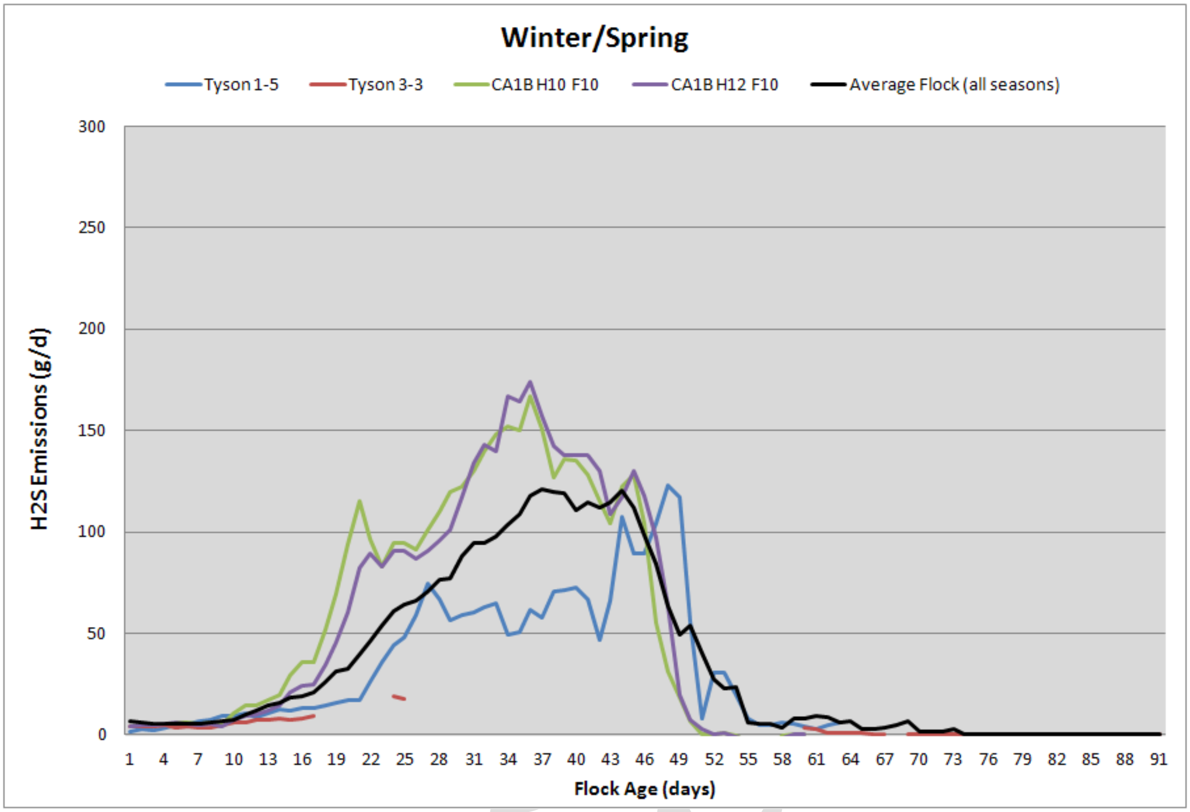


Figure 6-14. H_2S Emissions from the Broiler Sites for Winter/Spring

6.4 PM_{10} Emissions

6.4.1 General Trends

Figure 6-15 and Figure 6-16 present the daily PM_{10} emissions rates calculated over the study period for the CA1B and Kentucky sites, respectively. The figures show that emissions of PM_{10} tend to increase with bird age and weight and decrease during decaking and full litter clean-out periods (i.e., the same general trend as the other measured pollutants). However, the steep drop in PM_{10} emissions during litter removal periods is due to removal of the PM monitors for the first 4 to 9 days of the litter removal period. It is possible that spikes in PM_{10} emissions, similar to those seen for NH_3 and H_2S, occurred during these times; however, these spikes were not captured because the monitors were not operating. The PM_{10} measurements taken during litter removal periods reflect emissions from a clean house that is idle while waiting for the next flock of birds. The PM_{10} measurements do not reflect periods when the decaking or full litter clean-out activities were being conducted.

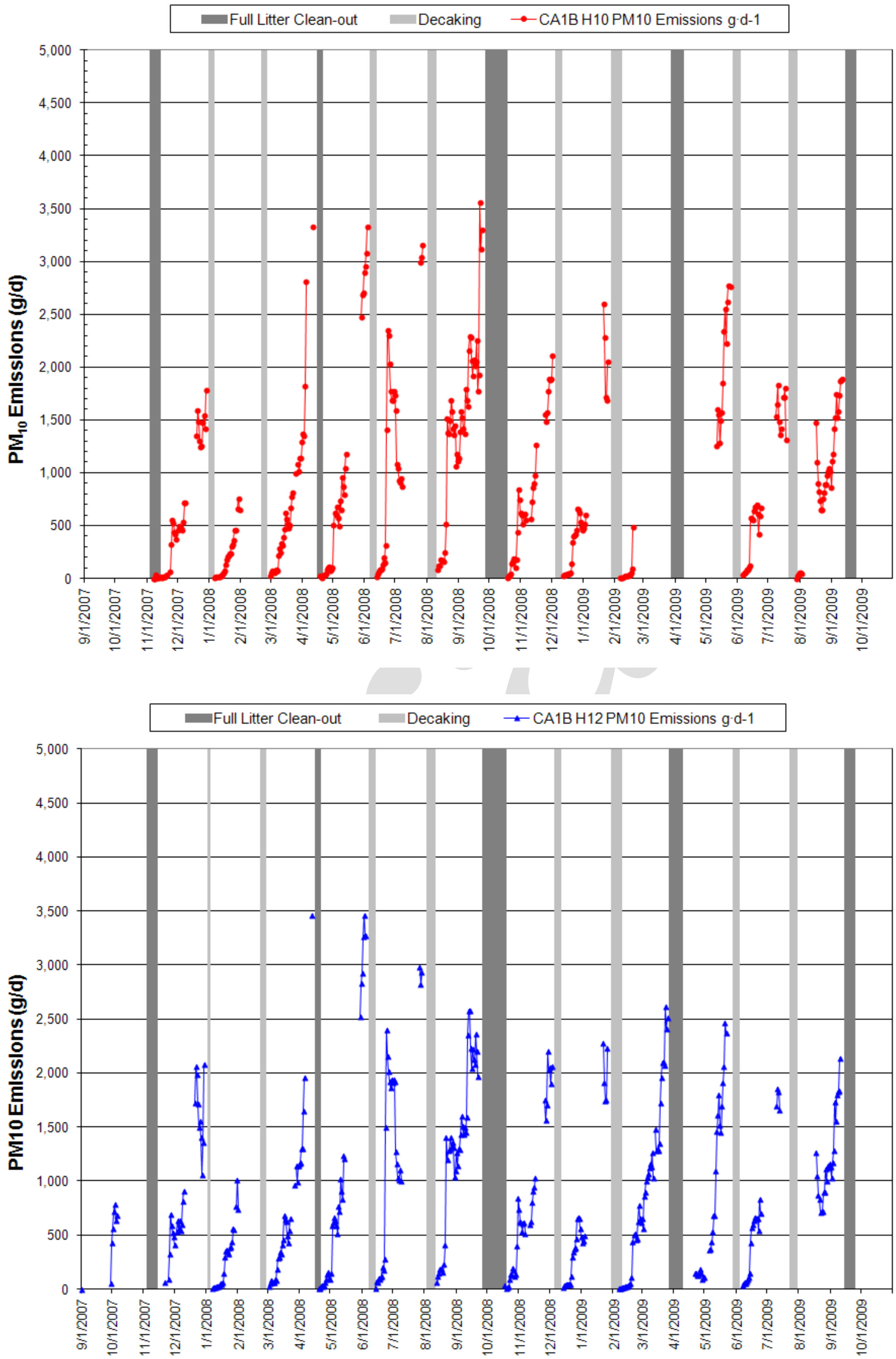


Figure 6-15. PM$_{10}$ Emissions from the CA1B Broiler Houses

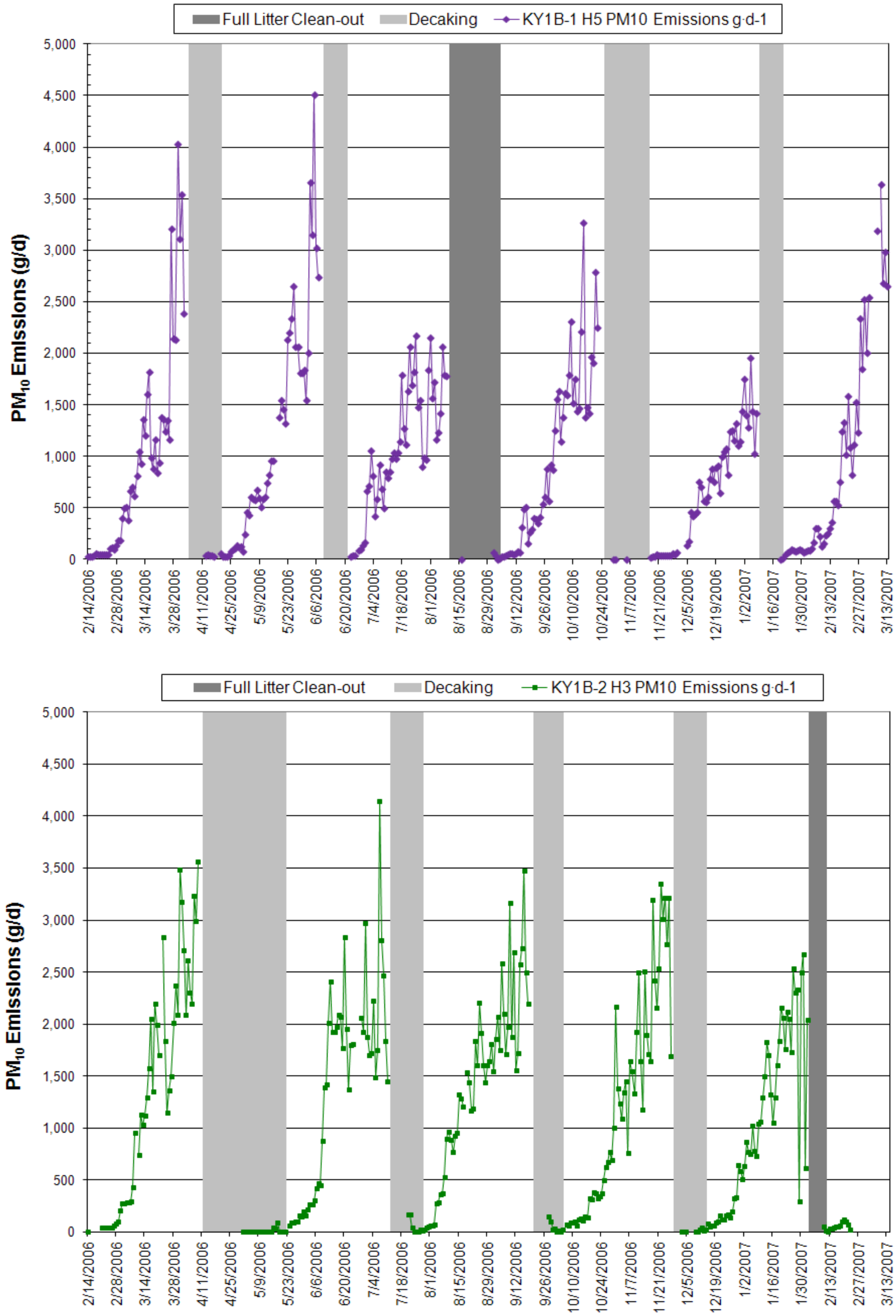


Figure 6-16. PM$_{10}$ Emissions from the Kentucky Broiler Houses

6.4.2 Seasonal Trends

Figure 6-17 presents the daily PM_{10} emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6-18, Figure 6-19, Figure 6-20 and Figure 6-21 present the same data shown in Figure 6-17, grouped by season. The black line on the figures represents the average emissions for all flocks.

These plots show that the PM_{10} emissions at the beginning of the grow-out period for several flocks were higher than the other flocks and were elevated for several days before returning to levels comparable with the other flocks. For site CA1B, the four flocks that stand out from the mean are flocks 6 and 7 from both Houses 10 and 12 for days 11 through 20 of the grow-out period. In addition, PM_{10} emissions were elevated from days 21 to 30 of the grow-out period for flock 2 at KY1B-2 H3. The grow-out periods for these five flocks occurred during the summer (see Figure 6-18) or during the transition period from summer to fall (see Figure 6-19). The confinement houses during these periods had above-average ambient temperatures and increased ventilation air flow rates, which could explain the increased PM_{10} emissions rates.

Emissions of PM_{10} also show seasonality with flocks. The PM_{10} emissions are higher than average from most flocks raised during the summer and below average from wintertime flocks. Emissions of PM_{10} for spring and fall flocks generally fall close to the average daily flock value.

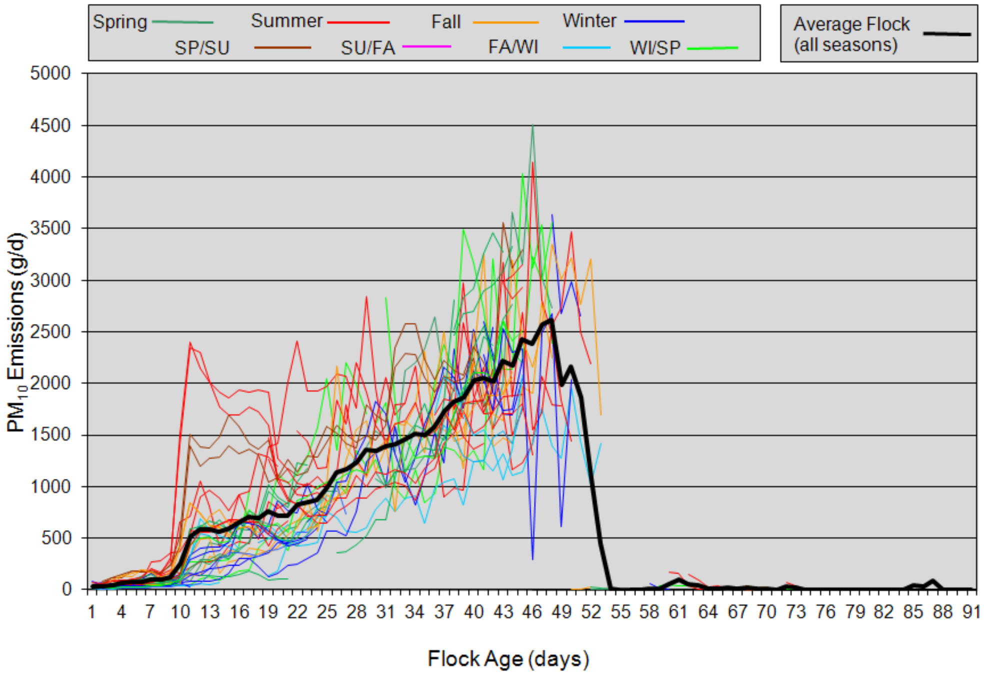


Figure 6-17. PM_{10} Emissions by Flock, Color Coded by Season

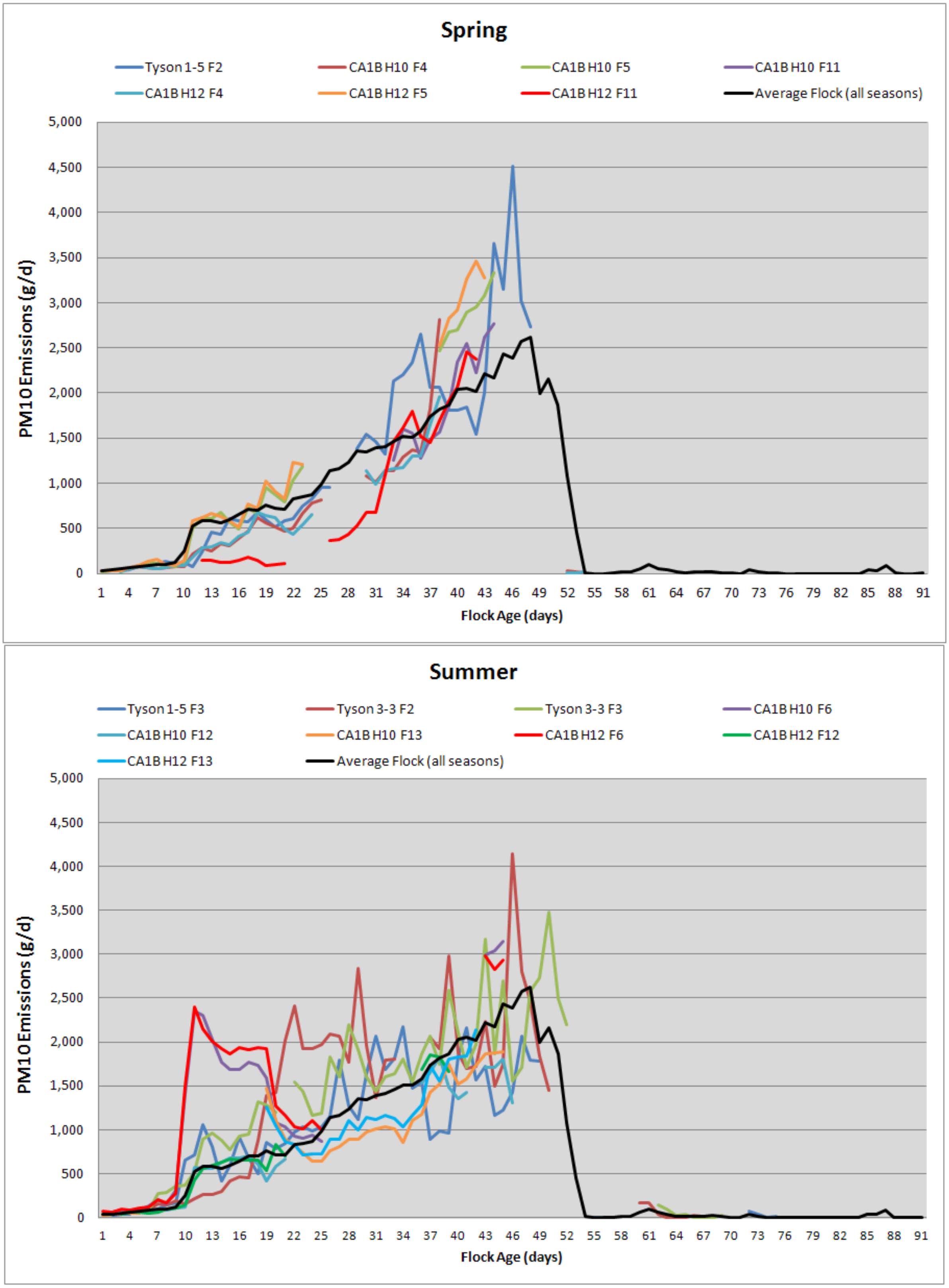


Figure 6-18. PM_{10} Emissions from the Broiler Sites for Spring and Summer

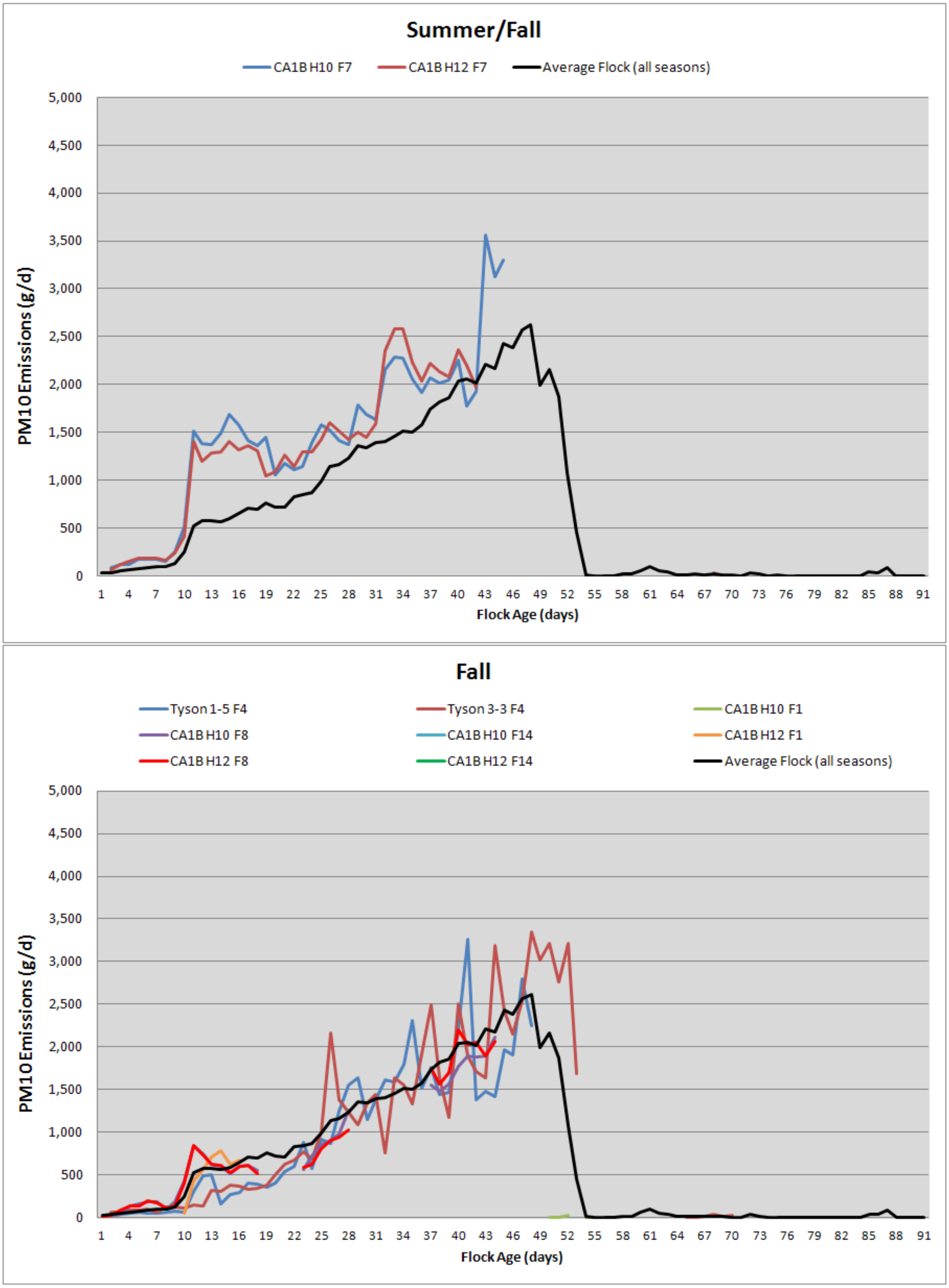


Figure 6-19. PM_{10} Emissions from the Broiler Sites for Fall and Fall/Winter

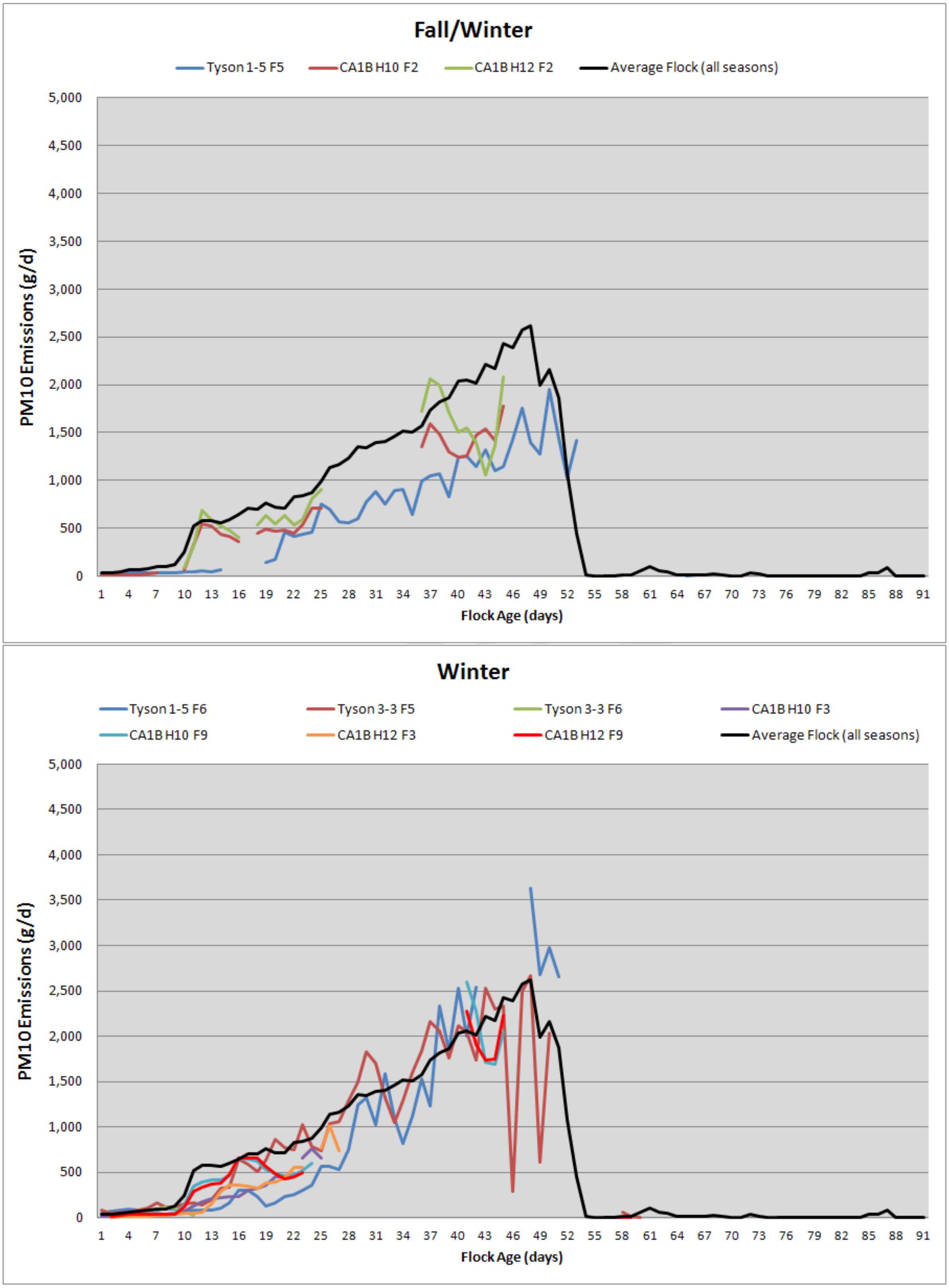


Figure 6-20. PM_{10} Emissions from the Broiler Sites for Fall/Winter and Winter

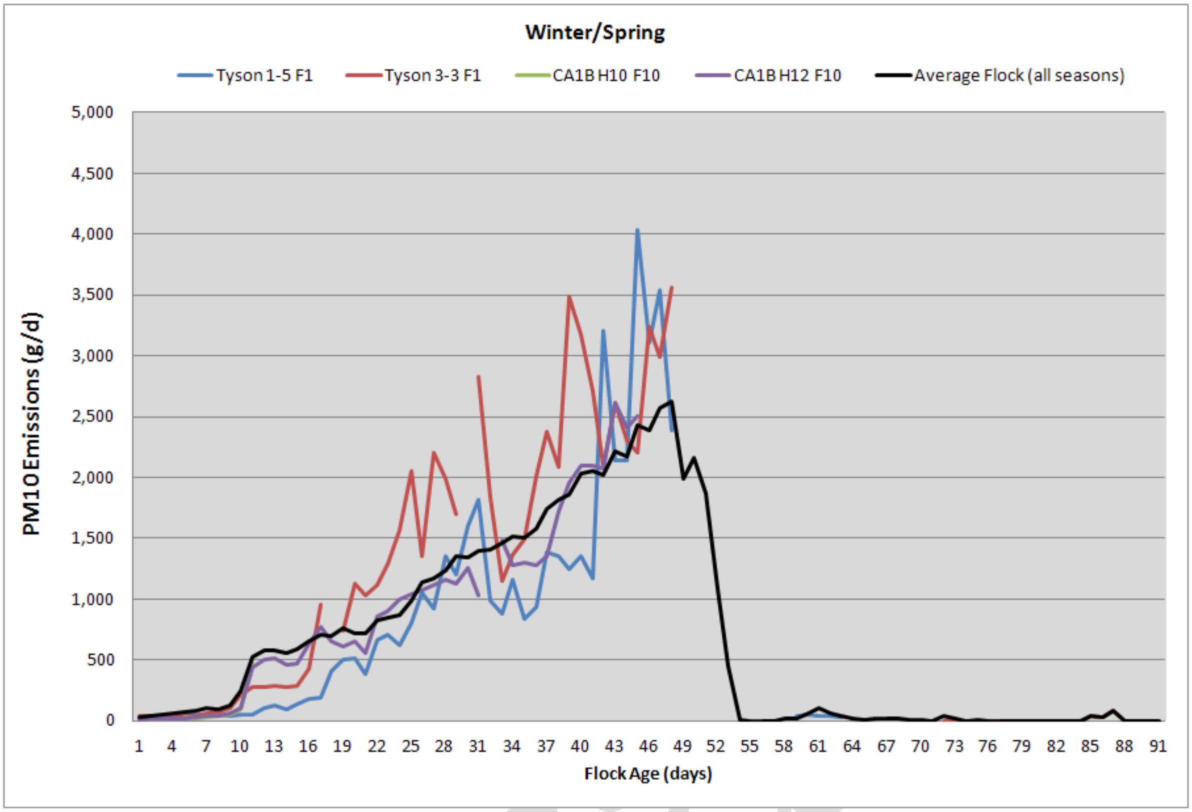


Figure 6-21. PM_{10} Emissions from the Broiler Sites for Winter/Spring

6.5 $PM_{2.5}$ Emissions

6.5.1 General Trends

The $PM_{2.5}$ emissions were monitored continuously over the study period for the two Kentucky sites. At site CA1B, $PM_{2.5}$ emissions were monitored in accordance with the monitoring protocol and data were collected for two weeks each during the summer and the winter to capture any differences in emissions between warm and cold seasons.

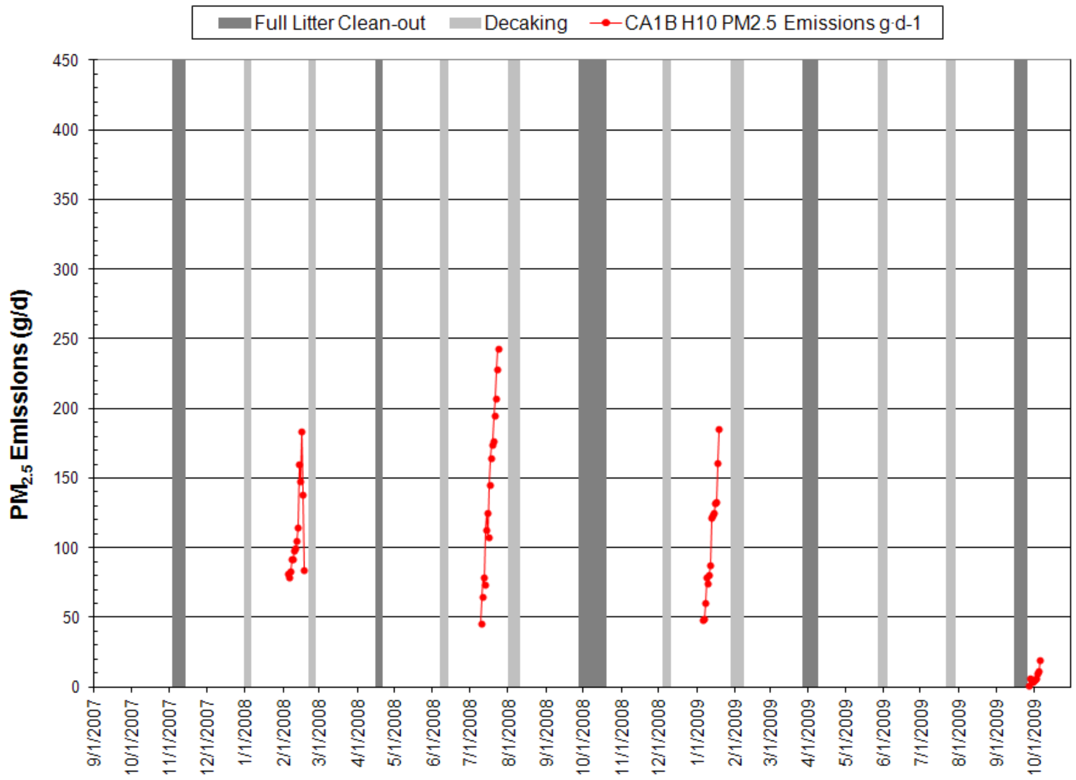
Table 6-4 shows the number of daily $PM_{2.5}$ emission values that are available for each day of the broiler grow-out, decaking and full litter clean-out periods, and illustrates the gaps in data from the CA1B houses. Section 5.1.3 presents the sampling schedule for $PM_{2.5}$ monitoring activities at CA1B.

Figure 6-22 and Figure 6-23 present the daily $PM_{2.5}$ emissions rates calculated over the study period for the CA1B and Kentucky sites, respectively. As with the other monitored pollutants, the figures show that the $PM_{2.5}$ emissions steadily increase over the grow-out period.

Table 6-4. Available $PM_{2.5}$ Emissions Days by Site

Cycle Day	Number of Available Daily $PM_{2.5}$ Emissions Values CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3
1	0	0	6	6
2	1	0	6	6
3	1	0	6	6
4	1	0	6	6
5	1	0	6	6
6	1	0	6	6
7	1	0	6	6
8	1	0	6	6
9	1	0	6	6
10	1	0	6	6
11	1	0	6	6
12	0	0	6	6
13	0	0	6	6
14	0	0	6	6
15	0	0	6	6
16	0	0	6	6
17	0	0	6	6
18	0	0	6	6
19	0	0	6	6
20	0	0	6	6
21	0	0	6	6
22	0	0	6	6
23	0	0	6	5
24	0	0	6	5
25	0	0	6	5
26	1	1	6	5
27	2	2	6	5
28	2	2	6	5
29	2	2	6	5
30	3	2	6	5
31	3	2	6	5
32	3	3	6	5
33	3	3	6	5
34	3	3	6	5
35	3	3	6	5
36	3	3	6	5
37	3	3	6	5
38	3	3	6	5
39	3	3	6	5
40	2	2	6	5
41	2	2	6	5
42	1	1	6	5
43	1	1	6	5
44	0	1	6	5
45	0	1	6	5
46	0	0	6	5

Cycle Day	Number of Daily $PM_{2.5}$ Emissions Values CA1B H10	CA1B H12	KY1B-1 H5	KY1B-1 H3
47	0	0	6	5
48	0	0	6	5
49	0	0	6	5
50	0	0	6	5
51	0	0	6	5
52	0	0	6	5
53	0	0	5	5
54	0	0	5	5
55	0	0	5	5
56	0	0	5	5
57	0	0	5	5
58	0	0	5	5
59	0	0	5	5
60	0	0	5	5
61	0	0	5	4
62	0	0	5	4
63	0	0	4	4
64	0	0	4	4
65	0	0	4	4
66	0	0	4	4
67	0	0	2	4
68	0	0	2	3
69	0	0	2	3
70	0	0	2	2
71	0	0	2	1
72	0	0	2	1
73	0	0	2	1
74	0	0	1	1
75	0	0	1	1
76	0	0	0	1
77	0	0	0	1
78	0	0	0	1
79	0	0	0	1
80	0	0	0	1
81	0	0	0	1
82	0	0	0	1
83	0	0	0	1
84	0	0	0	1
85	0	0	0	1
86	0	0	0	1
87	0	0	0	1
88	0	0	0	1
89	0	0	0	1
90	0	0	0	1
91	0	0	0	1
Total	**53**	**43**	**276**	**252**



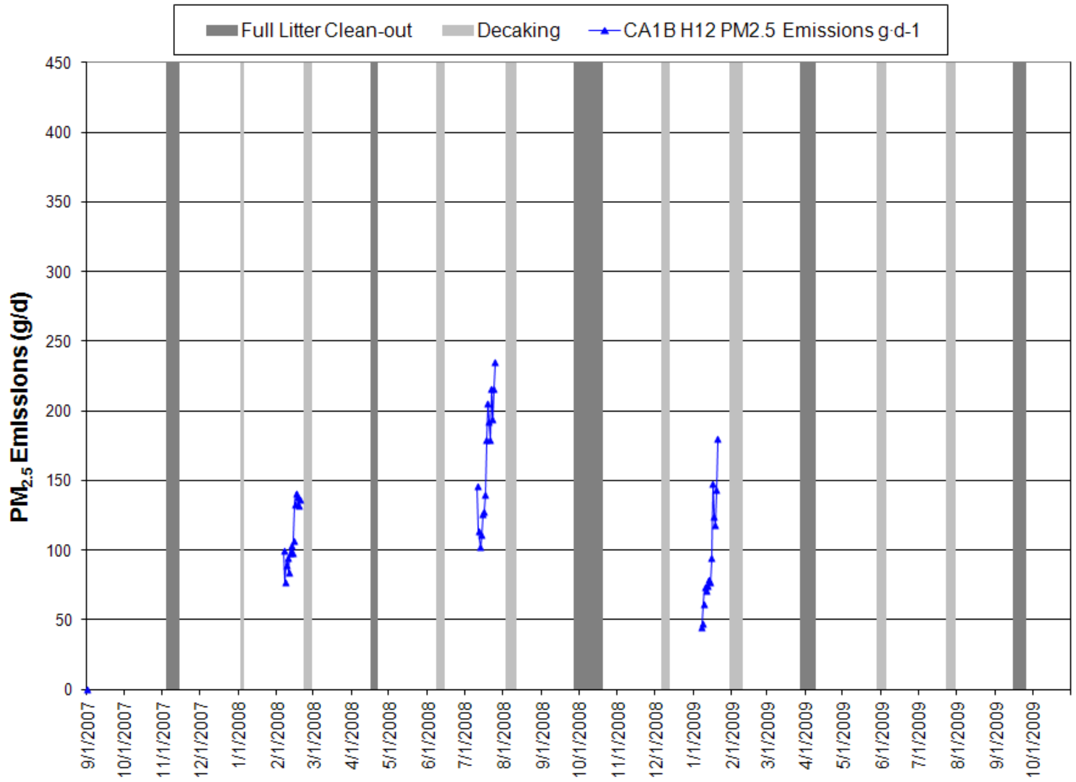


Figure 6-22. PM$_{2.5}$ Emissions from the CA1B Broiler Houses

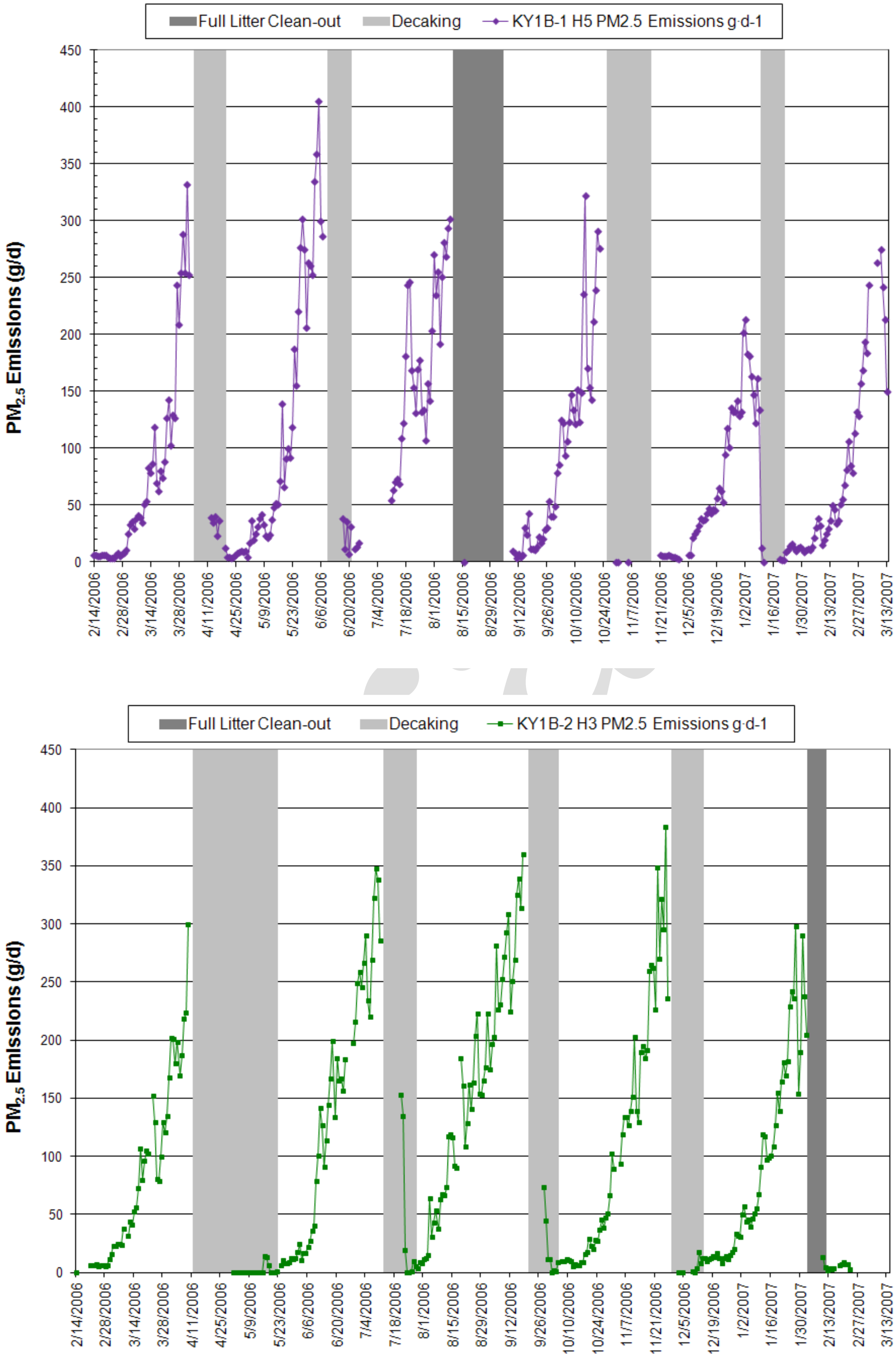


Figure 6-23. $PM_{2.5}$ Emissions from the Kentucky Broiler Houses

Data for $PM_{2.5}$ emissions were not collected at site CA1B during the decaking and full litter clean-out periods. At the Kentucky sites, the PM monitor was removed during the litter removal periods; monitoring resumed in 9 days, on average. As with PM_{10} emissions, the $PM_{2.5}$ emissions values recorded during litter removal periods presented in Figure 6-23 correspond to the time when the house was sitting idle waiting for the next flock to be placed (i.e., $PM_{2.5}$ emissions data were not collected while decaking and full litter clean-out activities were being conducted).

6.5.2 Seasonal Trends

Figure 6-24 presents daily $PM_{2.5}$ emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. Figure 6- 25, Figure 6-26 and Figure 6-27 present the same data as Figure 6-24, grouped by season. The black line on the figures represents the average emissions for all flocks.

Because of the small number of $PM_{2.5}$ emissions values available for site CA1B (see Table 6-4), the comparison of the seasonal trends among the different sites is limited. The average $PM_{2.5}$ emissions values for the fall from CA1B House 10, flock 14, are for the first 10 days of the grow-out period and do not represent the emissions over the entire period. The data for the winter flocks are from measurements taken late in the grow-out period, when emission rates are peaking (emissions data for days early in the grow-out period or during decaking and full litter clean-out periods are not available). Based on the available data, emissions for summer are typically above average, with winter falling just below average. Fall and spring emissions are close to the overall average, except spring deviates late in the grow-out period.

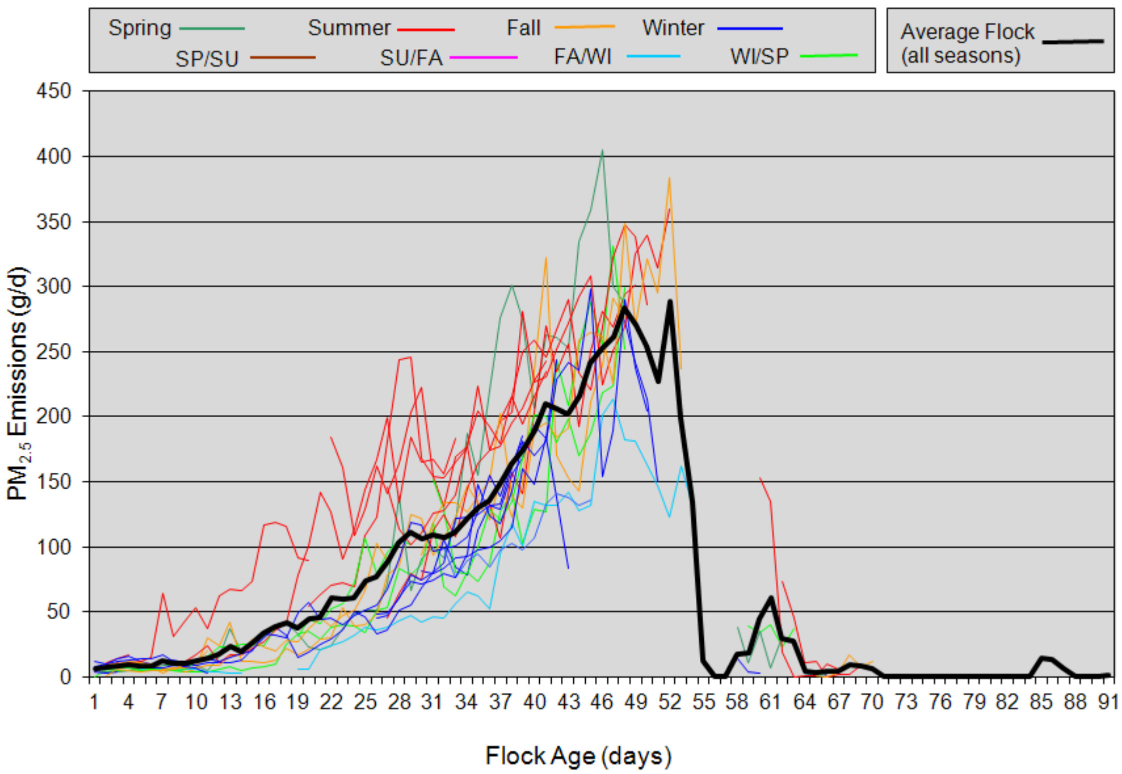


Figure 6-24. PM$_{2.5}$ Emissions by Flock, Color Coded by Season

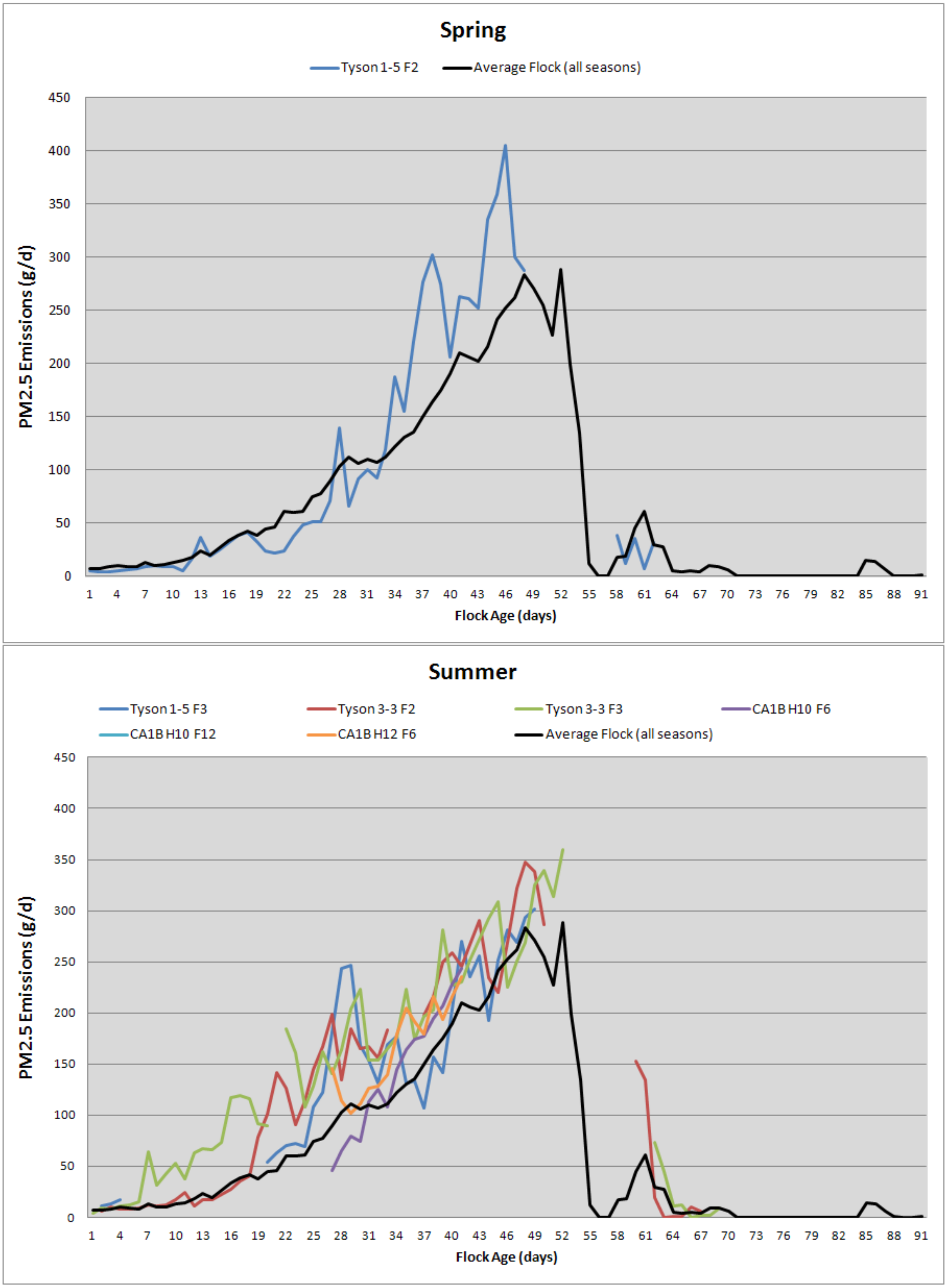


Figure 6-25. $PM_{2.5}$ Emissions from the Broiler Sites for Spring and Summer

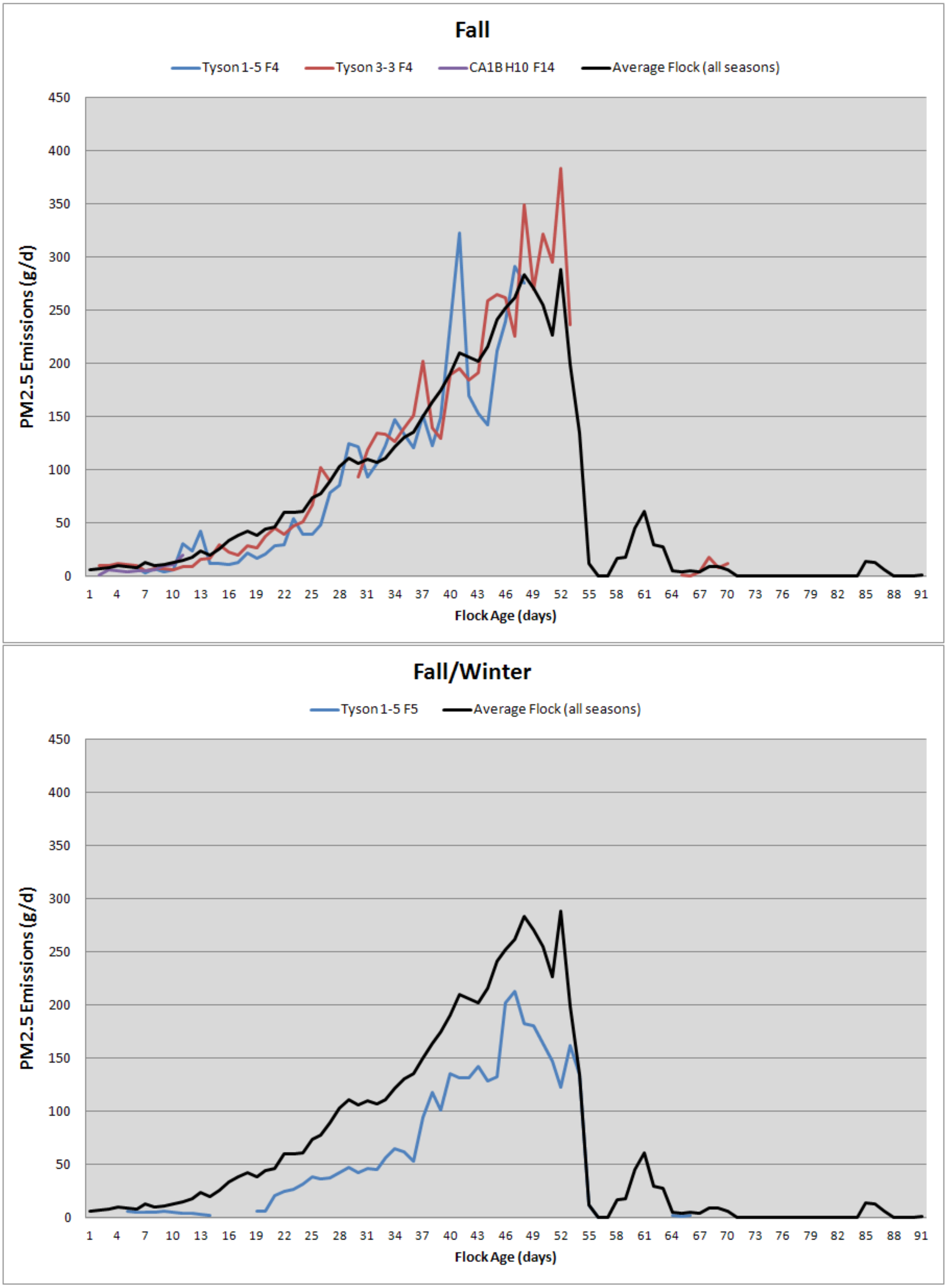


Figure 6-26. PM$_{2.5}$ Emissions from the Broiler Sites for Fall and Fall/Winter

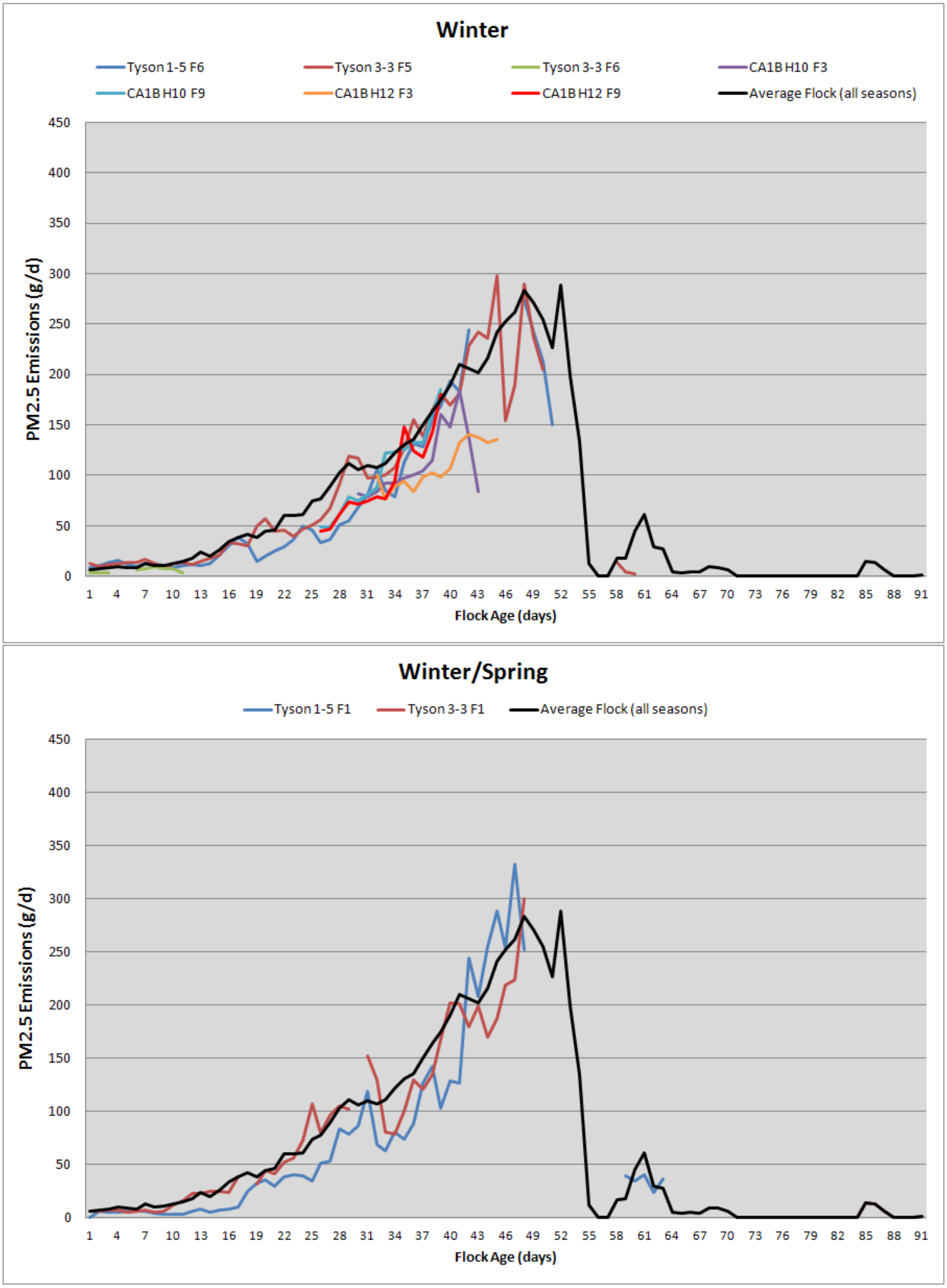


Figure 6-27. $PM_{2.5}$ Emissions from the Broiler Sites for Winter and Winter/Spring

6.6 TSP Emissions

6.6.1 General Trends

Figure 6-28 and Figure 6-29 present the annual emission plots for TSP for the CA1B and Kentucky sites, respectively. The plots of annual emissions from the CA1B site reflect the abbreviated sampling schedule for those houses. The CA1B study monitored one week out of every 8 weeks; in practice, this yielded 7 weeks of data collection. Table 6-5 shows the number of daily TSP emission values that are available for each day of the broiler grow-out, decaking and full litter clean-out periods, and illustrates the gaps in data from the CA1B houses. Section 5.1.3 presents the sampling schedule for TSP monitoring activities at CA1B. The Kentucky sites monitored TSP emissions continuously over their study period.

In general, the TSP emissions trend was similar to the other particulate sizes in that TSP emissions steadily increase over the grow-out period and decrease over the decaking and full litter clean-out periods. Data for TSP emissions were not collected from either house at the CA1B site during decaking or full litter clean-out periods. At the Kentucky sites, the PM monitor was removed during litter removal activities and reestablished in 7 to 10 days. As with PM_{10} and $PM_{2.5}$ emissions, the TSP emissions values for either type of litter removal period reflect emissions from the time when the house was sitting idle waiting for the next flock to be placed. The timing of the monitor removal makes it appear as though there is an abrupt decline in emissions when transitioning from the grow-out period to litter removal period, as opposed to a data gap.

Table 6-5. Available Daily TSP Emission Values by Site

Cycle Day	Number of Daily TSP Emissions Values			
	CA1B H10	CA1B H12	KY1B-1 H5	KY1B-2 H3
1	0	0	6	6
2	0	1	6	6
3	0	1	6	6
4	0	1	6	6
5	0	1	6	6
6	0	1	6	6
7	0	1	6	6
8	0	1	6	6
9	0	1	6	6
10	0	1	6	6
11	0	0	6	6
12	0	0	6	6
13	1	0	6	6
14	1	0	6	6
15	1	0	6	6
16	1	0	6	6
17	1	0	6	6
18	1	0	6	6
19	0	0	6	6
20	0	0	6	6
21	0	0	6	6
22	1	0	6	6
23	1	1	6	5
24	1	1	6	5
25	1	1	6	5
26	1	1	6	5
27	1	1	6	5
28	2	2	6	5
29	3	3	6	5
30	3	3	6	5
31	3	4	6	5
32	4	4	6	5
33	4	4	6	5
34	3	4	6	5
35	2	1	6	5
36	1	0	6	5
37	0	0	6	5
38	0	0	6	5
39	0	0	6	5
40	0	0	6	5
41	0	0	6	5
42	0	0	6	5
43	0	0	6	5
44	0	0	6	5
45	0	0	6	5
46	0	0	6	5
47	0	0	6	5
48	0	0	6	5
49	0	0	6	5
50	0	0	6	5
51	0	0	6	5
52	0	0	6	5
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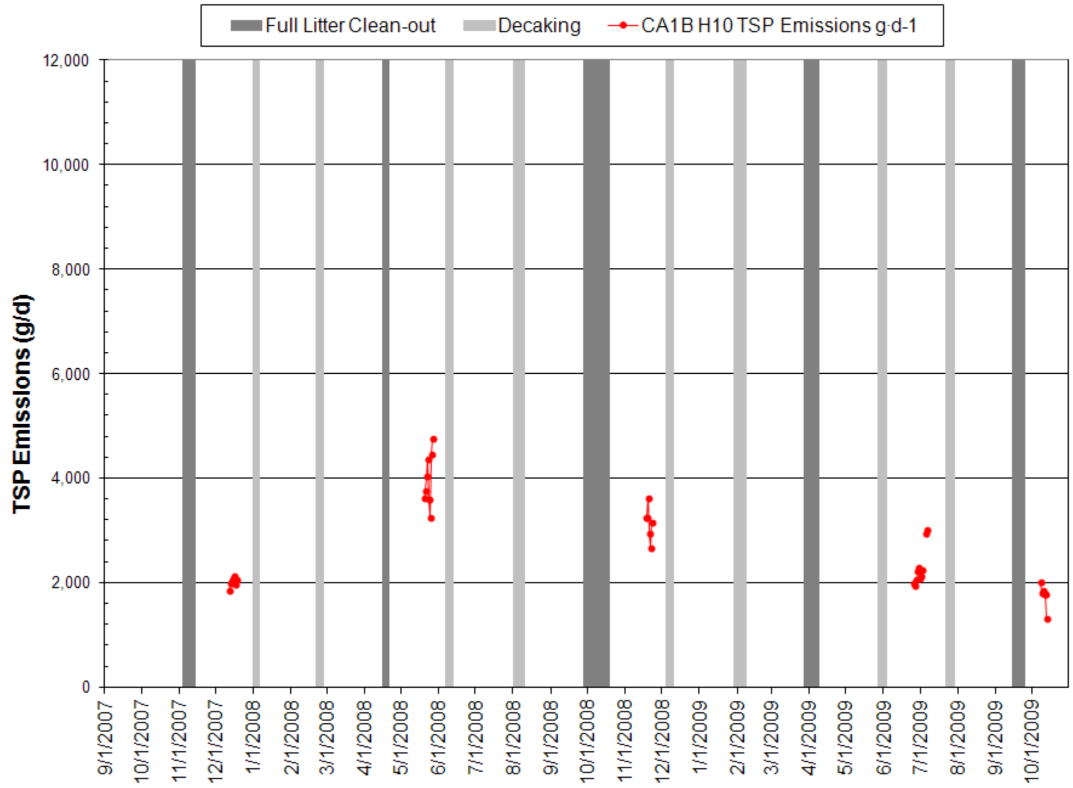
69	0	0	2	3
70	0	0	2	2
71	0	0	2	1
72	0	0	2	1
73	0	0	2	1
74	0	0	1	1
75	0	0	1	1
76	0	0	0	1
77	0	0	0	1
78	0	0	0	1
79	0	0	0	1
80	0	0	0	1
81	0	0	0	1
82	0	0	0	1
83	0	0	0	1
84	0	0	0	1
85	0	0	0	1
86	0	0	0	1
87	0	0	0	1
88	0	0	0	1
89	0	0	0	1
90	0	0	0	1
91	0	0	0	1
Total	**37**	**39**	**276**	**252**



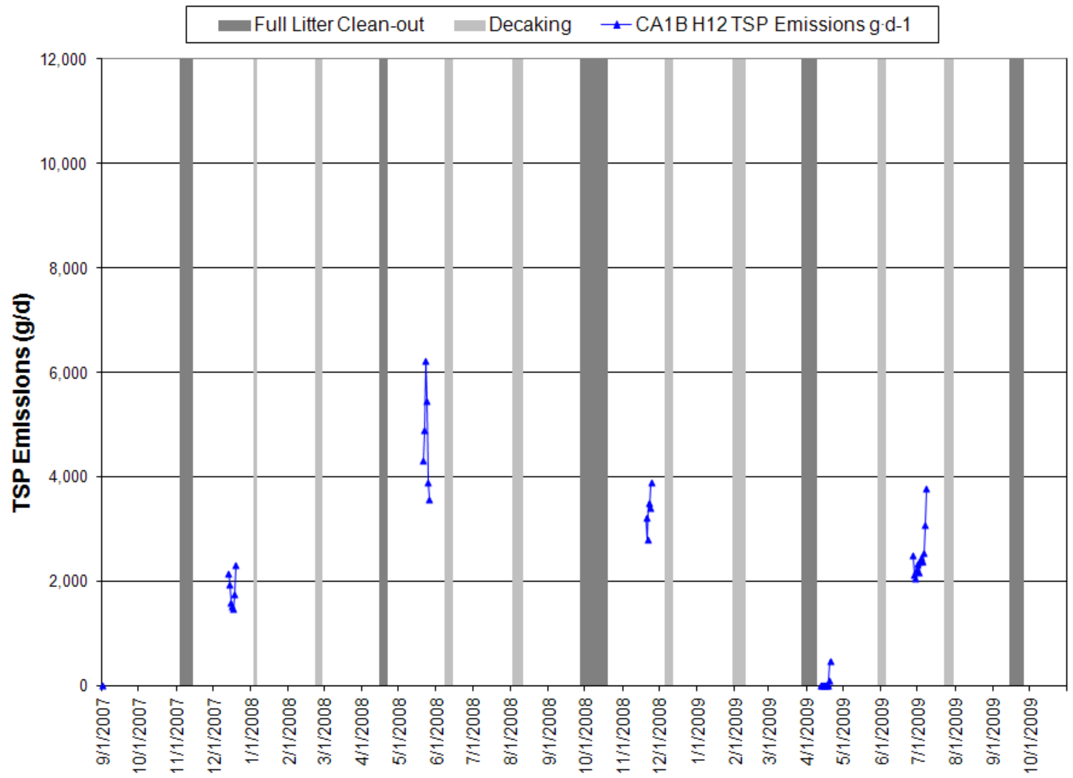


Figure 6-28. TSP Emissions from the CA1B Broiler Houses

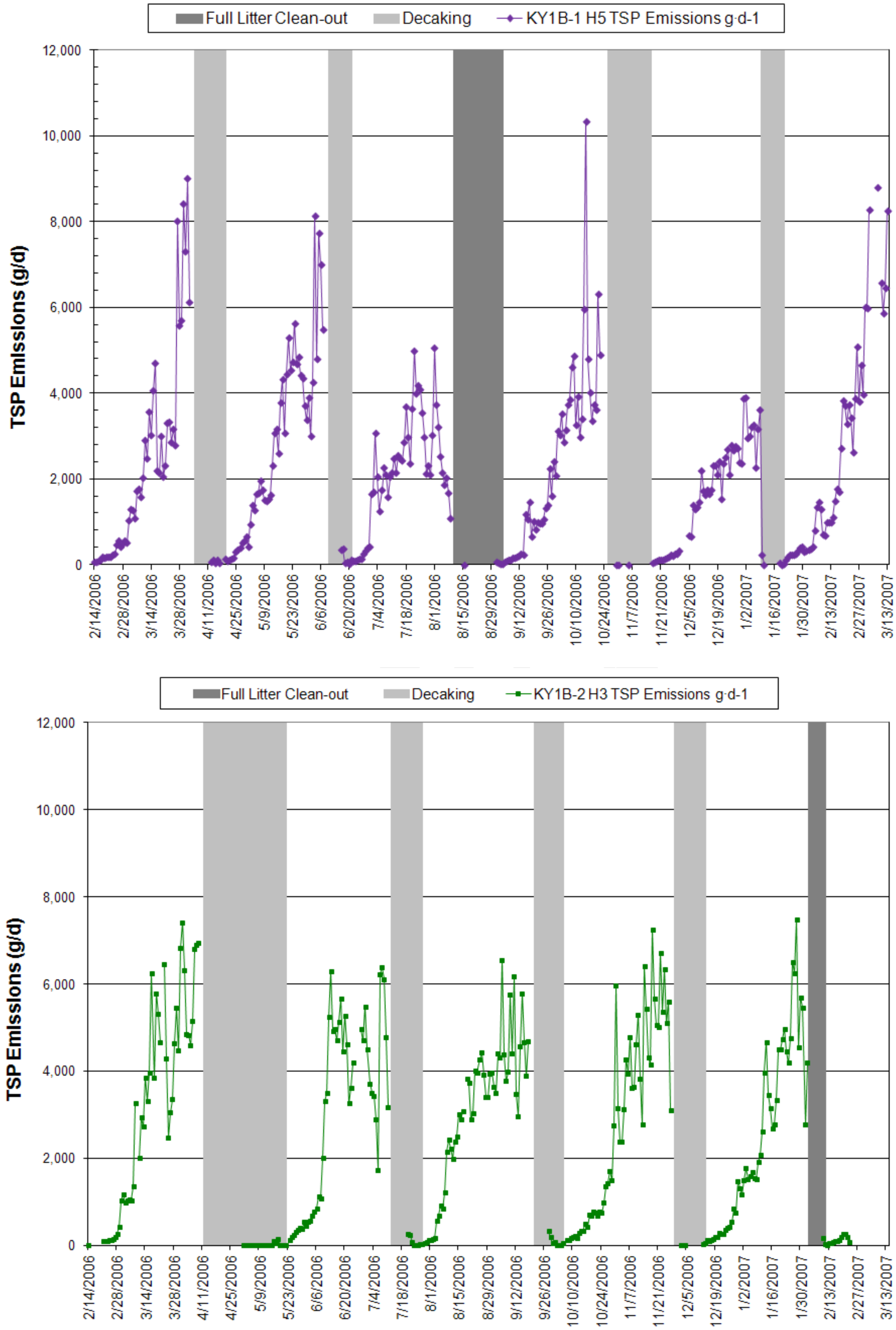


Figure 6-29. TSP Emissions from the Kentucky Broiler Houses

6.6.2 Seasonal Trends

Figure 6-30 presents daily TSP emissions for the grow-out, decaking and full litter clean-out periods for all flocks monitored under the NAEMS, color coded by season. The data spans both the grow-out and litter removal periods. The black line represents the average emissions for all flocks.

Comparisons between the TSP emissions for the different houses were limited due to the intermittent sampling periods for the CA1B houses. Available TSP emissions values from the CA1B houses are comparable to the emissions from the Kentucky houses, indicating that the emissions are representative of the housing type. The TSP emissions displayed a seasonal trend with emissions from summertime flocks typically above average and wintertime flocks below average. Figure 6-31, Figure 6-32 and Figure 6-33 present separate plots for each seasonal classification.

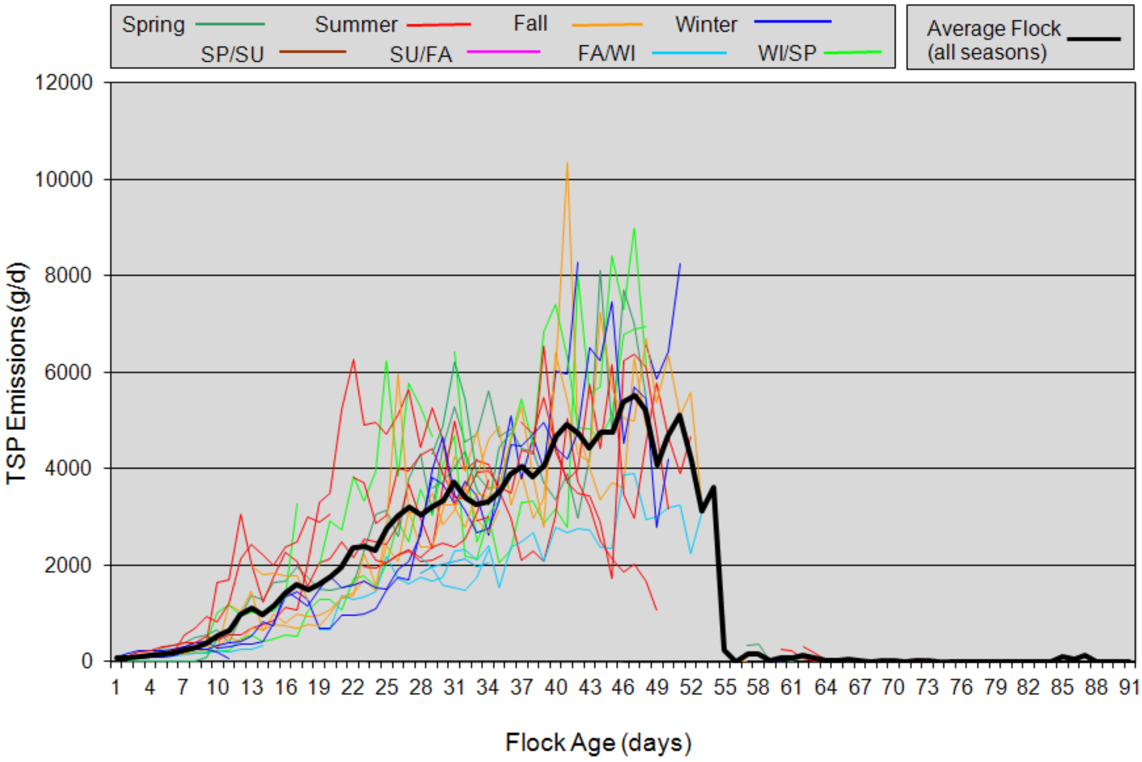


Figure 6-30. TSP Emissions by Flock, Color Coded by Season

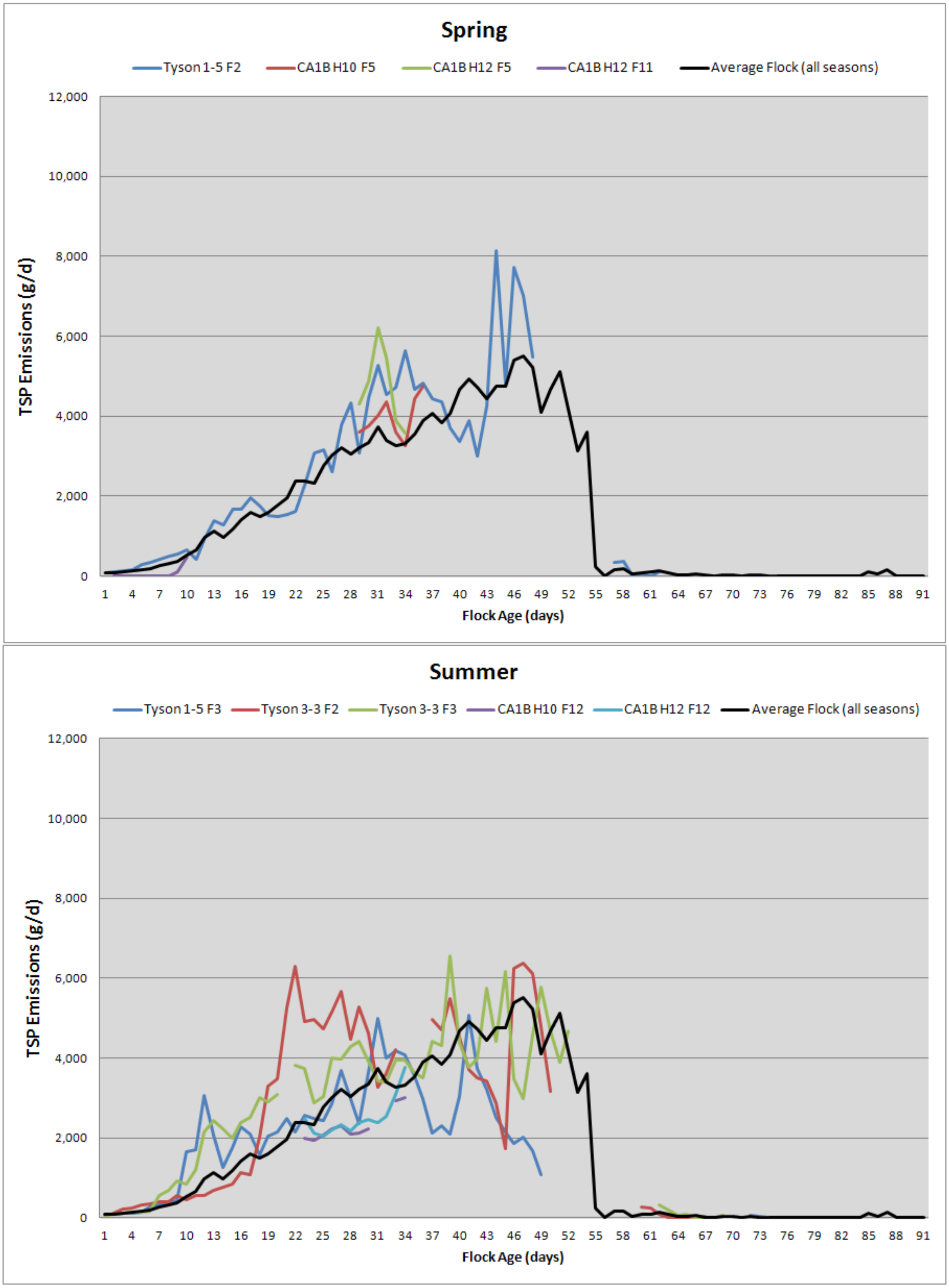


Figure 6-31. TSP Emissions from the Broiler Sites for Spring and Summer

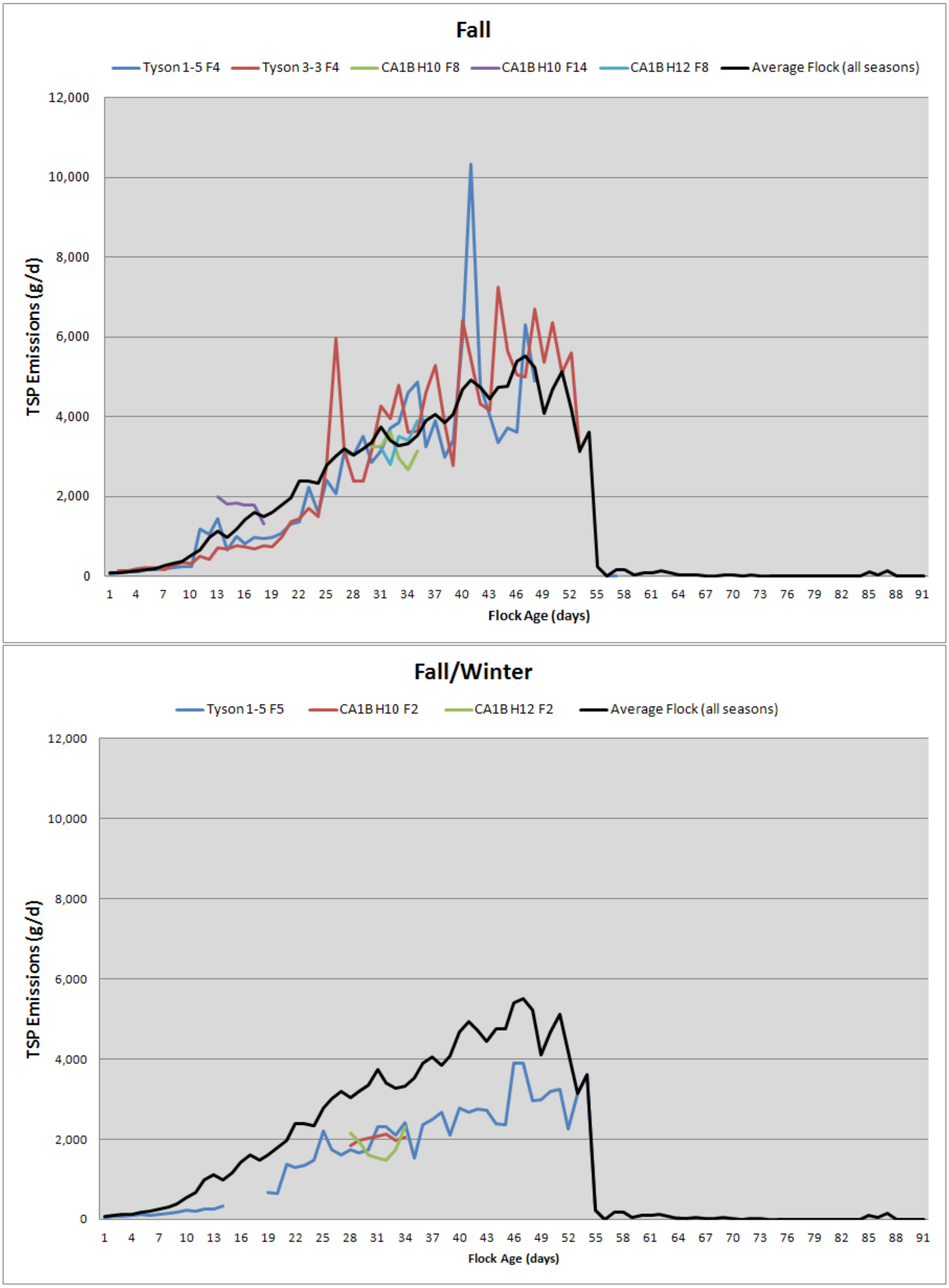


Figure 6-32. TSP Emissions from the Broiler Sites for Fall and Fall/Winter

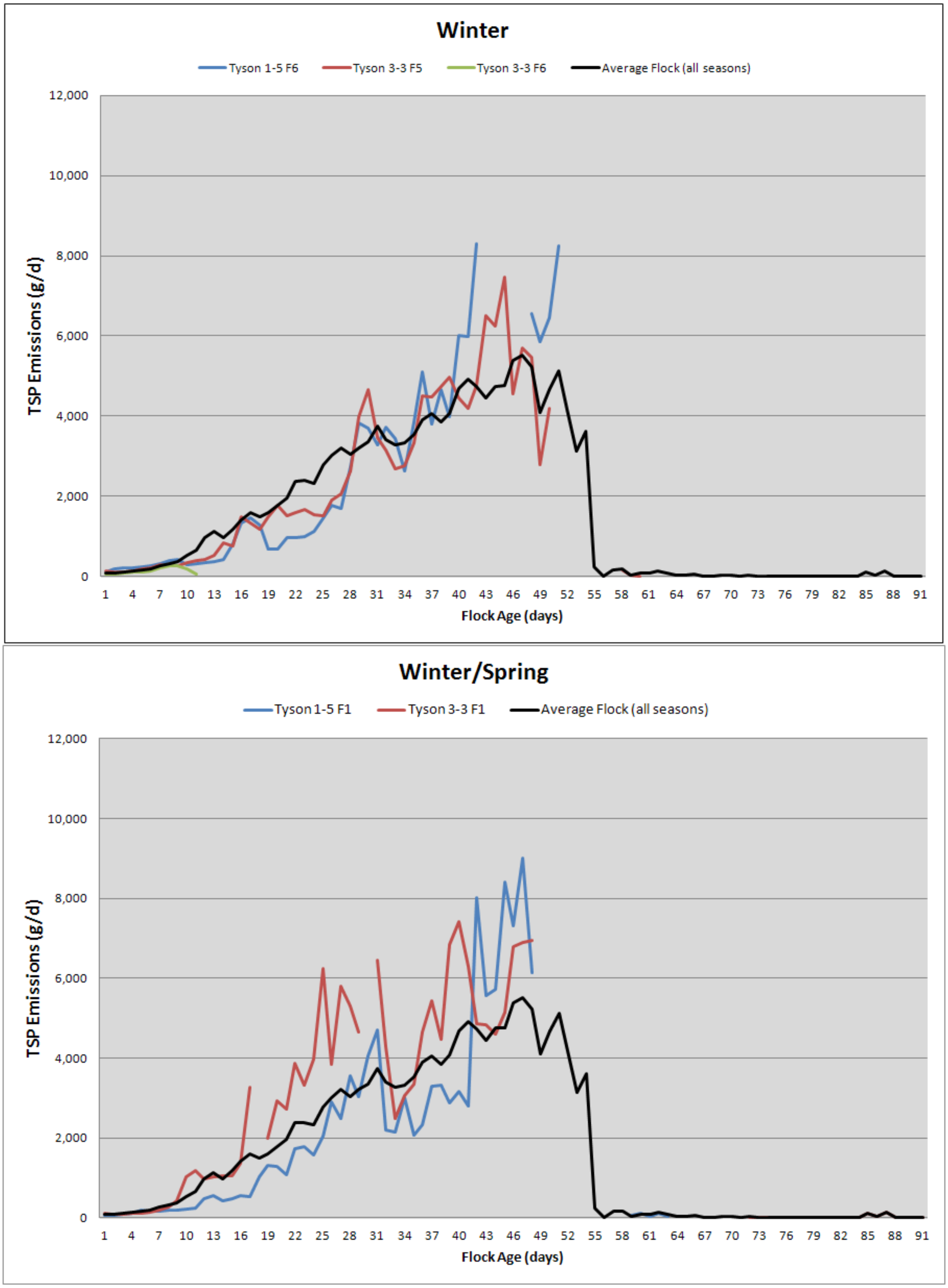


Figure 6-33. TSP Emissions from the Broiler Sites for Winter and Winter/Spring

6.7 VOC Emissions

6.7.1 General Trends

Figure 6-34 presents the annual emission plots for VOCs at the Kentucky broiler houses. The VOC data were collected continuously in the form of NMHC readings at the Kentucky sites. In general, emissions increase with bird age and weight, though the pattern is not as distinct as with the other gaseous species. Emissions of VOC are comparable between the two Kentucky houses.

At site CA1B, grab samples were collected periodically during the course of the study. Seven (7) grab samples were collected at House 10 and six (6) grab samples were collected at House 12. The samples were collected on nonconsecutive days from July 14, 2010 to October 7, 2010. Graphs of the grab sample data were not prepared because the limited number of data values and the short-term sampling period are not sufficient to indicate an emissions trends.

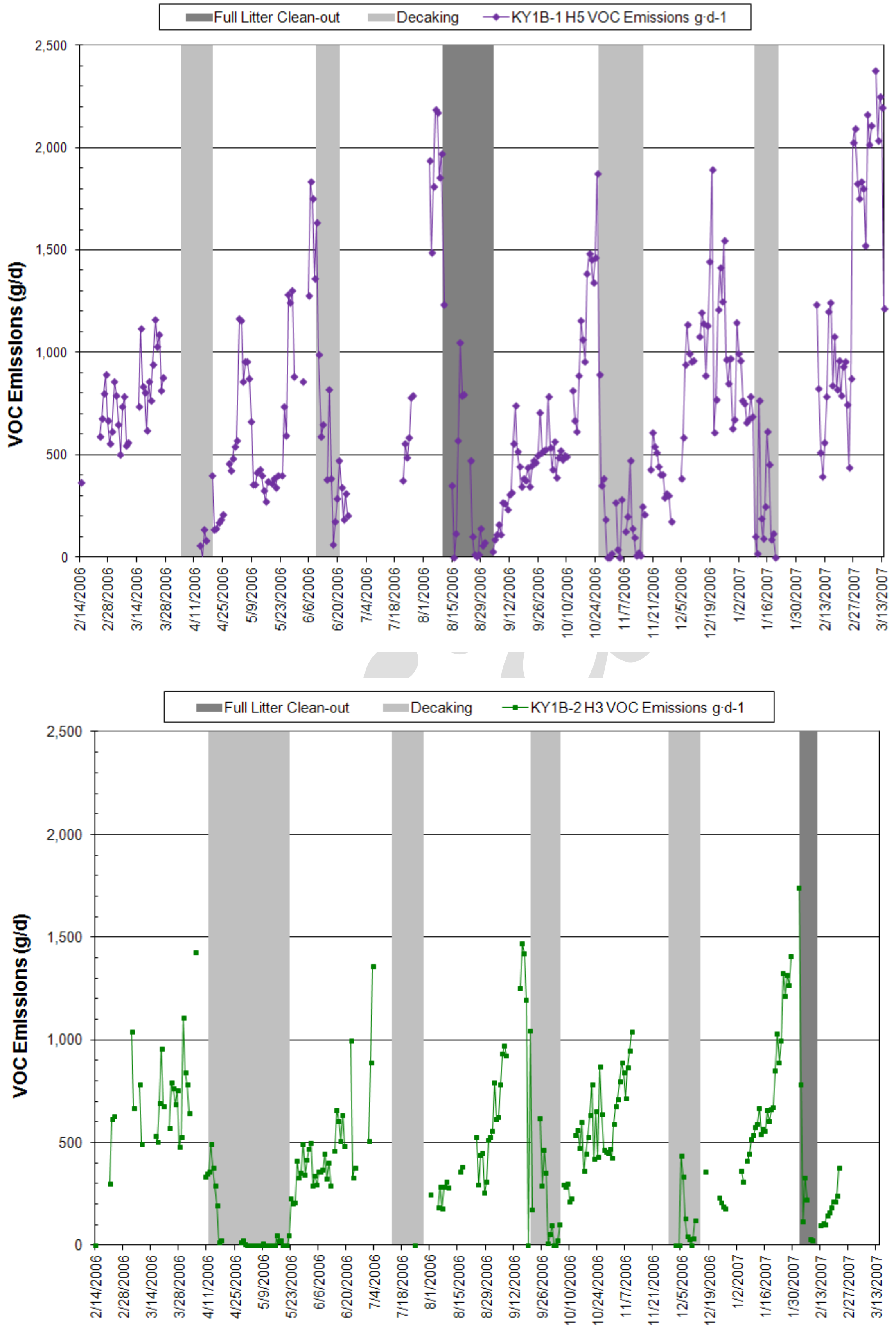


Figure 6-34. VOC Emissions from the Kentucky Broiler Houses

6.7.2 Seasonal Trends

Figure 6-35 presents flock VOC emissions for the Kentucky broiler houses, color coded by season. The data spans both the grow-out and litter removal periods. The black line represents average emissions for all flocks.

Based on the limited data (the two Kentucky houses were monitored for only one year each), VOC emissions do not appear to display any seasonality. Flock emissions for the various seasons tend to fluctuate across the average line (see Figure 6-36, Figure 6-37 and Figure 6-38). Emissions of VOC at site KY1B-1 H5 appear slightly higher than KY1B-2 H3 especially during the middle portion of the cycle, approximately days 35 to 50. Both house seem comparable, with KY1B-1 H5 running slightly higher than KY1B-2 H3, especially during the middle portion of the cycle (approximately day 35 to 50).

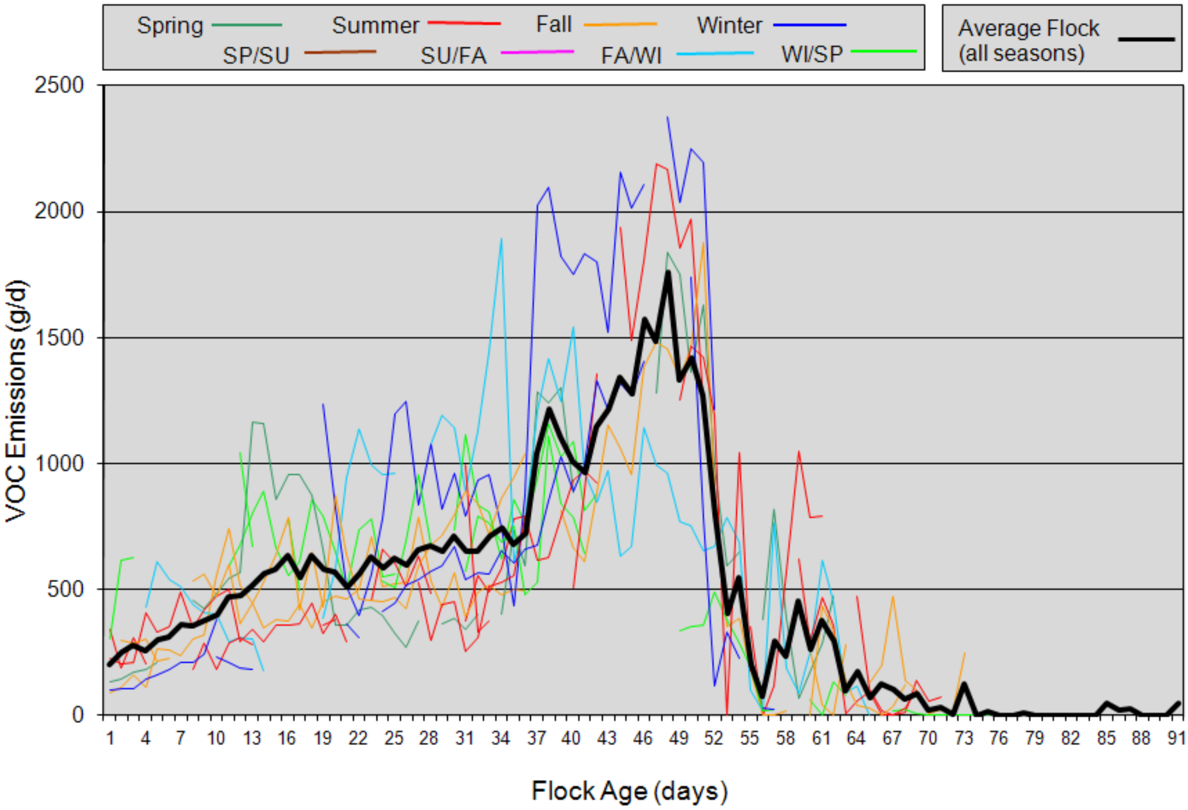


Figure 6-35. VOC Emissions by Flock, Color Coded by Season

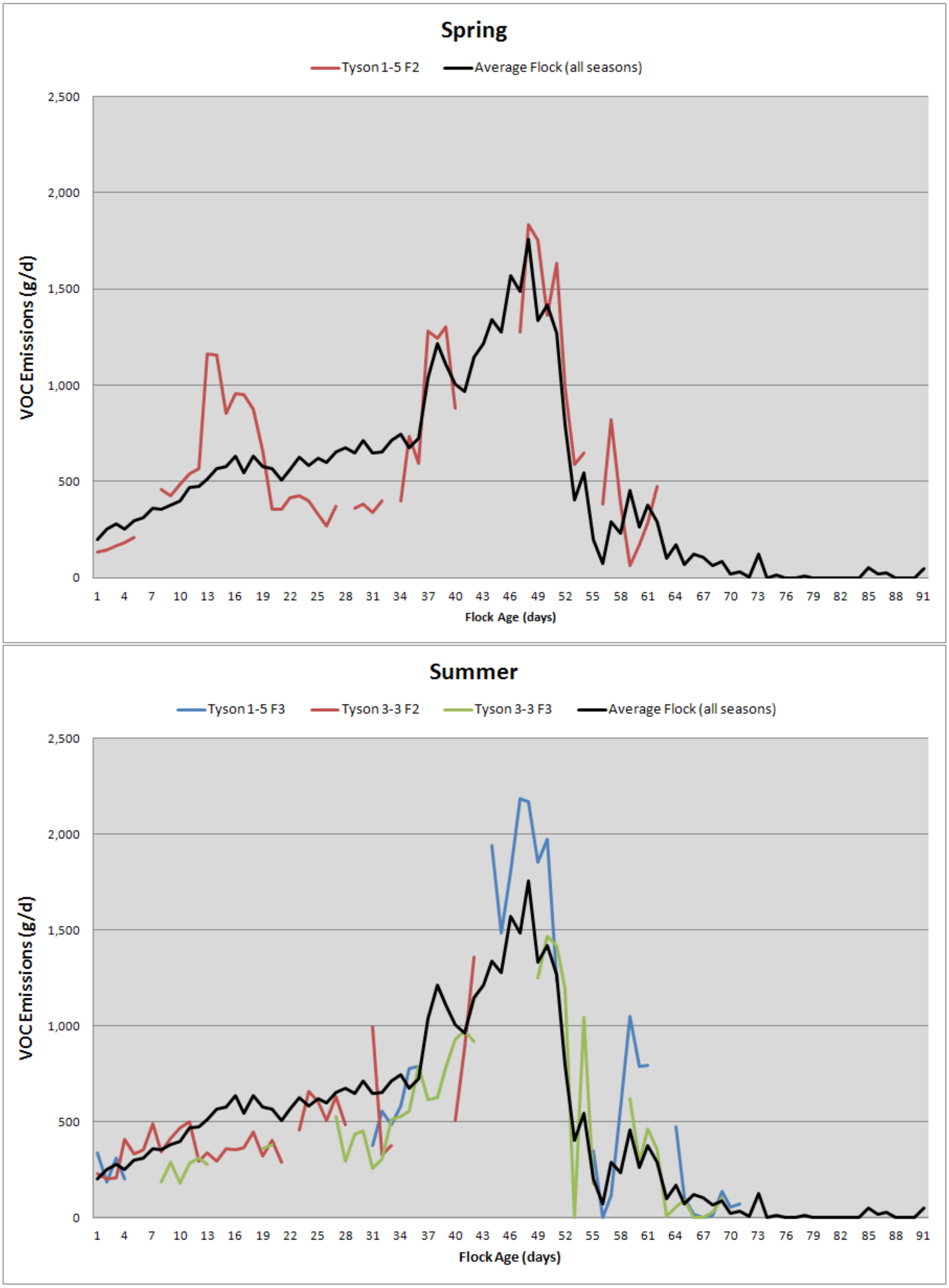


Figure 6-36. VOC Emissions from the Broiler Sites for Spring and Summer

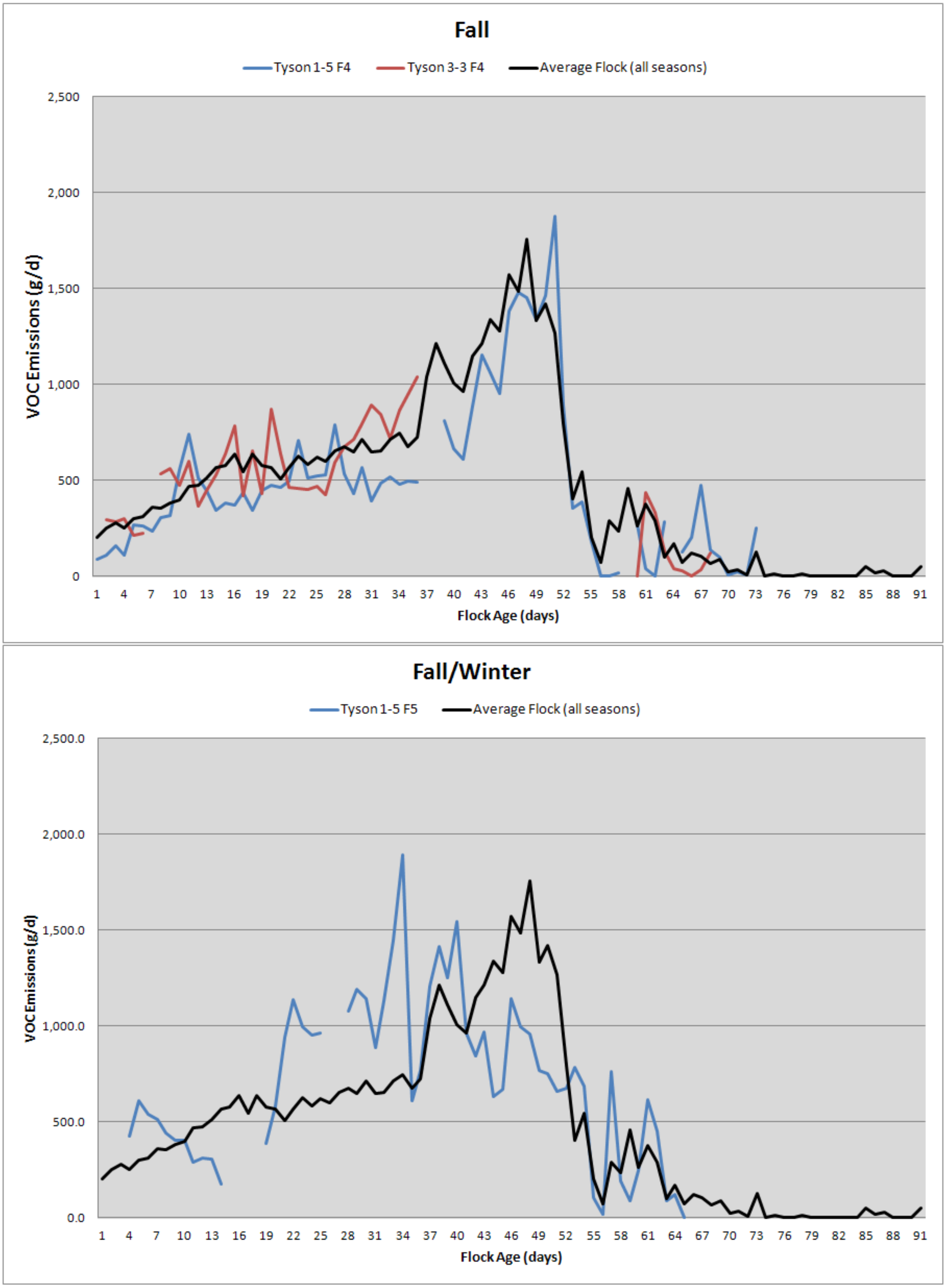


Figure 6-37. VOC Emissions from the Broiler Sites for Fall and Fall/Winter

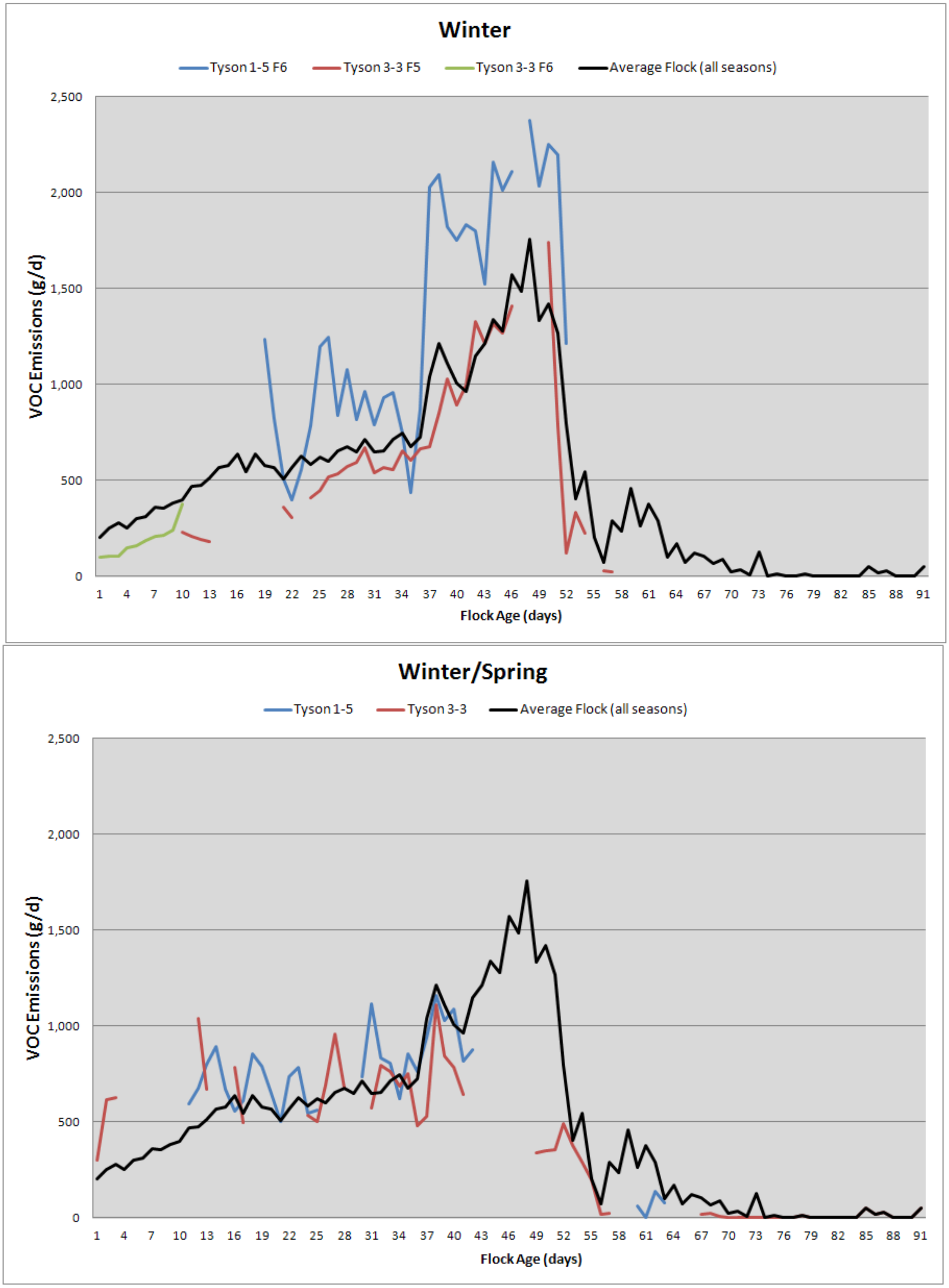


Figure 6-38. VOC Emissions from the Broiler Sites for Winter and Winter/Spring

7.0 DEVELOPMENT OF EEMS FOR GROW-OUT PERIODS

This section presents the statistical approach the EPA used to develop the EEMs for the grow-out periods associated with broiler operations using the NAEMS data. This section uses NH_3 as the example pollutant to demonstrate the statistical method. The remaining pollutants (H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs) followed this statistical approach and the resulting EEMs are presented in Section 8.

For each pollutant, the EPA developed an EEM for each of three sets of predictor variables: variables based on animal inventory alone (I), inventory variables supplemented with ambient meteorology (IA), and the combination of these variables with variables describing confinement conditions (IAC). For example, the I EEMs provide emissions estimates based on input data that characterize the bird population in the house (e.g., total bird inventory in the house and their average weight). These data are recorded routinely by growers and would not require additional data collection systems. For the IA EEMs, the input data include the bird inventory, average bird weight and ambient meteorological conditions (e.g., ambient temperature and relative humidity). Under the NAEMS, the ambient data were collected by a monitoring system installed at the participating farm. To apply the EEMs, ambient data gathered by other sources (e.g., National Weather Service stations) that are representative of the applicable site can be used if site-specific data are not available. For the IAC EEMs, the input data include the data used for the I and IA EEMs and data for confinement conditions (e.g., house temperature and relative humidity) that were collected for the NAEMS by a monitoring system installed in each house.

In previous sections, the terms “parameter” and “estimate” were used to describe the data and data collection methods used in the NAEMS. In this section, these terms are used in their formal statistical context. The term “parameter” refers to unknown constants (regression coefficients, the variance, and the auto-correlation coefficient, described below) whose values give the EEMs their shape. The EEM equations given in this section use Greek letters to represent parameters. The term “estimate” refers to the best approximation of a parameter value determined by fitting the EEM to the NAEMS data. The term “predict” refers to obtaining a value of emissions using the EEM, including the use of predictor variables and estimated parameters.

Each EEM produces a point prediction and a 95 percent prediction interval for pollutant emissions. A point prediction is a single value of emissions produced by the mean trend function (described below) for a given set of values of the predictor variables. A 95 percent prediction interval consists of two numbers, a lower and upper bound, on each side of the point prediction that quantify uncertainty about the point prediction due to natural variability in emissions and due to having estimated parameter values using data based on four broiler houses, which were selected under the NAEMS to represent all broiler houses in the United States.

Development of the EEMs followed the protocol outlined in Figure 7-1, in which the six phases parallel the structure of Sections 7.1 through 7.6. Phase 1 is the selection of the datasets to be used in EEM development. Part of this selection is based on the predictor variables that were monitored in the NAEMS as well as other important factors that affect emissions such as litter condition. The second part of dataset selection was based on additional analyses of data completeness.

Phases 2 through 6 involve the development and validation of the mathematical form of the EEM. Each EEM has three components: the probability distribution, the mean trend function, and the covariance function. Equation 7-1 provides the general form of each EEM, an explanation of which is given in the following paragraphs. Table 7-1 summarizes the symbols and terms used in the equation.

$$Y_{ht} = \beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht} + e_{ht}\,,\ h = 1, \ldots, 4,\ t \text{ varies}$$

$$\boldsymbol{e_{ht} \sim N\{0, \sigma^2\}, Cov\left(e_{ht}, e_{h't'}\right) = \begin{cases} 0 & h \neq h' \\ \sigma^2 \rho^{|t-t'|} & h = h' \end{cases}} \ ;\ \sigma > \mathbf{0}, \mathbf{0} < \boldsymbol{\rho} < 1 \qquad \text{Equation 7-1}$$

Table 7-1. Summary of Symbols and Terms Used in Equation 7-1

Description	Symbol
Index for houses	h
Index for dates	t
Mass of pollutant emitted from house h on date t	Y_{ht}
Index for regression coefficients, mean trend variables, and mean trend terms	p
Number of mean trend variables, number of regression coefficients, number of mean terms minus one (the intercept is also a mean term)	P
Value of mean trend variable p for house h on date t	x_{pht}
Regression coefficients	$\beta_p,\ p = 1, \ldots, P'$
Intercept	β_0
Mean trend terms	β_0 and $\beta_p x_{pht}$, $p = 1, \ldots, P$
Mean trend function	$\beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht}$
Deviation of emissions from house h on date t from the value given by the mean trend function	e_{ht}
Notation indicating that the random variables e_{ht} are normally distributed with mean 0 and variance σ^2	$e_{ht} \sim N(0,\sigma^2)$

Table 7-1. Summary of Symbols and Terms Used in Equation 7-1

Description	Symbol
Notation indicating the serial correlation between emissions observed day-to-day	$Cov(e_{ht}, e_{h't'})$
Variance of the random deviations e_{ht} (a measure of both natural variability and uncertainty)	σ^2
The correlation between two deviations from the same house, separated by one day	ρ

In the first line of Equation 7-1, Y_{ht} represents pollutant emissions from house h on date t, where the index h takes values 1 through 4, corresponding to monitored houses CA1B H10, CA1B H12, KY1B-1 H5 and KY1B-2 H3, respectively. Values of t are nested within values of h, so that dates for different houses can be the same or different. The values that t takes for each house over the grow-out periods are given in Section 5.3.1. Due to missing data, the dates were not always consecutive.

The expression $\beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht}$ is the "mean trend function," and it describes the relationship between the predictor variables and the expected value of pollutant emissions. In the mean trend function, x_{pht} represents the value of the p^{th} mean trend variable for house h on date t, the symbol β_p denotes the regression coefficient for that variable and the symbol β_0 represents the intercept. The mean trend variables differ from the predictor variables in that they represent the functional form through which the predictor variables enter the mean trend function. This distinction will be discussed in detail in Section 7.3. Lower-case p is an index for regression coefficients β_p, mean trend variables x_{pht}, and their products, the non-intercept mean trend terms $\beta_p x_{pht}$. The index p takes values $1,\cdots, P$, so that upper-case P is the number of non-intercept mean trend terms.

In the second line of Equation 7-1, the symbol e_{ht} represents the deviation of emissions from house h on date t from the value given by the mean trend function. Because the e_{ht} are random variables, full EEM specification requires selecting a probability distribution and an appropriate covariance function for them. The notation $e_{ht} \sim N(0,\sigma^2)$ translated, says that the random variables e_{ht} are normally distributed with mean 0 and variance σ^2. The expression for the covariance, $Cov(e_{ht}, e_{h't'})$, describes the serial correlation between emissions observed day-to-day. Because the e_{ht} are random variables, and because the Y_{ht} are functions of them, the Y_{ht} are also random variables. Although the values of the mean trend variables x_{pht} differ for different values of h and t, for one specific combination of values of h and t, they are fixed (not random), known quantities. All of the parameters in the EEM (the intercept, β_0; the regression coefficients, β_p; the variance, σ^2; and the auto-correlation coefficient, ρ) were estimated based on the NAEMS data. The estimates of the parameters are written with "hats" on top of them (e.g., $\widehat{\beta_0}$).

The choice of probability distribution, the variables included in the mean trend function, and the form of the covariance function were all based on analyses of a subset of the NAEMS data called the “base” dataset, validated using another subset of the NAEMS data called the “cross-validation” dataset, and then modified and re-validated when necessary. After the final mathematical forms were chosen, the EPA re-estimated the parameters using the “full” dataset (i.e., the combined base and cross-validation datasets).

The following sections describe this process in detail. Section 7.1 describes selection of the full, base, and cross-validation datasets based on data completeness. Section 7.2 shows why the normal distribution was selected as the probability distribution. Section 7.3 details development of candidate mean trend variables from the predictor variables. Section 7.4 lists components considered for the covariance function and tells why some were included and others not. Section 7.5 describes the process through which final mean trend variables were chosen from the candidates. Section 7.6 describes how the EEMs are used to generate point and interval predictions for a single day and for the sum of days. The EEM development and results for H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs are explained in Section 8.

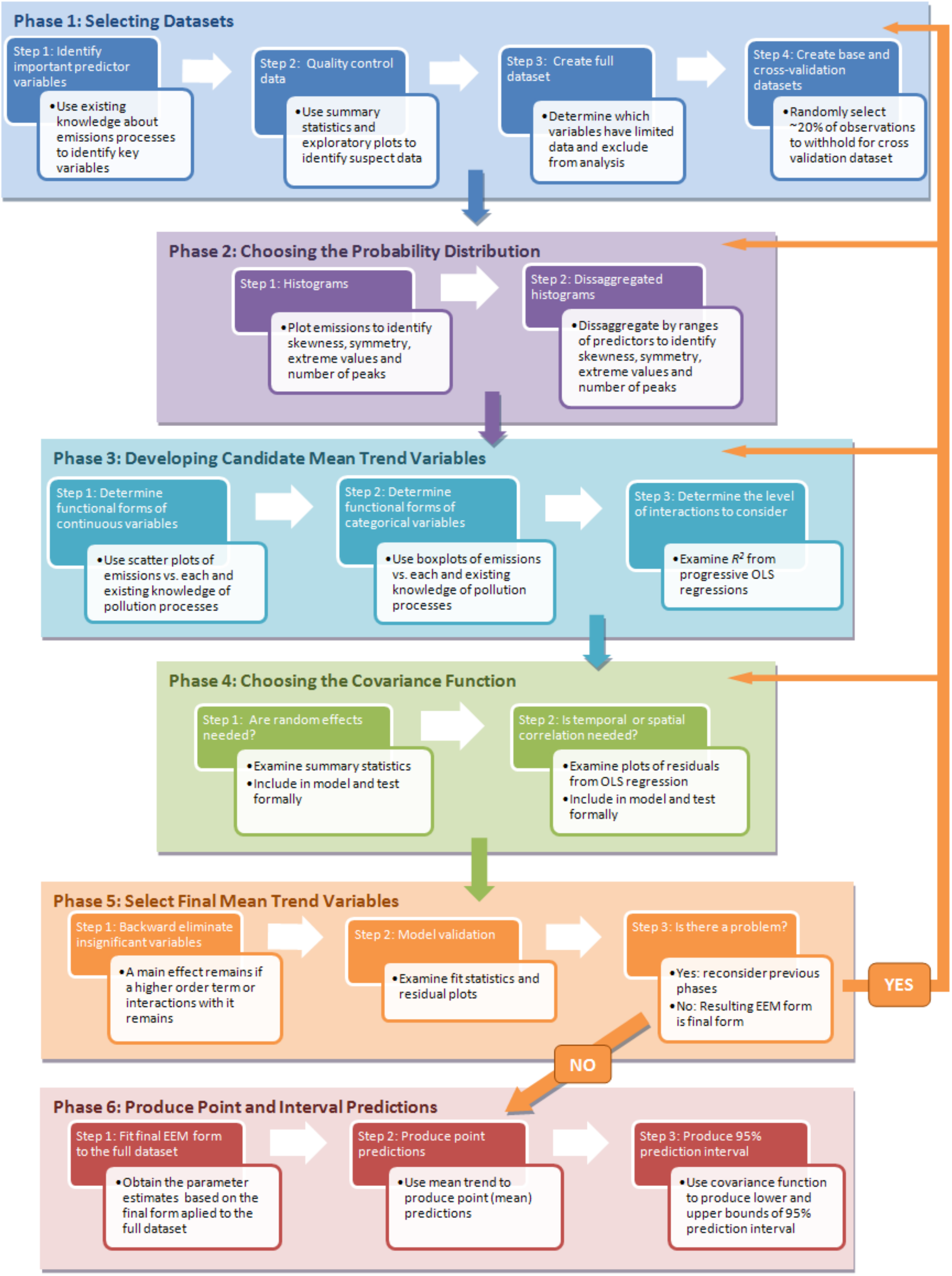


Figure 7-1. General Approach for EEM Development

7.1 Selecting Datasets

The data used to develop the EEMs for NH_3 were collected under the NAEMS from four houses at three sites: CA1B H10; CA1B H12; KY1B-1 H5; and KY1B-2 H3. Table 7-2 lists, for each of the three categories [animal inventory (I), ambient meteorology (A) and confinement conditions (C)], available predictor variables, the definitions and units of measure for each. Although ventilation flow rate and differential static pressure were monitored at each of the houses, they were not considered for use as confinement predictor variables for a variety of reasons. Because pollutant emissions are calculated using flow rate, and flow rate is calculated using differential pressure, the validity of using these as predictor variables is questionable. Additionally, the EPA did not consider ventilation flow rate and differential static pressure as predictor variables because these values are not expected to be readily available. For the NAEMS, differential static pressure ports were installed in the monitored houses and the ventilation flow rate values were calculated using continuous measurements of fan operational status (on/off), differential static pressure and fan-specific performance curves. In some cases, the flow rates of selected fans were directly measured using anemometers. The EPA does not expect that these types of monitoring systems and data will be available at typical broiler operations.

As explained in Section 5, the EPA did not use negative emissions to develop EEMs. Additionally, the EPA identified cases late in the grow-out period where bird inventory values remained constant for several consecutive dates. Figure 7-2 shows the number of birds for each date for the first flock monitored at KY1B-1 H5. The red box on the figure highlights the constant inventory values that were removed from the full dataset. This phenomenon occurred for every flock at sites KY1B-1 and KY1B-2, for 5 out of 14 flocks at CA1B H10, and for two flocks at CA1B H12. The EPA contacted the researchers for the California and Kentucky sites and industry representatives to determine whether the constant bird inventory values were valid. These contacts confirmed that the flat inventory values likely did not reflect the number of birds in the house on those dates. According to these contacts, to avoid stressing the birds in the last days of the grow-out period before harvesting, farm personnel did not enter the houses to count mortalities. In these instances, the personnel entered the same number of birds for several consecutive dates.

Table 7-2. Predictor Variables

Category	Predictor Variable[a]	Definition	Units
I: Inventory	*birds**	Number of birds	Thousands of birds
	*avem**	Average live bird mass	Kilograms (kg)
	*buildup**	Number of flocks since last full litter clean-out in house	Number of flocks
A: Ambient meteorology	*ta**	Temperature outside house	°C
	*ha**	Relative humidity outside house	%
	*pa**	Barometric pressure outside house	kilopascals (kPa)
C: Confinement conditions	*tc**	Temperature inside house	°C
	*hc**	Relative humidity inside house	%

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

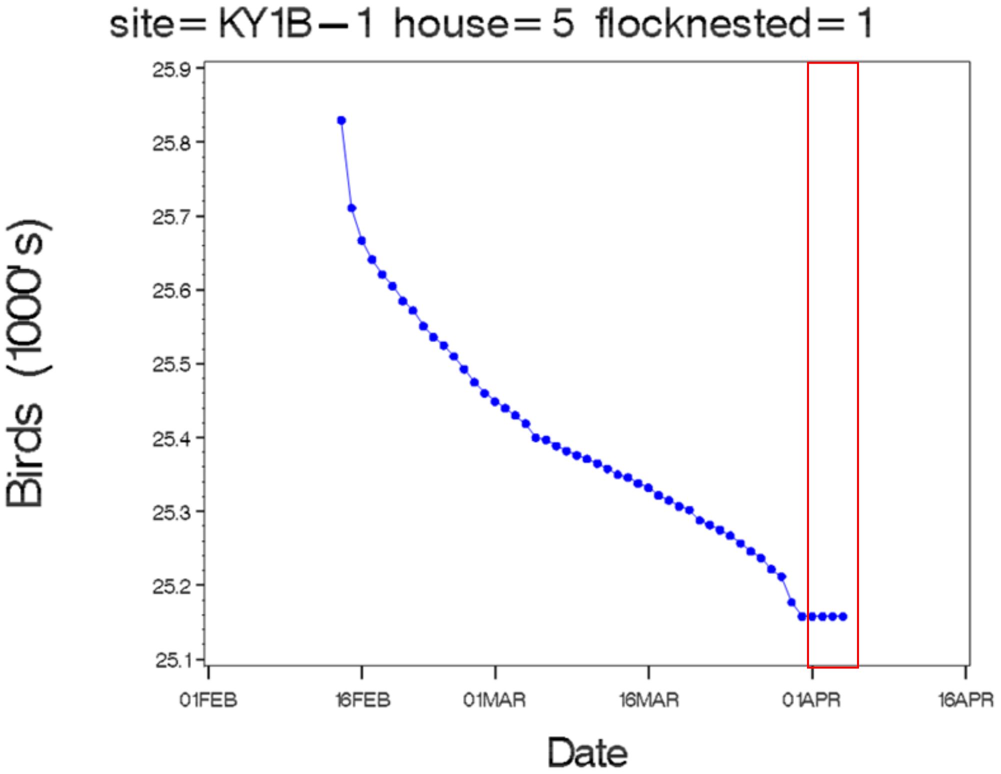


Figure 7-2. Example of Constant Late-Period Bird Inventory

Because it was unclear whether these constant inventory values represented the number of birds in the house on that date, the EPA excluded from the full dataset observations that satisfied the following criteria. If the number of birds in the house on date *t+1* was equal to the number of birds on date *t*, and these dates occurred at the end of the grow-out period, the observation for date *t+1* was excluded. Using this approach, the EPA excluded 44 observations for the grow-out period data for all sites, houses and flocks.

Table 7-3 shows the observations available for each monitoring site after exclusion of negative NH_3 emissions and constant late-period inventory values. For example, the total number of grow-out period observations for site CA1B H10 is 642, the number of days for which the NH_3 emissions value was available is 382, and the percent available is 60 percent. Although sites KY1B-1 and KY1B-2 conducted monitoring for approximately one year while site CA1B monitored for two years, the greater level of data completeness for KY1B-1 and KY1B-2 caused the number of available observations to be on the order of only 100 days fewer for the houses at each of the Kentucky sites than for the two houses at CA1B.

Table 7-3. Data Completeness for NH_3

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All	No. of grow-out dates	642	647	288	267	1,844
	No. of NH_3 days available	382	385	280	232	1,279
	Percent complete	60%	60%	97%	87%	69%
Winter	No. of grow-out dates	150	153	87	74	464
	No. of NH_3 dates available	100	105	80	50	335
	Percent complete	66%	69%	92%	68%	72%
Spring	No. of grow-out dates	157	158	83	55	453
	No. of NH_3 dates available	133	134	82	49	398
	Percent complete	85%	85%	99%	89%	88%
Summer	No. of grow-out days	156	157	55	74	442
	No. of NH_3 dates available	109	108	55	70	342
	Percent complete	70%	69%	100%	95%	77%
Fall	No. of grow-out dates	179	179	63	64	485
	No. of NH_3 days available	40	38	63	63	204
	Percent complete	22%	21%	100%	98%	42%

7.1.1 Full dataset

To ensure that the data selected for EEM development were representative of more than one of the monitored sites, the EPA limited the dataset for use in EEM development to those records for which data values were available for all of the inventory, ambient, and confinement predictor variables. To identify this refined dataset, the EPA first evaluated the data records available for the I EEM.

The variables EPA considered for the I EEM were *birds** and *avem**. All of the 1,279 days with NH_3 observations include values for *birds**; however, 32 values for *avem** were missing. Examination of the sites, houses and dates for which *avem** values are missing shows that their absence appeared to be random (i.e., not all missing observations occur when NH_3 emissions are high or low). To confirm that the missing data would not bias the development of EEMs, the EPA compared the distribution of emission on the days with the missing values to the distribution of emissions in the full dataset across the quartiles (i.e., minimum, Q1, Q2, Q3, Q4, and maximum). This five-number summary for NH_3 emissions for the 32 dates missing *avem** is 0.08, 3.2, 9.3, 20 and 36, while the five-number summary over all 1,279 dates is 0.06, 3.3, 9.4, 19 and 36. Because the numbers for each component of the five-number summary are similar in magnitude, the EPA concluded that the distribution of the missing values was random. Excluding the 32 records for which *avem** values are not available results in a total of 1,247 observations for use in developing the I EEM for NH_3.

The ambient variables considered by EPA for the IA EEM were *ta**, *ha** and *pa**. Of the 1,247 observations in the NH_3 dataset, the number of missing values for each of the ambient variables is, respectively, 23, 23 and 9. Not all of the missing data occurred on the same days, thus there was a total of 36 missing observations. Excluding these values leaves 1,211 observations for the NH_3 dataset. Although wind speed, wind direction, and solar radiation were recorded at site CA1B, these data were not recorded at sites KY1B-1 and KY1B-2. Consequently, the EPA excluded these data from consideration. Confinement variables considered were *tc** and *hc**. Of the 1,247 observations for which none of the NH_3 emissions or the inventory variables are missing, the number of missing values for *tc** and *hc** are 0 and 5, respectively. The five observations missing for *hc** correspond to missing observations of other variables. Therefore, the EPA chose the data subset containing the 1,211observations for which none of the variables *ta**, *ha**, *pa**, *tc** or *hc** are missing. Hereafter, the EPA refers to this dataset as the “full” dataset.

7.1.2 Base and Cross-Validation Datasets

As one means of evaluating EEM performance, the EPA randomly selected 217 (approximately 20 percent) of the 1,211 observations in the full dataset to withhold as the “cross-validation" dataset. The remaining 994 observations are referred to as the "base" dataset. The EPA made decisions regarding the probability distribution, candidate mean trend variables and the covariance function using the base dataset for exploratory analyses, initial parameter estimation and tests of the significance of covariance parameters.

To select the final mean trend variables, the EPA primarily used p-values calculated on the base dataset to determine whether to keep or eliminate terms in a backward-elimination process. At each step in the backward-elimination process, however, the EPA also compared emissions predicted by the EEM to measured emissions contained in the cross-validation dataset. This practice, described in more detail in Section 7.5.1, ensured that the statistical significance of the estimated regression coefficients captured trends that applied generally, rather than over-fitting the data.

Analysis of cross-validation fit statistics and plots of cross-validation residuals also helped to validate the overall mathematical form of the EEM. The EPA performed multiple iterations of making EEM decisions in Phases 1 through 5, validating the resulting EEMs, modifying decisions, and re-validating. One of the decisions the EPA modified was the means of choosing the cross-validation dataset.

Initially, the EPA constructed the cross-validation dataset by withholding data for entire flocks. Of the 40 flocks in the NAEMS data, the EPA withheld data for six flocks that were chosen so that both the base and cross-validation datasets contained flocks from each season-site combination. A validation analysis later showed that the initial selection of cross-validation dataset resulted in disproportionate representation of different values of *buildup* in the two datasets. *Buildup* was not initially included as a predictor variable, and this same validation analysis led to an investigation of the data that revealed its importance.

The EPA attempted to modify selection of the cross-validation flocks to evenly represent site-season-*buildup* combinations in both the base and cross-validation datasets. However, due to the patterns of missing data, it was not possible to choose entire flocks in this manner without over-representing the Kentucky sites in the cross-validation dataset. On a flock-by-flock basis, the Kentucky flocks had fewer missing values than the flocks at site CA1B.

The EPA therefore chose to randomly select observations to withhold as the cross-validation dataset. To ensure that disproportionate representation of one or more sets of conditions in the cross-validation and base datasets chosen in this manner would not affect results, the EPA created two additional cross-validation datasets with corresponding base datasets and checked the results for the two additional cross-validation datasets for gross aberrations.

7.2 Choosing the Probability Distribution

Identifying the appropriate probability distribution ensures the validity of the p-values that are used to determine the statistical significance of regression coefficient estimates. The appropriate probability distribution is also needed to produce prediction intervals that quantify the uncertainty regarding the point predictions of NH_3 emissions. Many physical phenomena are normally distributed under a fixed set of conditions, and the point predictions and 95 percent prediction intervals generated from the normal distribution are easy for the EEM user to implement and interpret. Therefore, the normal distribution is commonly used unless there is substantial evidence that another distribution is more appropriate.

The EPA plotted the empirical distribution (i.e., histogram) of observed NH_3 emissions to determine whether use of the normal distribution could be justified. Figure 7-3 shows that there are many NH_3 observations at lower values, with a single peak around 2.5 kg, and the number of observations decreases as emissions increase. In statistical jargon, the empirical distribution is unimodal and skew right. This observation might at first seem to provide evidence against using the symmetric and bell-shaped normal distribution, but the second line of Equation 7-1 does not say that NH_3 emissions under all conditions have the same distribution. Instead, the equation says that the distribution of the deviations from the mean trend function, e_{ht}, are normally distributed. In other words, if the number of birds was 20,000 and the temperature was 20^{o} C, NH_3 emissions would have a symmetric and bell-shaped normal distribution centered at the value given by the mean trend function. For a different number of birds and temperature, the bell-shaped curve would be centered in a different location.

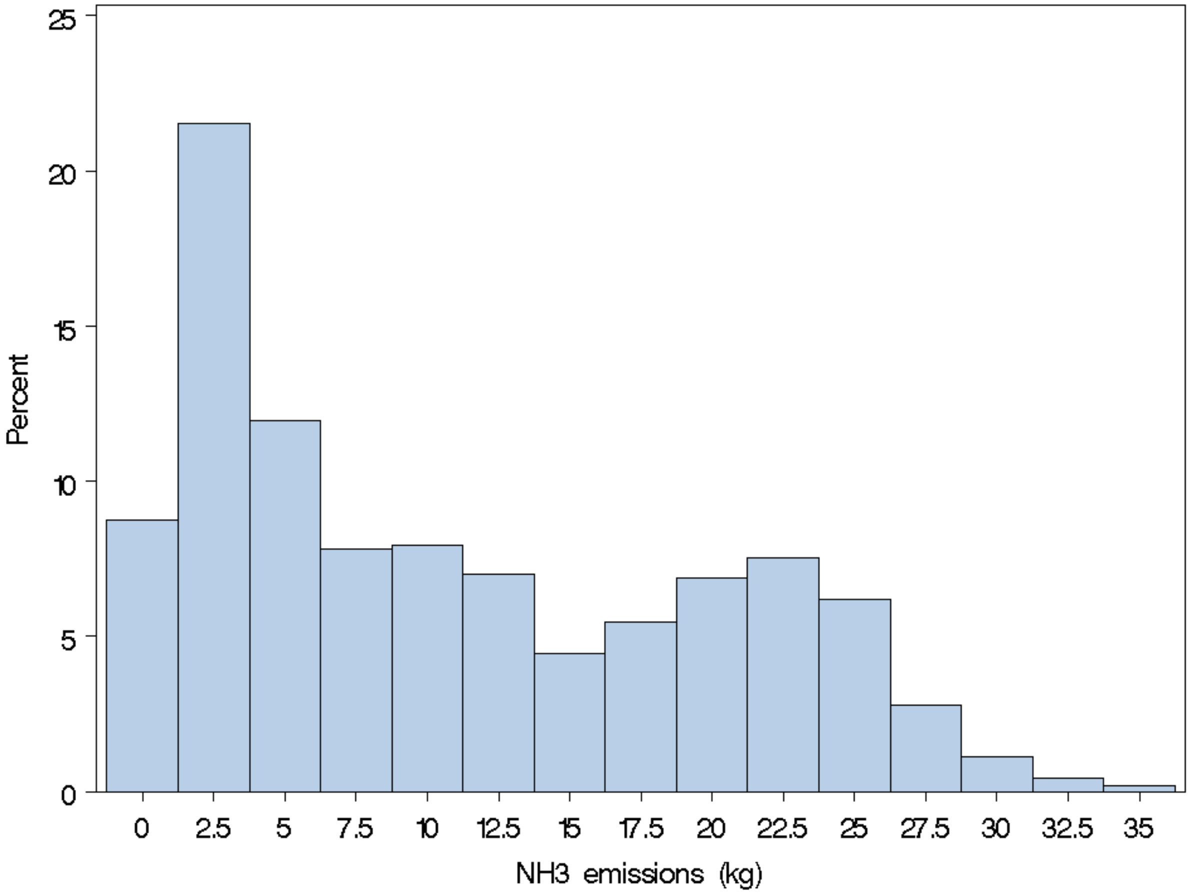


Figure 7-3. Histogram of NH_3 Emissions in the Base Dataset

Because aggregating all conditions into a single histogram masks differences in the distribution for different sets of conditions, the EPA separated the base dataset into bins according to values of average bird mass. Bin 1 contains the observations for which average bird mass takes values (in kg) 0.0 to 0.5; bin 2, 0.5 to 1.0; bin 3, 1.0 to 1.5; bin 4, 1.5 to 2.0; bin 5, 2.0 to 2.5; and bin 6, 2.5 to 3.0. The disaggregated histograms given in Figure 7-4 show that the NH_3 distribution for bins 1 and 2 are skew right, those for bins 3 and 5 are symmetric, and those for bins 4 and 6 are skew left. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern is by no means ubiquitous. There are not enough observations under any specific set of conditions to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

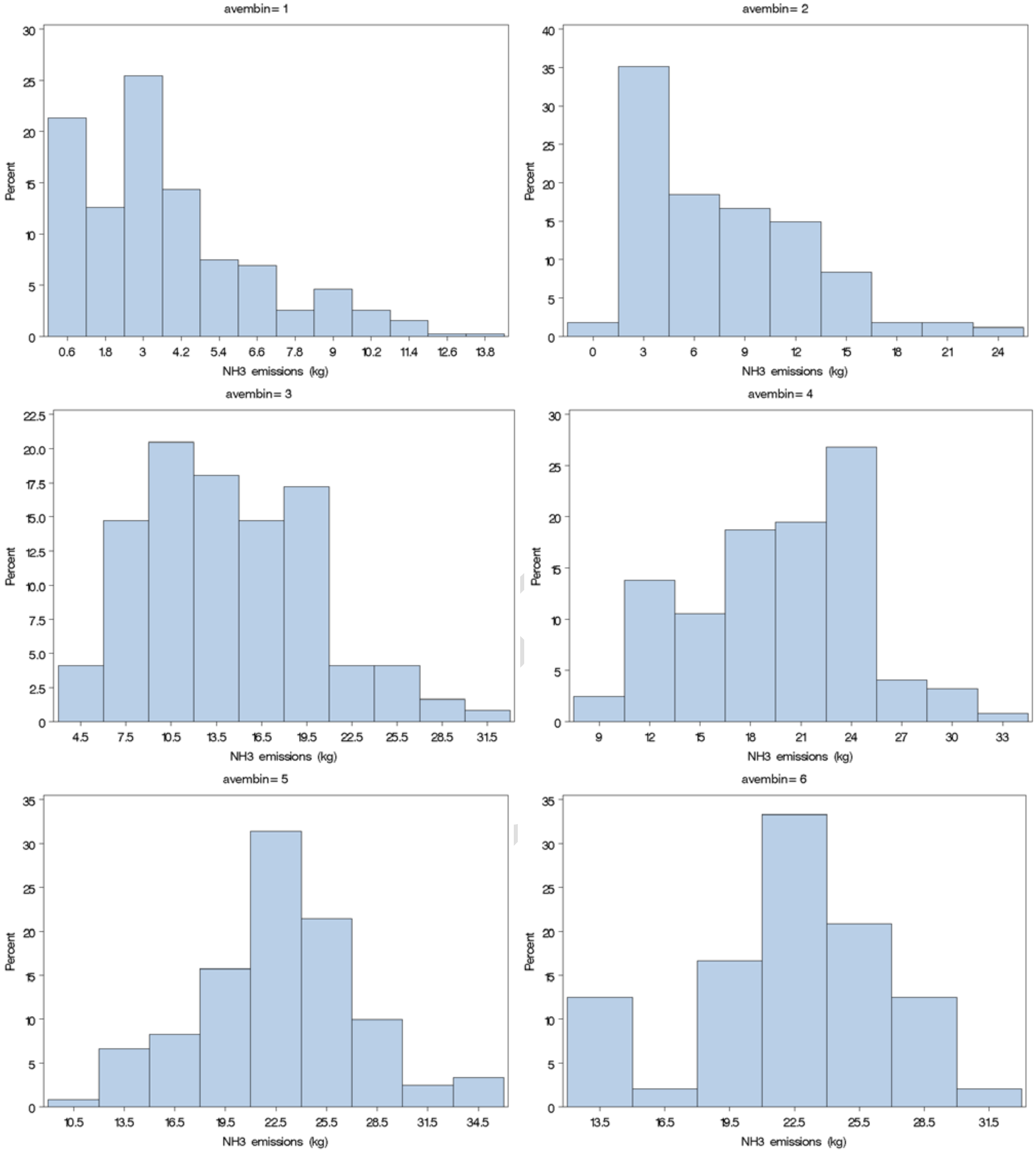


Figure 7-4. Histograms by *avem* Bins

7.3 Developing Candidate Mean Trend Variables

Development of candidate mean trend variables requires first choosing the appropriate functional form to describe the dependence of pollutant emissions on each predictor variable. Section 7.3.1 describes how one or more main effect mean trend variables were created as functions of the predictor variables. Section 7.3.2 explains the importance of including interactions between main effect mean trend variables, and shows how the EPA determined what level of interactions to include as candidate mean trend variables.

7.3.1 Choosing Predictor Variable Functional Forms

The EPA used a variety of exploratory plots, existing knowledge of the chemistry through which NH_3 emissions are formed in a broiler confinement house, and results from other studies to discover functional forms describing the relationship between NH_3 emissions and the predictor variables listed in Table 7-2. For continuous predictor variables, EPA prepared scatter plots of emissions versus the variable to determine if a relationship exists. If emissions increase (or decrease) as the predictor variable increases, and the rate of increase (or decrease) does not change, then a linear function of the predictor variable is appropriate. If emissions increase (or decrease) as the predictor variable increases, but the slope changes, a variety of functions could be considered, one of which is the exponential function. If emissions increase and then decrease (or decrease and then increase), this single change in direction of the relationship could be represented with a quadratic function. If there were two changes of direction (e.g., if emissions decrease, increase, then decrease or vice versa), a cubic polynomial would be appropriate. For discrete variables such as *buildup*, the decision is whether to allow each value of the variable (e.g., 0, 1, 2, 3, 4 and 5) to have a different effect on emissions, or whether to consolidate some of the values into a smaller number of categories.

Figure 7-5 displays a scatter plot of NH_3 emissions versus average live bird mass aggregated over all sites. The figure shows that, for values of $avem^*$ near 0, emissions range from 0 to approximately 15 kg, forming a “tail” on the leftmost side of the graph. The high variability in values decreases before average live bird mass reaches 0.125 kg. The plot slopes upward, with increasing steepness, until approximately 1.5 kg, when the steepness declines.

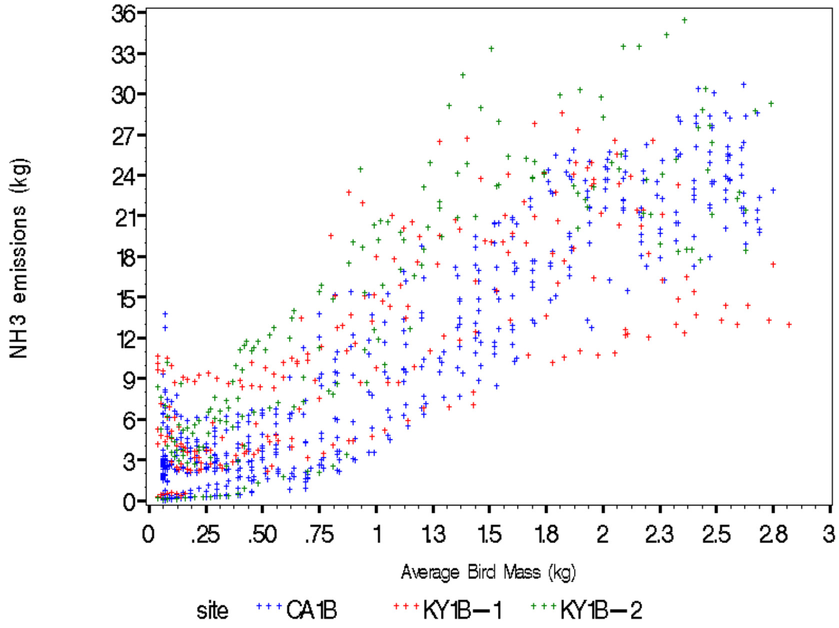


Figure 7-5. NH_3 Emissions vs. Average Live Bird Mass

To further investigate the relationship between NH_3 emissions and *avem**, the EPA created the variable *buildup* to represent the number of flocks introduced into a house since the last full litter clean-out. Although *buildup* takes values 0 through 5, values of 4 and 5 occurred only for site KY1B-2 H3. Site KY1B-1 H5 had a maximum *buildup* value of 3, and the CA1B houses had maximum *buildup* values of 2.

Figure 7-6 shows plots of NH_3 emissions disaggregated by house and with the value of *buildup* as the plot symbol. The curves with red zeros show that the flocks for which *buildup* = 0 have NH_3 emissions near 0 when *avem** is near 0. When the value of *buildup* is greater than zero, NH_3 values have greater variability, and the center of the distribution is greater than zero.

To determine how best to use the number of flocks since a full litter clean-out in the mean trend function, the EPA created two additional candidate mean trend variables: *build* and *bld*. The indicator variable *build* is defined as 0 when *buildup* is 0, and 1 otherwise. The categorical variable *bld,* takes the value 0 when *buildup* is zero, 1 when *buildup* is 1, 2 when *buildup* is 2, and 3 when *buildup* is greater than or equal to 3.

Table 7-4 summarizes the three variables that the EPA created to investigate the relationship between NH_3 emissions and the number of flocks since a full litter clean-out.

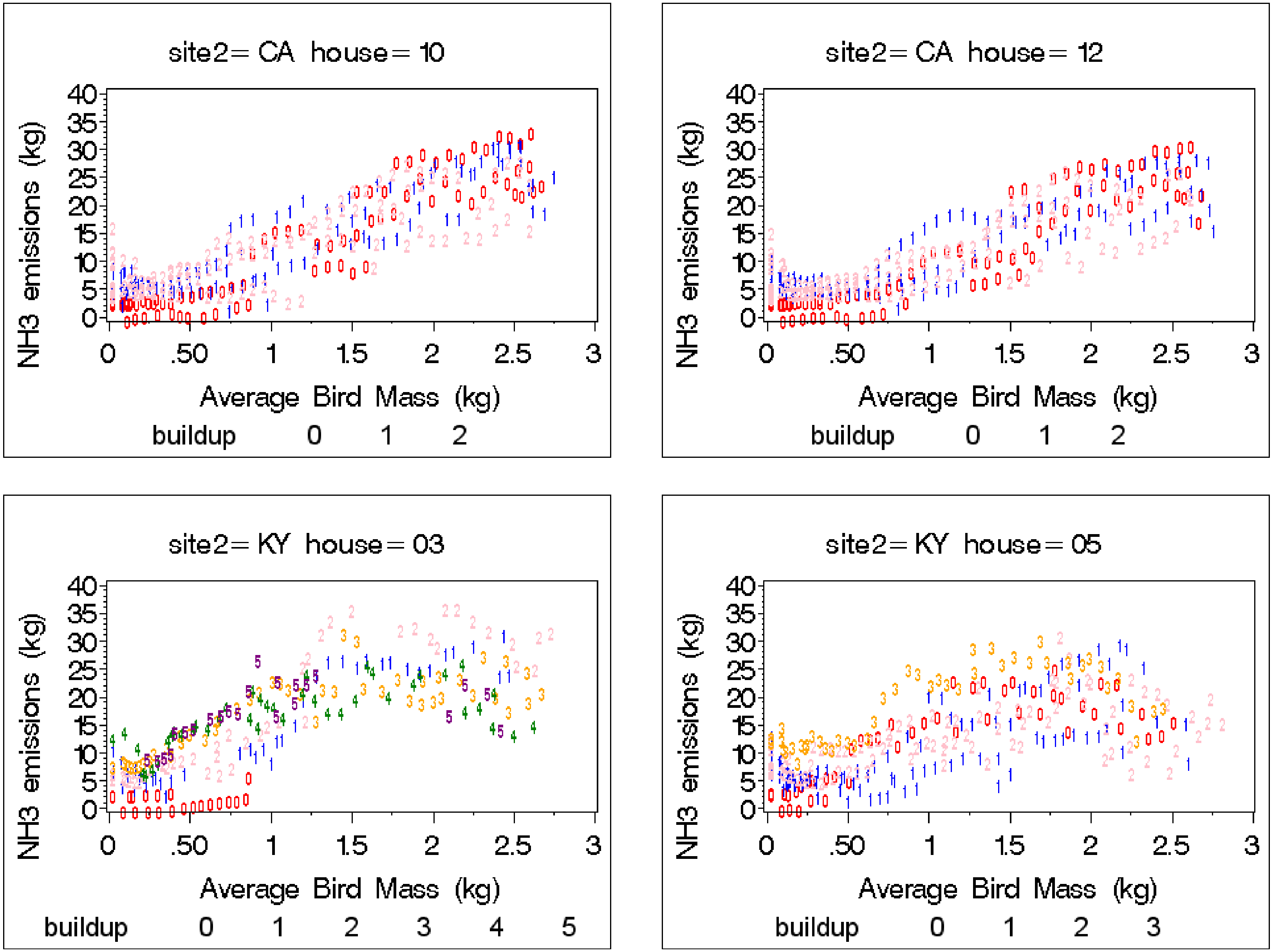


Figure 7-6. Overlay of *buildup* on NH_3 Emissions vs. Average Live Bird Mass

Table 7-4. Potential Mean Trend Variables to Account for Built-up Litter

Variable	Definition
buildup	No. of flocks introduced since last full litter clean-out: $0 \leq buildup \leq 5$
bld	0 if *buildup* = 0 1 if *buildup* = 1 2 if *buildup* = 2 3 if *buildup* $\geq$3
build	0 if *buildup* = 0 1 otherwise

Figure 7-7 shows three sets of box plots with NH_3 emissions on the vertical axis, and each of the three built-up litter variables on the horizontal axes. The edges of the boxes represent the first and third quartiles (25th and 75th percentiles) of the distribution of emissions for the value of the variable on the horizontal axis. The line in the middle of the box represents the median or 50th percentile. The “whiskers” extending above and below the box extend to the maximum or minimum value of NH_3 emissions, unless there are outliers, which are indicated with dots beyond the edges of the whiskers. An outlier is defined as a value that falls below (or above) the first (or third) quartile by more than 1.5 multiplied by the difference between the third and first quartile. Outliers were analyzed by the NAEMS Science Advisor and were determined to be valid emission values. As such, these values remained in the dataset for EEM development.

In the first set of box plots, when *buildup* = 0, the minimum and first quartile are indistinguishable, indicating that the first 25 percent of values of NH_3 emissions are near 0. Although the box covers all values of NH_3 emissions when *buildup* = 0, the values from the minimum to the first quartile are the values of interest. This range of NH_3 emissions occurs when $avem^*$ is near 0, when much of the NH_3 emissions signal might be attributable to built-up litter. In this same set of box plots, when *buildup* = 1 or 2, the minima and first quartiles are similar to each other and are both higher than the minimum and first quartile when *buildup* = 0. When *buildup* = 3, 4 or 5, the minima and first quartiles are higher again. These last three boxes, however, represent data from the Kentucky sites only, and the total number of observations represented by each box is 95, 42 and 24, respectively, while the number of observations represented by the first three boxes are 266, 383 and 402, respectively. The EPA decided against drawing conclusions regarding the effect of *buildup* from a small number of data points that do not represent all houses.

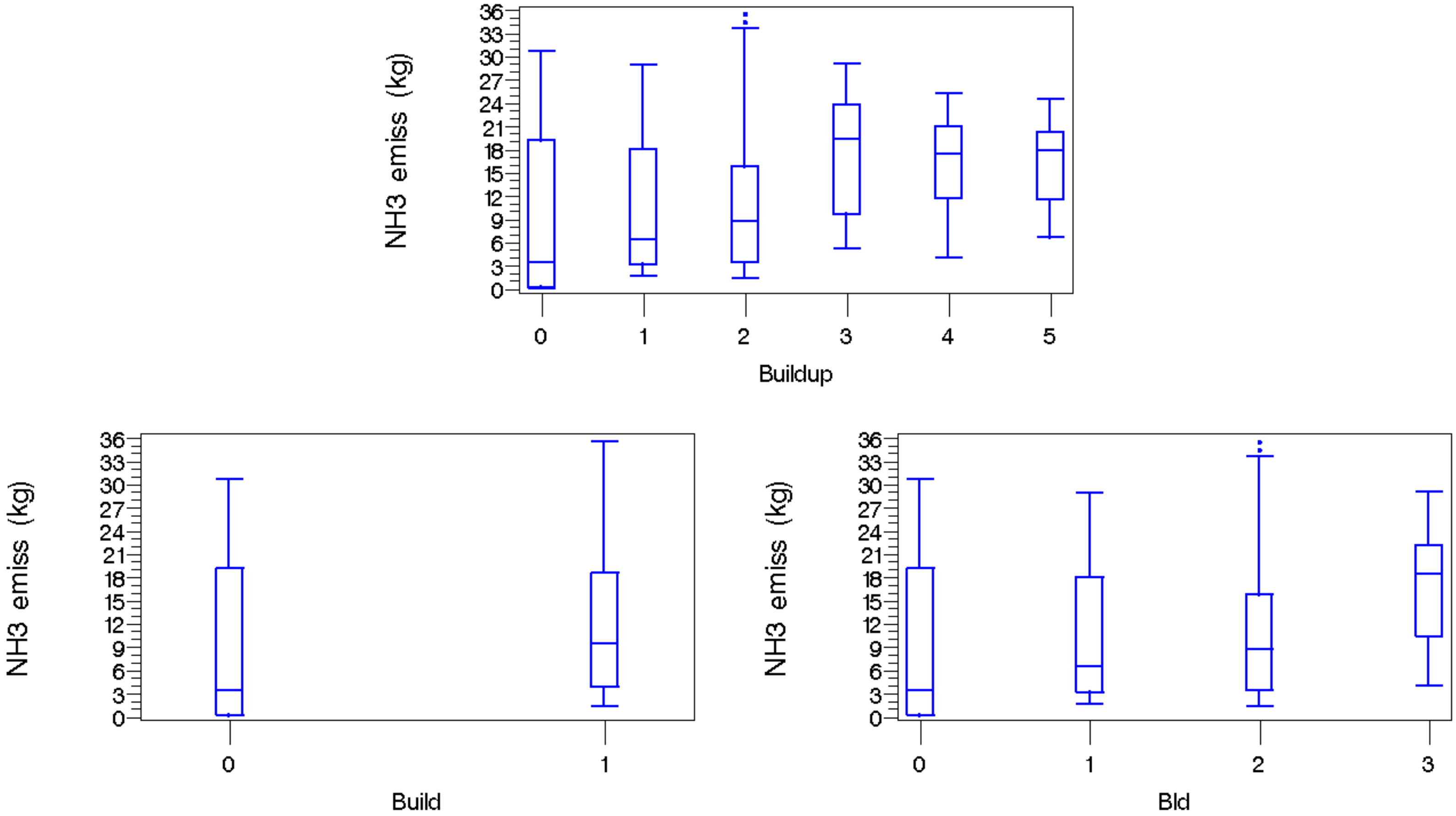


Figure 7-7. Box Plots of NH_3 Emissions vs. Candidate Categorical Variables

In the third set of plots, with *bld* on the horizontal axis, the first three boxes are the same as the first three boxes in the *buildup* plots, and the fourth box, where *bld* = 3, combines the data from the last three boxes in the *buildup* plots. Notice that the minimum and first quartile for *bld* = 3 are both higher than the minima and first quartiles for the other values of *bld*, but, again, all of the data in this box comes from the Kentucky sites. When *bld* = 1 or 2, there is very little difference in the minima or first quartiles, whether due to noise in the data or to an actual lack of signal, so that the EPA saw no use in distinguishing between these two values. The EPA therefore used the variable *build*, which simply indicates presence or absence of built-up litter, as the functional form through which the variable *buildup* enters the mean trend function. The second set of plots show the distinct difference in the minima and first quartiles for the boxes representing *build* = 0 and *build* = 1.

In determining the appropriate functional form through which *avem* enters the mean trend function, the EPA noticed that the slope in Figure 7-5 becomes steeper and then at some point becomes less steep. This change in slope was apparent as a more distinct leveling off or turning down for site KY1B-1 H5 (see Figure 7-6). The EPA further disaggregated the data into plots for individual flocks in Figure 7-8, Figure 7-9 and Figure 7-10. For site CA1B, flocks 1 and 2 were not included in the plots because there were 0 and 2 observations for House 10, and 0 and 3 observations for House 12. These figures show that for all houses, more often than not, NH_3 emissions as a function of $avem^*$ slopes upward with increasing steepness, then the slope begins to decrease, and then the slope either becomes zero or negative. For a few flocks the curve continued to increase, and for a few flocks, missing data prohibited examination of a pattern.

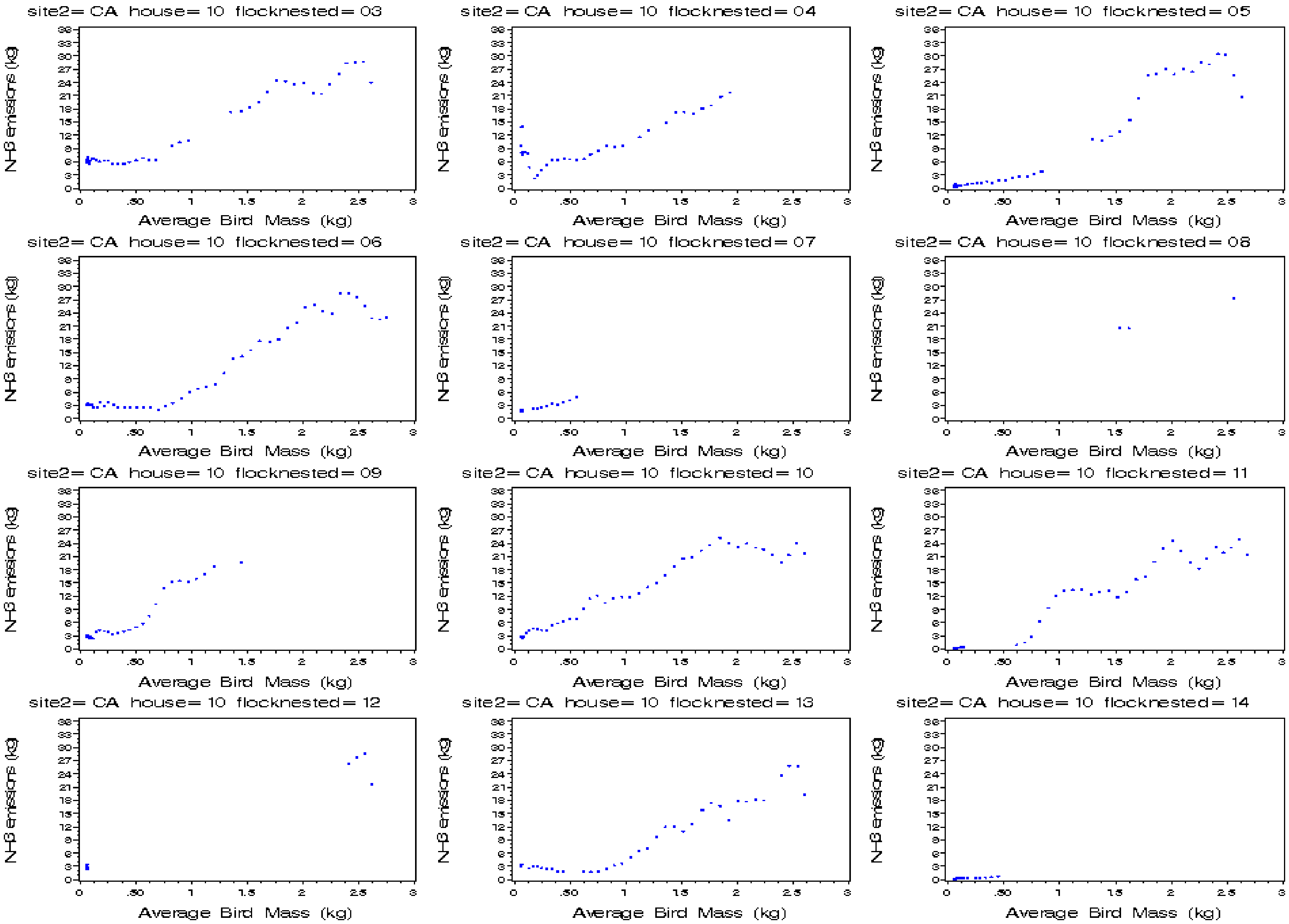


Figure 7-8. NH$_3$ Emissions vs. *avem* for Individual Flocks at CA1B H10

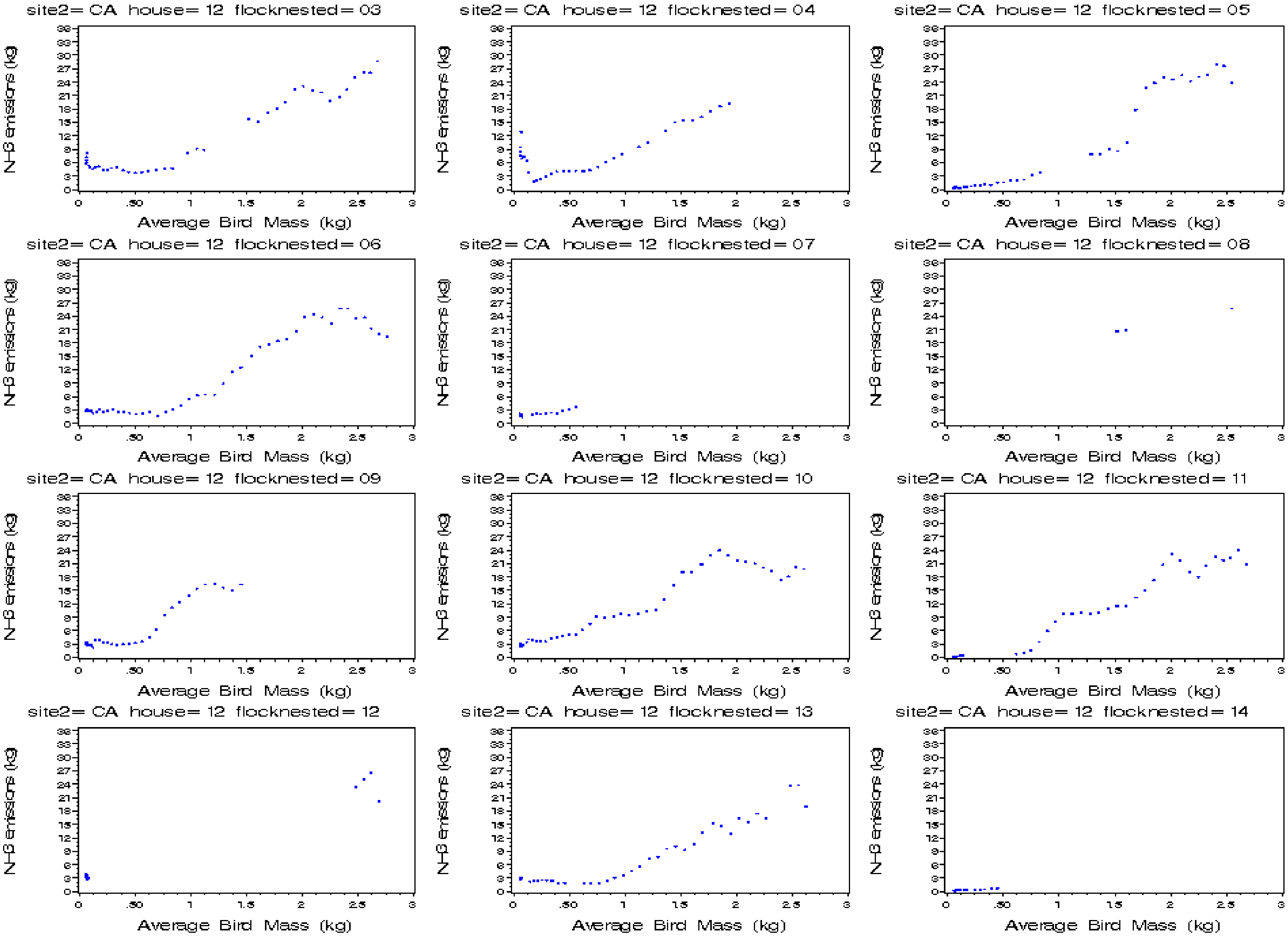


Figure 7-9. NH$_3$ Emissions vs. *avem* for Individual Flocks at CA1B H12

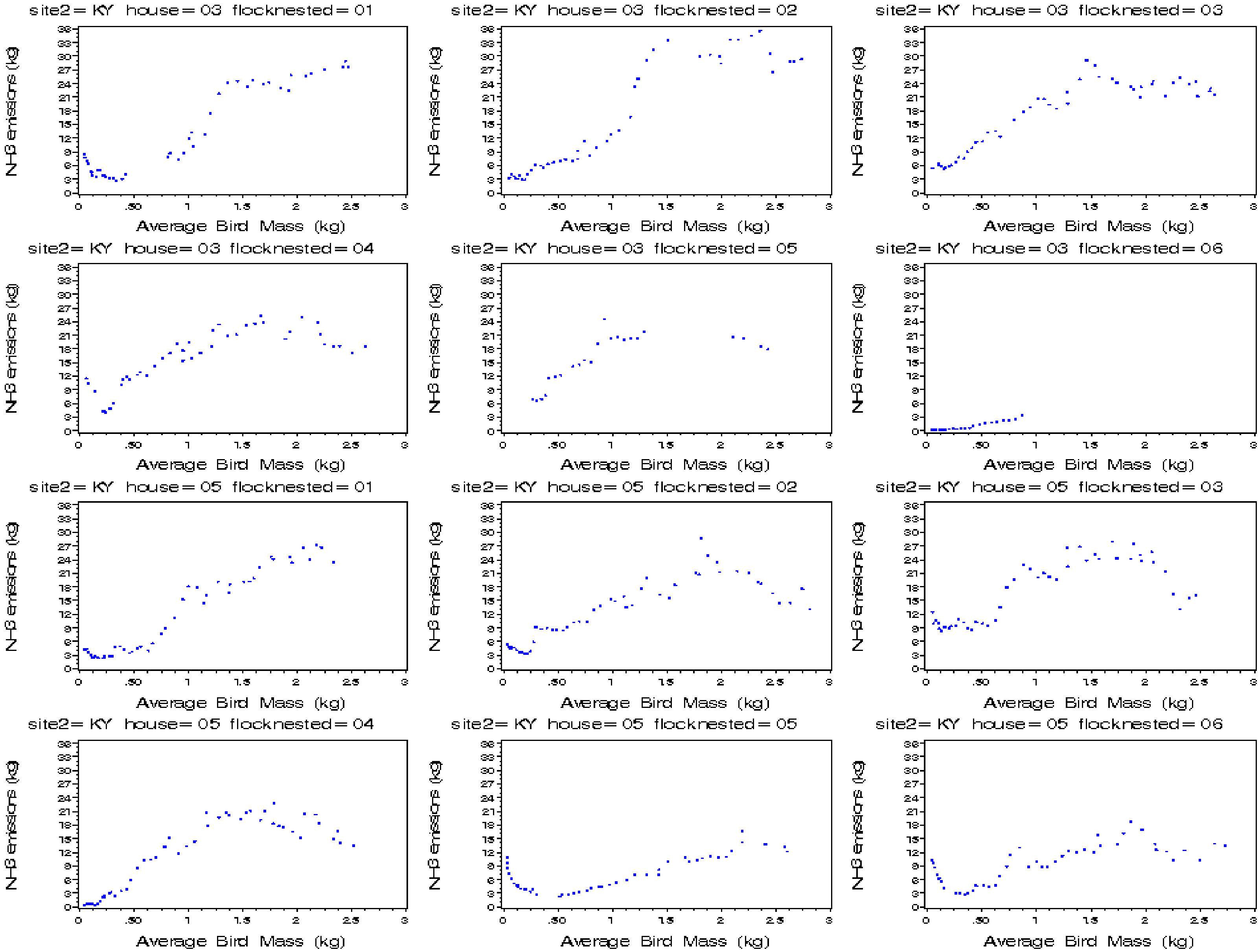


Figure 7-10. NH$_3$ Emissions vs. *avem* for Individual Flocks at the Kentucky Sites

The decreasing steepness and subsequent leveling-off and/or decrease in slope is apparent in the emissions plots contained in the final report for the Kentucky sites (see Appendix D). In conversations between the EPA, the researchers for the California and Kentucky sites and industry representatives, the hypotheses was raised that the slope may reflect changes in feed protein content that occur at multiple stages of the grow-out period. Protein excreted by the birds is the precursor to NH_3 emissions. As birds grow, metabolic changes lead to decreases in protein uptake. Therefore, it is a common practice in the broiler industry to progressively reduce the proportion of protein in the feed during the grow-out period. Reduced protein in the feed reduces protein excreted, thereby reducing the NH_3 precursor. To account for this curvature, the EPA chose a cubic polynomial to represent the main effect of average live bird mass on NH_3 emissions.

Figure 7-11, Figure 7-12 and Figure 7-13 display scatter plots of NH_3 emissions versus the remaining predictor variables. Intuition suggests that emissions of a pollutant will be greater when the number of birds is greater, if all other variables, especially average live bird mass, were held constant. The plot of NH_3 emissions versus *birds* corroborates this intuition. For example, consider a flock made up of 25,000 birds on the date of introduction into the house. On this date, the number of birds for this flock takes its maximum value, while the average live bird mass takes its minimum value. The total live bird mass, and thus the production of manure, is likely at or near its minimum value for this flock on this date. As each day passes, the bird inventory decreases due to mortality, but the average live bird mass increases, and the mortality rate is low enough that the total live bird mass, and thus the quantity of manure, increases as the grow-out period progresses. Thus, for a given flock, pollutant emissions increase as the number of birds decrease, as manifested by the collection of downward-sloping lines, some of which are indistinguishable from one another, in the scatter plot.

Now consider the difference between hypothetical flocks 1 and 2, with 25,000 and 21,000 birds, respectively, on the date of introduction to the house. Because the bird mortality rate is approximately the same for different flocks, if all other variables are held constant, flock 1 should produce more of the pollutant than flock 2. The tops of the downward sloping lines represent maximum NH_3 emissions for individual flocks, which occur when the number of birds for each flock is at its minimum. Notice that as the number of birds increases, the values of NH_3 emissions at the tops of those lines increase. After the effect of average live bird mass and the interaction between number of birds and average live bird mass were accounted for, the EPA expected the effect of *birds* to be positive. Figure 7-11 does not indicate that the EPA should use a functional form other than linear in the EEM. Thus, the mean trend variable, *birds*, represents the main effect of the predictor variable *birds*[*].

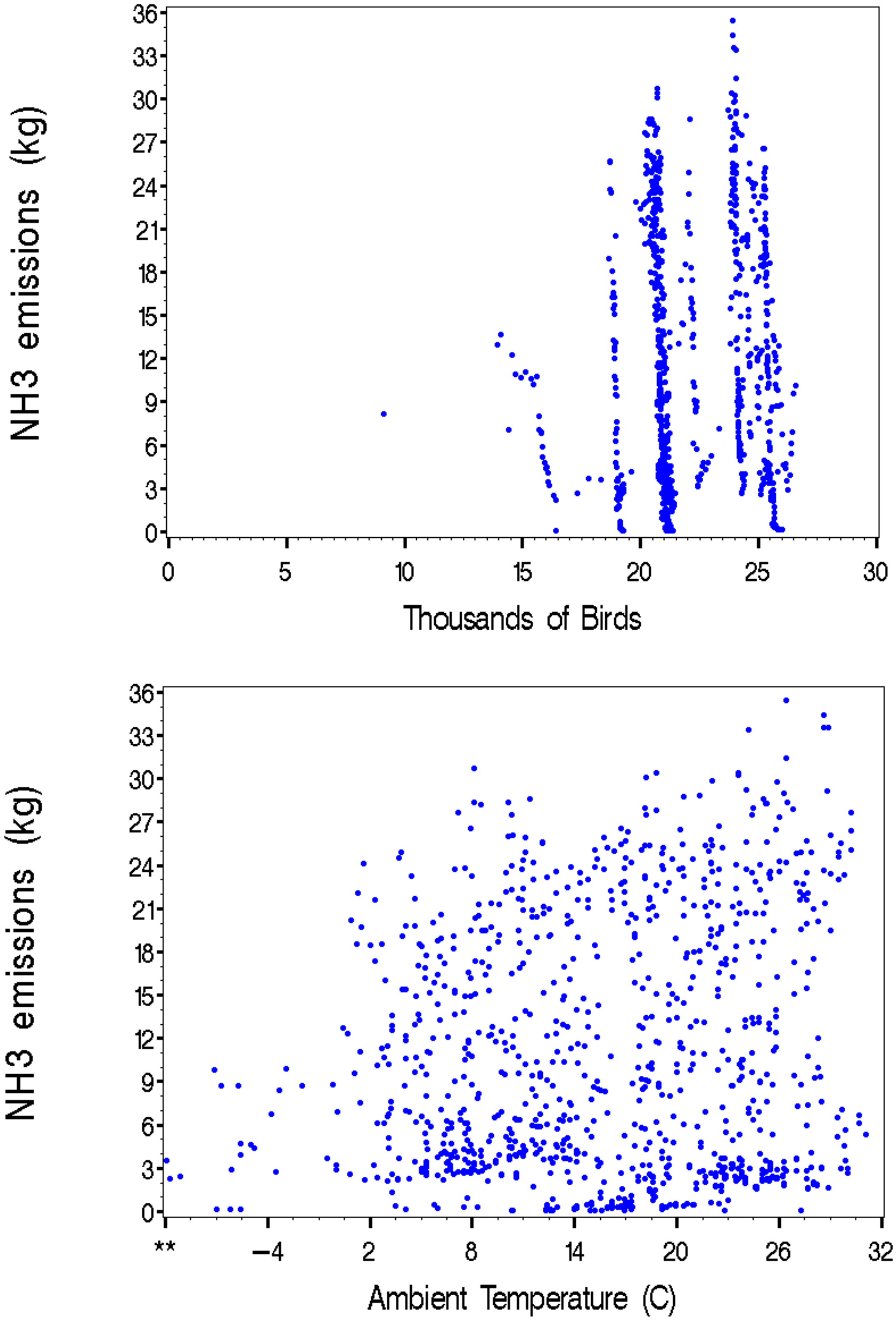
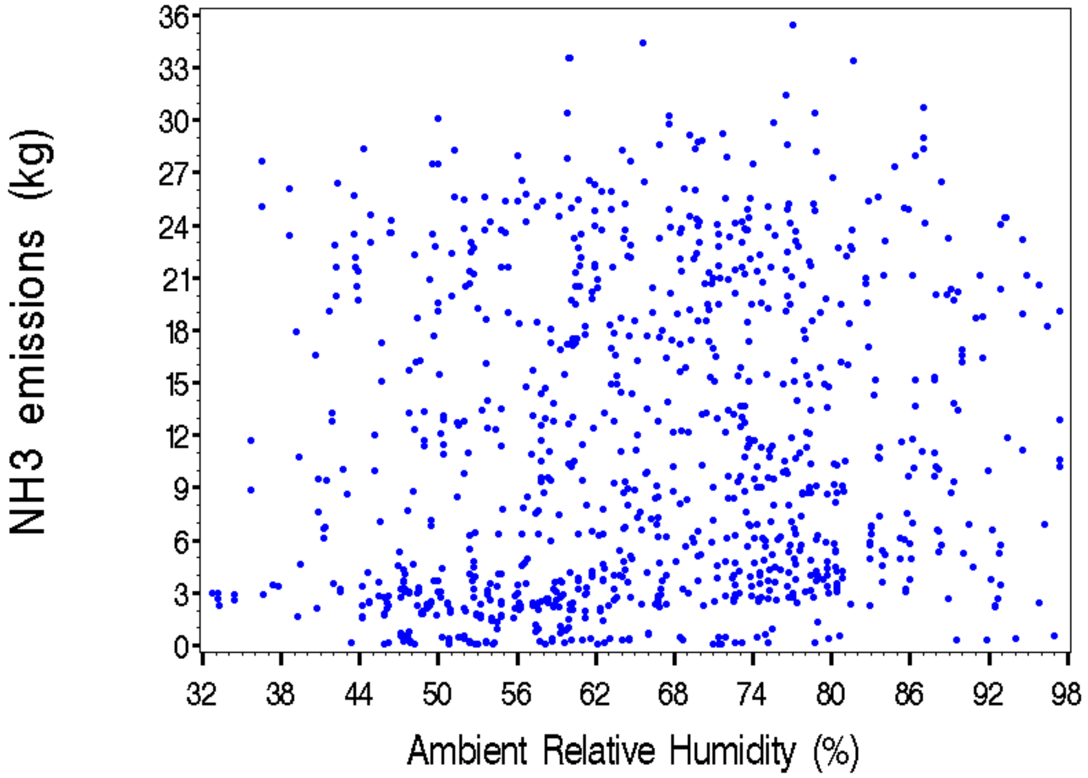


Figure 7-11. NH$_3$ Emissions vs. Predictor Variables _birds_* and _ta_*



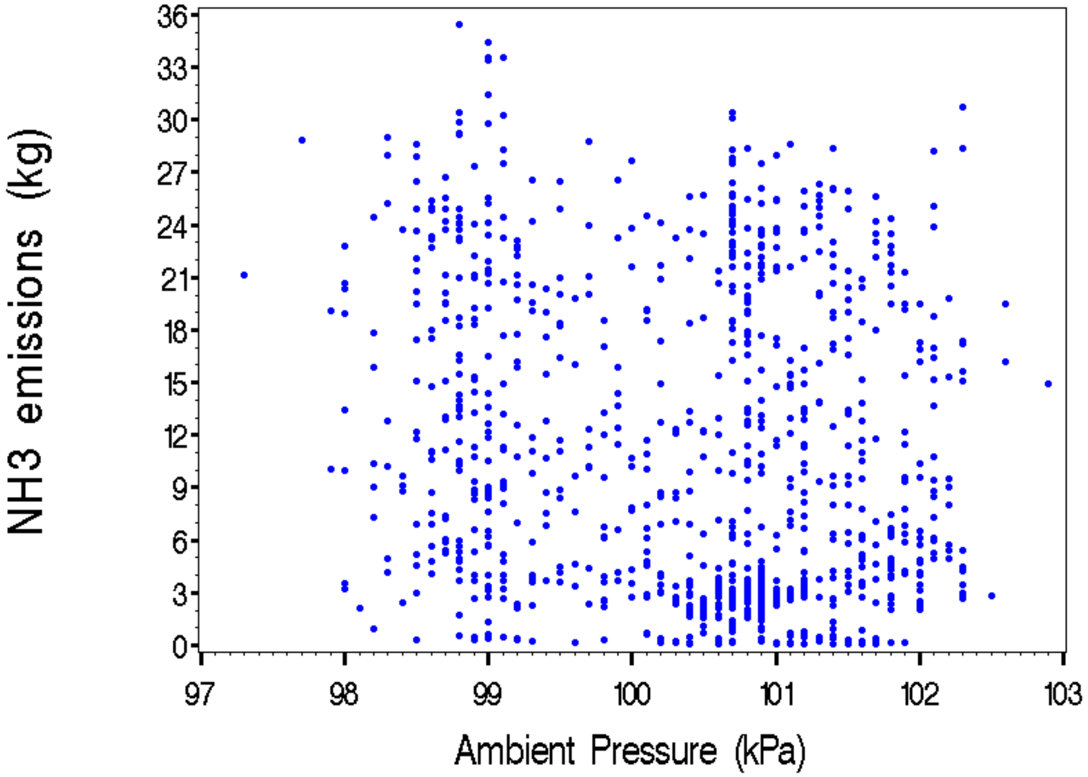
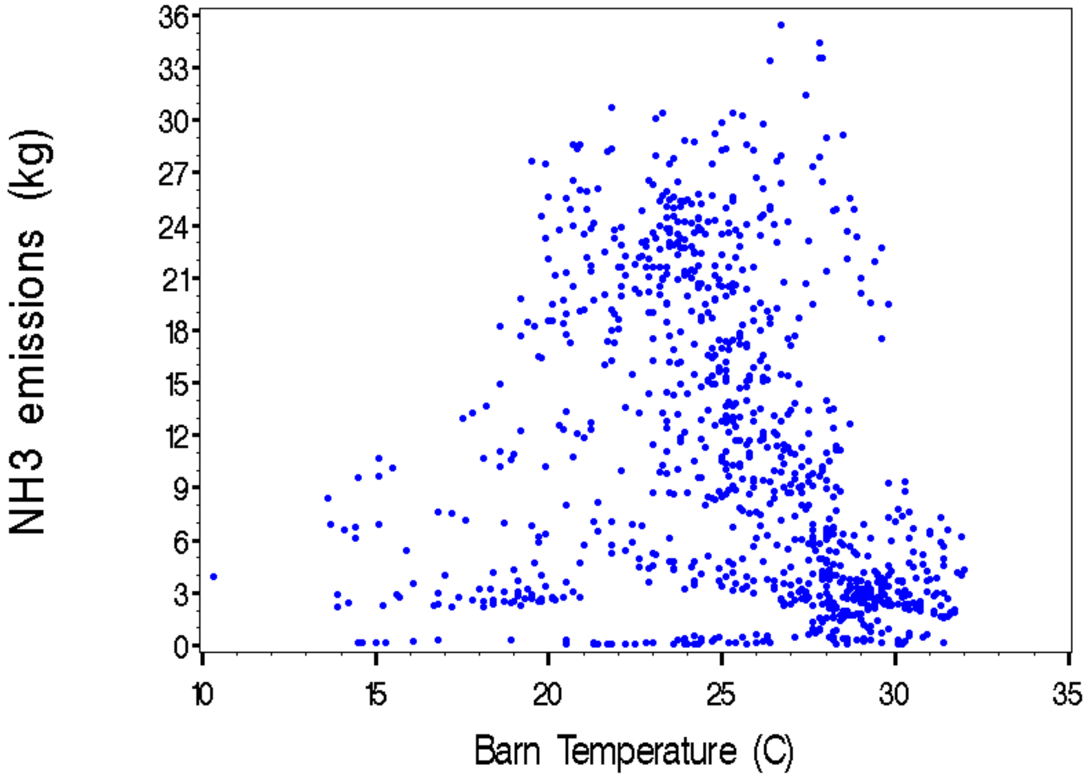


Figure 7-12. NH_3 Emissions vs. Predictor Variables *ha and *pa***



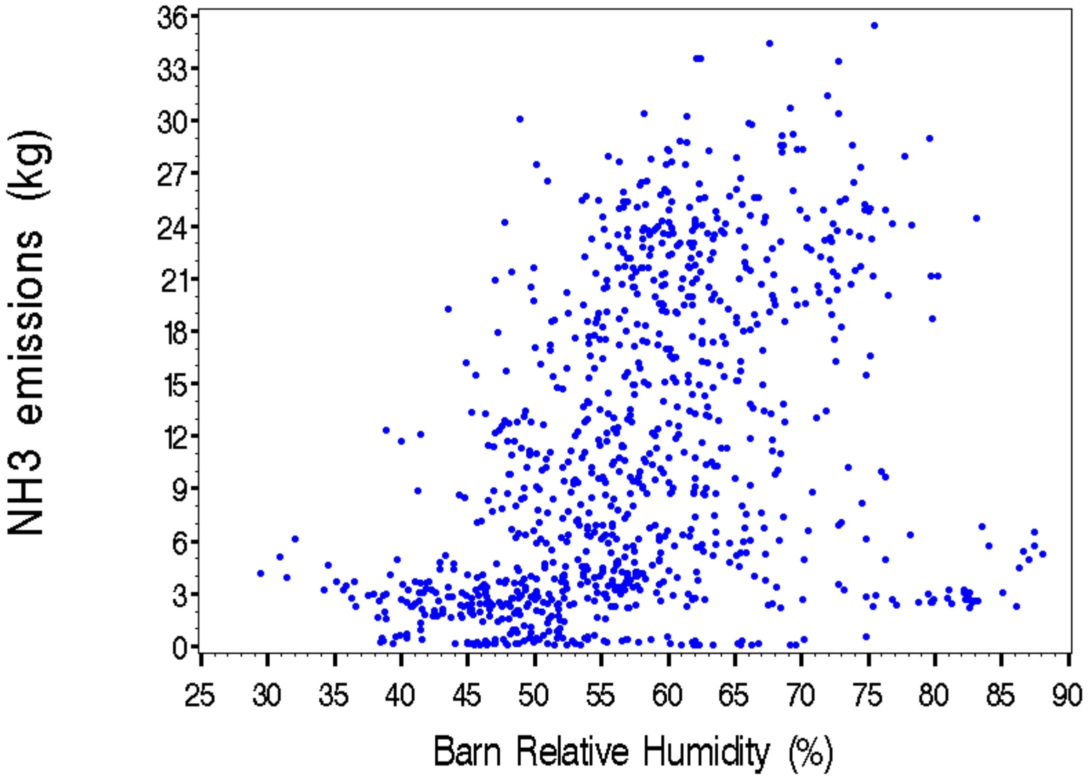


Figure 7-13. NH_3 Emissions vs. Predictor Variables *tc and *hc***

The relationships between NH_3 emissions and each of the ambient meteorological variables were not apparent in the plots of Figure 7-11 and Figure 7-12, nor were the relationships between NH_3 emissions and the confinement variables apparent in Figure 7-13. Such relationships are often hidden in plots aggregated over many different sets of conditions. Consequently, the EPA plotted NH_3 emissions versus each variable separately for the six $avem^*$ bins.

Figure 7-14 displays example plots of NH_3 emissions versus ha^*. Excluding bin 1, which has added variability due to differences in *buildup*, when enough data are available within a bin, the EPA detected a slight increasing trend. For each of these variables, the EPA chose a linear functional form, in the absence of a clear signal or a process-based reason to do otherwise.

Table 7-5 summarizes the functional form chosen by EPA to describe the dependence of NH_3 emissions on the original predictor variables. The first column gives the original predictor variable, and the second states the functional form chosen. The last column gives the mean trend variable or variables that represented the main effect of each predictor variable. For the discrete predictor variable *buildup*, the indicator variable *build* will be the mean trend variable.

Table 7-5. Summary of Main Effect Mean Trend Variables

Original Predictor Variable[a]	Functional Form Chosen	Centering Value	Scaling Value	Main Effect Mean Trend Variable(s)
*buildup**	Indicator variable	Not applicable	Not applicable	*build*
*birds**	Linear	22	2.5	*birds*
*avem**	Cubic polynomial	1.1	0.87	$avem$, $avem^2$, $avem^3$
*ta**	Linear	15	8.2	*ta*
*ha**	Linear	66	14	*ha*
*pa**	Linear	100	1.1	*pa*
*tc**	Linear	25	3.8	*tc*
*hc**	Linear	58	9.9	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before centering and scaling (see Section 7.3.1).

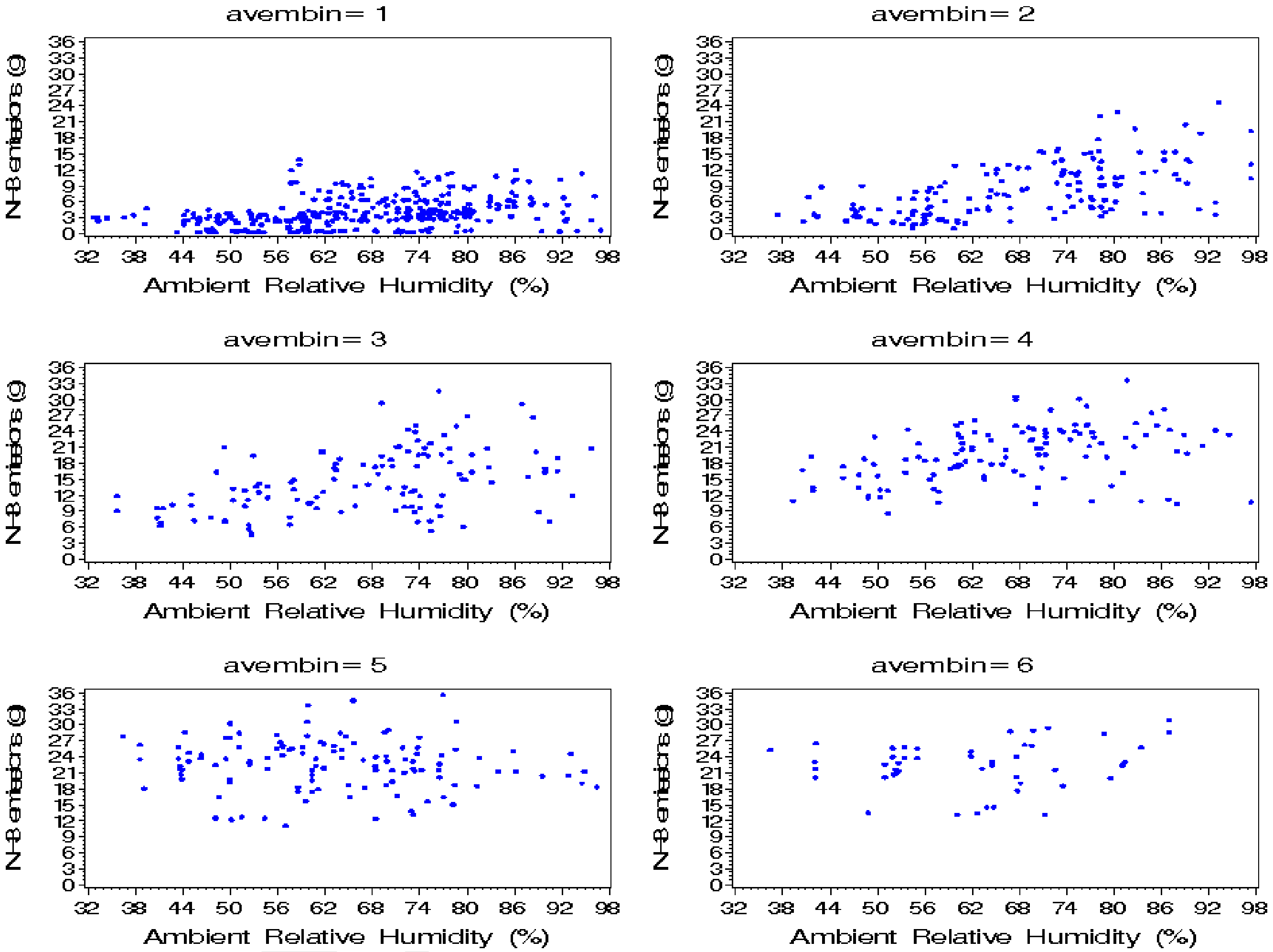


Figure 7-14. NH$_3$ Emissions vs. *ha** for Six *avem* Bins

All of the other predictor variables were continuous variables. Following standard statistical practice, the EPA transformed each predictor variable in Table 7-5 by subtracting the mean value of the original predictor variable and then dividing by the standard deviation. This practice is called centering and scaling the continuous predictor variables. For example, the mean value of $birds^*$ in the base dataset, rounded to two significant digits, was 22, and the standard deviation was 2.5 (the unit of measure was thousands of birds.) The EPA created the new variable $birds = (birds^* - 22)/2.5$, and because the functional form chosen for birds is linear, the new variable *birds* is the mean trend variable that represents the main effect of birds. All of the variables except *avem** followed the same pattern as *birds*, with different centering and scaling values. For *avem**, the new variable *avem* was created by centering and scaling, and then the cubic polynomial functional form chosen for *avem* was represented by the terms *avem*, $avem^2$ and $avem^3$.

The reason for centering and scaling the continuous predictor variables prior to creating mean trend variables from them is to prevent collinearity problems. Collinearity occurs when one mean trend variable is equal to, or very nearly equal to, a linear combination of other mean trend variables. In lay terms, it can be thought of as the condition in which two or more mean trend variables in a multiple regression analysis are highly correlated. Collinearity problems can be produced when mean trend terms are created as the squared or cubed value of a predictor variable that takes primarily positive values. They can also be produced when one mean trend variable that takes primarily positive values is multiplied by another that takes primarily positive values to create an interaction between the two. The predictor variables *avem, ha, pa, tc* and *hc* have positive values for all 1,211 observations in the NAEMS data, but the centered and scaled versions *avem*, ha*, pa*, tc** and *hc** have positive values for half the observations, and negative values for the other half.

The potential negative effect of collinearity is that when it is present, small changes in the data could produce very different regression coefficient estimates, but these changes *do not* produce very different emissions predictions unless the collinearity is quite severe. Because the EPA prevented severe collinearity by centering and scaling the continuous predictor variables, and because the purpose of the EEMs is to produce predictions, collinearity is not a problem for the EEMs developed for broiler houses.

Table 7-5 shows the centering and scaling values used for each continuous predictor variable. The centering value for each variable is the mean value of that variable in the base dataset, and the scaling value is the standard deviation. When using the EEMs, new centering and scaling values are not calculated. The centering and scaling values in Table 7-5 must be used because the EEMs were created using these values.

7.3.2 Creating Mean Trend Variables from Main Effects and Interactions

After identifying functional forms through which each predictor should enter the mean trend function, the EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables. An interaction between two mean trend variables occurs when the effect, or slope, of a main effect variable is different for different values of another variable.

A two-way interaction is the product of two main effect variables. For the I EEM, the two-way interaction between *build* and *birds* is the product *buildbirds.* The two-way interaction between build and avem consists of the collection of products *buildavem*, $buildavem^2$ and $buildavem^3$, and the 2-way interaction between *birds* and *avem* consists of the collection of products *birdsavem*, $birdsavem^2$ and $birdsavem^3$. A three-way interaction is the product of three main effect variables. The three way interactions for the I EEM included *buildbirdsavem*, $buildbirdsavem^2$ and $buildbirdsavem^3$. Higher order interactions for the I EEM were irrelevant.

Failure to consider interactions among main effect mean trend variables can result in exclusion of important variables from the EEM due to failure to notice their statistical significance. Some variables might affect NH_3 emissions only by way of an interaction with another variable. For example, the main effect of a variable such as *ta* might drop out of the EEM due to an insignificant regression coefficient. However, when its interaction with *avem* is considered, the regression coefficient for the interaction term might be statistically significant.

Furthermore, even if the main effects of both *ta* and *avem* were statistically significant, it might be the case that an interaction between them allows the EEM to explain even more of the variability in NH_3 emissions. Failure to consider such an interaction would result in decreased predictive performance in terms of both accuracy (establishing the optimal mean trend function) and precision (minimizing prediction error variance, manifested by the width of the prediction intervals). Including three-way interactions, or n-way interactions for $n > 3$, particularly when the set of predictor variables is large, might not improve the predictive ability of the EEM, and might lead to extreme collinearity. Therefore, the EPA adopted the following protocol, illustrated with the I EEM, for determining what level of interactions to use as candidate mean trend variables.

The EPA performed an ordinary least squares (OLS) regression of NH_3 emissions in the base dataset on main effect inventory variables, then repeated the regression adding two-way interactions, then three-way interactions. With each regression, the EPA examined the value of R^2 to determine what percent of variability in NH_3 emissions in the base dataset were explained by each set of variables. Using the maximum value of R^2 calculated from a regression on the base dataset is not appropriate to determine what mean trend variables should be included in the final EEM because adding variables to the EEM always increases R^2, even if some are spurious variables or if they explain anomalies in the base dataset as opposed to signals that apply generally. If adding variables increases R^2 only slightly, however, those additional variables are not important. Therefore, the EPA decided that only if increasing the level of interactions in the OLS regression from n-way to $n + 1$ way increased R^2 by 0.01 or more would the $n + 1$ way interactions be included as candidate mean trend variables.

Table 7-6 shows that including only main effects for the I EEM resulted in $R^2 = 0.8127$, and adding two-way interactions resulted in $R^2 = 0.8457$. Because the difference between the R^2 values was 0.033, the EPA included the two-way interactions. Because adding 3-way interactions produced $R^2 = 0.8493$, an increase of only 0.0036, the EPA did not include 3-way interactions in the set of candidate mean trend variables.

Table 7-6. Proportion of Base Dataset Variability Explained by EEMs by Interaction Level

EEM	Interaction Level	P	R^2
I	Main effects	5	0.8127
	Add 2-way	12	0.8457
	Add 3-way	15	0.8493
IA	Main effects	8	0.8365
	Add 2-way	33	0.9013
IAC	Main effects	10	0.8401
	Add 2-way	52	0.9149

Because they contain a superset of the predictor variables in the I EEM, the EPA did not consider interactions beyond two-way for the IA and IAC EEMs. However, the EPA conducted a test to determine whether adding two-way interactions to the main effect for these two EEMs was necessary. Because the OLS regression of NH_3 emissions on main effects for the IA EEM resulted in $R^2 = 0.8365$, and adding two-way interactions produced $R^2 = 0.9013$, the EPA considered two-way interactions for the IA EEM. Because the OLS regression of NH_3 emissions on main effects for the IAC EEM resulted in values of $R^2 = 0.8401$, and adding two-way interactions produced $R^2 = 0.9149$, the EPA also considered two-way interactions for the IAC EEM.

7.4 Choosing the Covariance Function

Use of OLS regression to determine what mean trend variables are statistically significant and to obtain prediction intervals requires that the random deviations e_{ht} are independent and identically distributed with mean 0 and variance σ^2. If they are not independent, the dependence, which is called correlation or covariance, can be accounted for in the EEM using random effects and/or a covariance function, via generalized least squares (GLS) regression. If they are not identically distributed, differences in the variance parameter σ^2 can be eliminated by transforming the original response variable (NH_3 emissions) or by allowing different values of σ^2 under different conditions.

Section 7.4.1 explains the meaning of and distinction between correlation and covariance. Sections 7.4.2 and 7.4.3, respectively, describe how the EPA assessed the need to account for serial correlation or correlation due to random effects. Section 7.4.4 explains the EPA's decision to use the single variance parameter σ^2 calculated from all four broiler houses and all three sites in the NAEMS.

7.4.1 Correlation Function as Subset of Covariance Function

The auto-correlation coefficient, ρ, which falls between -1.0 and 1.0, is a measure of the strength and direction of a linear relationship between two random variables. Values closer to 0 indicate little or no relationship, values close to -1.0 indicate a strong negative association, and values close to 1.0 indicate a strong positive association. In the EEM context, the random variables are both the random deviations, e_{ht}, from the mean trend function, and the NH_3 emissions, Y_{ht}, which are functions of the e_{ht}.

The covariance between two random variables is the correlation coefficient multiplied by the standard deviation of each: $\rho\sigma_1\sigma_2$. If the two have the same standard deviation (i.e., $\sigma_1 = \sigma_2 = \sigma$), then the covariance is simply the product $\rho\,\sigma^2$ of the correlation coefficient ρ and the variance σ^2. In short, the covariance is a measure of alikeness, for which the units are the squared units of the random variable (kg squared in the case of daily NH_3 emissions).

For the EEMs, EPA used the covariance matrix to calculate prediction error. The covariance matrix specifies the joint probability of all types of errors that are possible in the mean trend terms over all dates, houses and sites. For example, the EEM would specify a greater prediction error for mean trend values that are at the extreme values measured in the NAEMS monitoring study than for values that are closer to the central tendency of the measured emissions data.

Because the I EEM has fewer mean trend variables than the other EEMs, the covariance function has to account for more variability in NH_3 emissions than it will for the other EEMs. The EPA therefore used only inventory-based mean trend terms to make initial covariance function decisions. However, the EPA continually re-assessed the statistical significance of covariance parameters during the final EEM selection process in case addition of mean trend variables from the ambient and confinement categories explained so much more variability in NH_3 emissions that the covariance parameters were no longer needed.

7.4.2 Serial Correlation

Serial correlation in NH_3 emissions, Y_{ht}, occurs if the value of emissions at one point in time is related to the value at a nearby point in time. The deviations from the mean trend function, e_{ht}, can display serial correlation even when many of the reasons for the similarity between emissions for two consecutive days have been accounted for with the mean trend function. To assess the need to account for serial correlation in the deviations from the mean trend function, the EPA fit an OLS regression model, which does not account for serial correlation or random effects, to the base data and plotted pairs of residuals from the same house, $\hat{e}_{ht}$, (which are estimates of the deviations) at time t versus those at time t–1, (see Figure 7-15). Because of the strong relationship between the two terms, EPA accounted for serial correlation with the auto-regressive order 1 (AR(1)) covariance function. This function expresses the covariance $Cov(e_{ht}, e_{ht'})$ between two deviations from the mean trend function within the same house on different dates (t and t') as the product, $\sigma^2\rho^{/t-t'/}$, of the variance parameter, σ^2 , and a power of the auto-correlation coefficient, ρ. Restricting ρ to take values between 0 and 1 ensures that when the distance, $| t-t' |$, between two dates increases, the correlation $\rho^{| t-t' |}$ between the two deviations decreases.

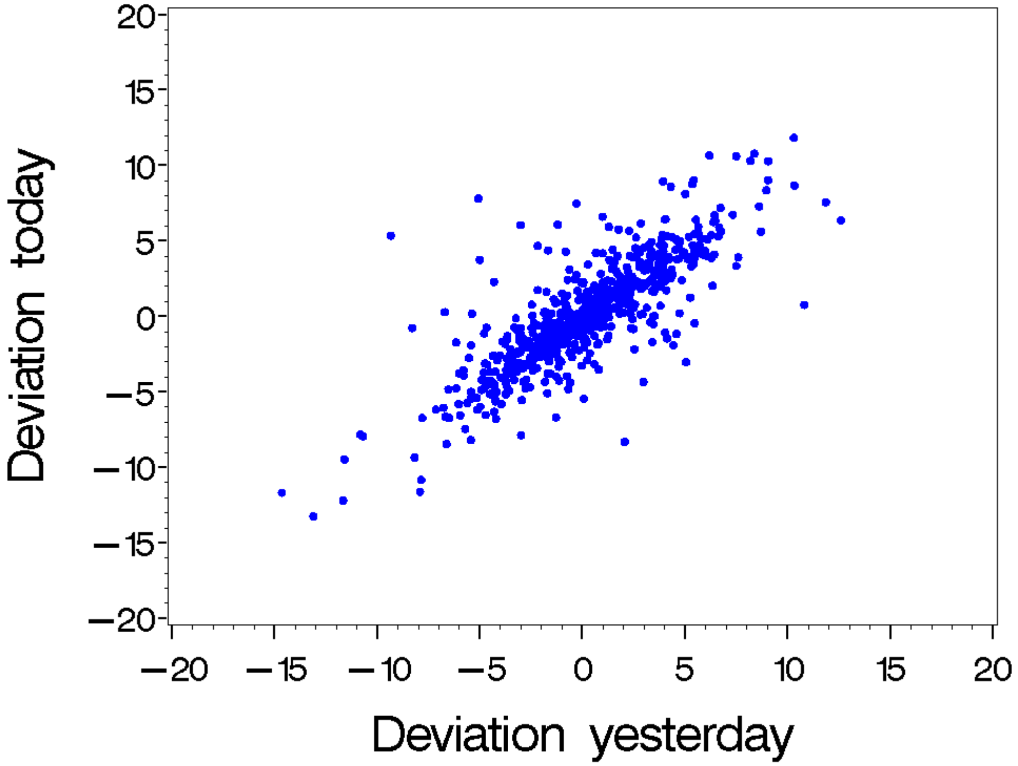


Figure 7-15. Deviations from the Mean Trend Function on Date *t* vs. Date *t*-1

7.4.3 Random Effects

Random effects must be accounted for if a variable that cannot be used as a predictor might nonetheless affect the value of NH_3 emissions. Variables that might affect pollutant emissions from broiler houses include information that was not provided by the NAEMS such as the nitrogen content of feed rations and the timing of changes in feed rations. Such variables might be the same for a given farm or company, but different for different farms or companies. The genetic make-up of the birds might also be the same for a given farm or company, but different for different farms or companies. Other variables that might affect the pollutant emissions measurements, which is different from affecting actual emissions, include the people conducting the measurement activities, the proximity of the house to another emissions source, and the distance separating the outdoor ambient monitor from the house. If, for hypothetical house 1, the distance between the outdoor monitor and the house were less than that of hypothetical house 2, the ambient emissions concentration from house 1 might be more contaminated by emissions from the house, and thus not represent background emissions alone. Then for house 1, the emissions measurement resulting from subtracting the outdoor "background" NH_3 concentration from the indoor concentration would not be as representative of true emissions as would the emissions measurement from house 2. To allow for differences in emissions due to such farm-to-farm, company-to-company, or house-to-house differences, known or unknown, the EPA considered random effects of site and house.

The EPA assessed the need to account for random effects first using summary statistics, and then by including each type of random effect in an EEM and testing the statistical significance of the effect. When values of other predictor variables such as *buildup*, $avem^*$ (*or avem*) and *birds** (*or birds*) are kept constant, a consistent pattern in mean emissions for the different houses or sites would support the need for a random effect. Table 7-7 shows mean NH_3 emissions within each house for different ranges of $avem^*$ for the subset of the base data for which *build* = 0. (Note that for the only flock for which KY1B-2 H3 had *build* = 0, the data beyond the first three weeks were missing.) For $avem^*$ bins 1 through 3, KY1B-1 H5 had a higher mean than CA1B H10 and CA1B H12, but the pattern did not continue over bins 4 through 6. Other breakdowns of the data showed a similar lack of consistent pattern. This observation implies that random effects of house or site are not needed.

Table 7-7. Mean NH_3 Emissions (kg) After Litter Clean-out

		Average Bird Mass											
		0-0.5 kg		**0.5-1.0 kg**		**1.0-1.5 kg**		**1.5-2.0 kg**		**2.0-2.5 kg**		**2.5-3.0 kg**	
Site	**House**	**n**	**NH_3**	**n**	**NH_3**	**n**	**NH_3**	**n**	**NH_3**	**n**	**NH_3**	**n**	**NH_3**
CA1B	10	41	0.42	12	3.97	9	12.4	14	19.1	14	24.7	8	25.2
	12	40	0.36	12	2.89	9	9.32	14	17.0	14	23.3	8	24.1
KY1B-1	5	17	1.78	8	11.6	7	18.9	9	19.4	7	17.0	1	13.3
KY1B-2	3	15	0.36	7	2.18	0	a	0	a	0	a	0	a

[a] Site KY1B-2 only had three weeks of data on new bedding.

To formally test the need for a random effect in the EEM, Equation 7-2 presents a modification of Equation 7-1 that includes a random effect of house, A_h. If there were a consistent pattern in mean NH_3 emissions for each house, then the random variables A_h, h = 1,…4, will have variance parameter, σ^2_H, significantly different from zero. Note that σ^2_H represents a single parameter, whereas the notation σ^2_h, h = 1,...,4, which will be used in Section 7.4.4, represents four different parameters.

$$Y_{ht} = \beta_0 + \beta_1 x_{1ht} + \cdots + \beta_p x_{pht} + \cdots + \beta_P x_{Pht} + A_h + e_{ht}\,,\ h = 1, \ldots, 4,\ t \text{ varies},\ p = 1, \ldots, P$$

$$e_{ht} \sim N(0, \sigma^2);\quad A_h \sim N(0, \sigma_H^2);$$

$$Cov\left(e_{ht}, e_{h't'}\right) = \begin{cases} 0 & h \neq h' \\ \sigma^2 \rho^{|t-t'|} & h = h' \end{cases};\quad 0 < \rho < 1$$

Equation 7-2

The first column of Table 7-8 lists all of the covariance parameters, and the second gives the estimate for each. The third column gives the p-value of a test of the null hypothesis that the covariance parameter equals zero. The p-value gives the probability (between 0 and 1) that the actual covariance parameter would be as far from zero as the estimate obtained if the null hypothesis were true. Because a small p-value indicates that the estimated value of the parameter is not significantly different from zero, the results provide strong evidence that the random effect of *house* is not needed in the EEM, but that the auto-correlation coefficient ρ and variance parameter σ^2 are needed. The EPA performed a similar test for the random effect of *site* instead of *house*, and in that case the estimated variance component for site $\hat{\sigma}_S^2$ was 0.27, and the p-value was 0.40. Consequently, the EPA did not include a random effect of either *house* or *site* in the EEMs.

Table 7-8. Covariance Parameter Estimates

Covariance Parameter	Estimate	P-value
$\hat{\rho}$	0.9157	<0.0001
$\hat{\sigma}_h^2$	13.7004	<0.0001
$\hat{\sigma}_s^2$	0.2726	0.4028

7.4.4 Constant Variance

Another decision to be made regarding the covariance function was whether to use the same covariance parameters, σ^2andρ, for all houses and conditions. If the variance, σ^2, of the deviations, e_{ht}, from the mean trend function increase with the mean, or if they exhibit non-constant variance for some other reason, then a transformation of the response variable, NH_3 emissions, would be the most commonly used remedy. Such a transformation, however, would have made both the exploratory plots in Section 7.3, and the regression coefficient estimates, $\hat{\beta}_p$, more difficult to interpret.

The EPA did not find evidence supporting an increase in the variance of emissions with increasing values of mean emissions. Table 7-9 shows the mean and standard deviation for six different ranges of values of NH_3 emissions for which the first five ranges has enough data to discern patterns. As the mean increases from the first range to the third, the standard deviation does increase, but an increase of 0.1 kg is of no practical significance. Because these are standard deviations of NH_3 emissions, Y_{ht}, as opposed to the deviations from the mean trend function, e_{ht}, the EPA decided that it was not necessary to account for a variance that increases with mean emissions.

Table 7-9. Sample Size, Mean and Standard Deviation for NH_3 Bins

Range of NH_3 Emissions in kg	N	Mean (kg)	Std Dev (kg)
0-6	484	2.7	1.6
6-12	231	8.8	1.7
12-18	172	15	1.8
18-24	209	21	1.8
24-30	104	26	1.6
30-36	11	32	1.9

The plots in Section 7.3.1 showed that variability in NH_3 emissions was greater for the Kentucky houses than for the houses at site CA1B. If these differences were statistically significant, then an EEM with four variance parameters, σ_h^2, h = 1. …, 4, might fit the NAEMS data better than the EEM of Equation 7-1. These differences in the variability of emissions for the houses, which might require different variance parameters, σ_h^2, h = 1. …, 4, should not be confused with differences in mean emissions that would require a single random effect parameter, σ_H^2, as discussed in Section 7.4.3. It might also be the case that the auto-correlation coefficient, ρ, is different from house to house, so that an EEM with four auto-correlation coefficients, ρ_h^2, h = 1, …, 4, would fit the NAEMS data better than Equation 7-1.

An EEM with different variance parameters and auto-correlation coefficients for each house, however, could not be used to predict emissions for sites not included in the NAEMS. A variance and auto-correlation coefficients estimated for CA1B H10, for example, could only be used to predict emissions from CA1B H10. Because the NAEMS sites were selected to represent emissions for the industry as a whole, and the EEM will be used to quantify all such emissions, the EPA used a single pooled variance parameter, σ^2, and a single auto-correlation coefficient, ρ, the estimates of which were based on all four houses in the NAEMS.

7.5 Selecting Final Mean Trend Variables

Table 7-10 gives the candidate mean trend variables for the I, IA and IAC EEMs. To choose final mean trend variables from these candidates, the EPA used an approach that included simultaneous evaluation of fit statistics calculated on the base dataset with fit statistics calculated on the cross-validation dataset. Section 7.5.1 explains the process using the I EEM as an example, and Sections 7.5.2 and 7.5.3 follow with results for the IA and IAC EEMs.

Table 7-10. Candidate Mean Trend Variables for the I, IA and IAC EEMs

EEM	Main Effects	Two-Way Interactions
I	*build, birds,* *avem*, $avem^2$, $avem^3$	*buildbirds,* *buildavem*, $buildavem^2$, $buildavem^3$, *birdsavem*, $birdsavem^2$, $birdsavem^3$
IA	Same as I EEM plus: *ta, ha, pa*	Same as I EEM plus: *buildta, buildha, buildpa,* *birdsta, birdsha, birdspa,* *avemta*, $avem^2ta$, $avem^3ta$, *avemha*, $avem^2ha$, $avem^3ha$, *avempa*, $avem^2pa$, $avem^3pa$, *taha, tapa, ha, pa*

Table 7-10. Candidate Mean Trend Variables for the I, IA and IAC EEMs

EEM	Main Effects	Two-Way Interactions
IAC	Same as IA EEM plus: tc, hc	Same as IA EEM plus: $buildtc$, $buildhc$, $birdstc$, $birdshc$, $avemtc$, $avem^2tc$, $avem^3tc$, $avemhc$, $avem^2hc$, $avem^3hc$, $tatc$, $tahc$, $hata$, $hahc$, $patc$, $pahc$, $tchc$

7.5.1 Inventory EEM

As discussed in Section 7.1.1, the fact that the EPA centered and scaled predictor variables prior to squaring, cubing or multiplying to create main effect and interaction variables necessitates that backward elimination of mean trend variables follows a particular protocol. Under this protocol, no lower-order term can be removed if a higher-order version of it or an interaction containing it remains in the EEM. Because the EPA treated the collection of terms $avem$, $avem^2$ and $avem^3$, as the main effect of *avem*, an interaction between *avem* and another mean trend variable, (e.g., *ta*) was considered to be the three new variables formed by multiplying each of the three *avem* terms by the other variable (e.g., $avemta$, $avem^2ta$, $avem^3ta$). This collection of terms could only be removed as a group if a test of the null hypothesis that all three regression coefficients equal zero could be rejected. If a mean trend variable has a regression coefficient equal to zero, then it is not needed in the EEM.

According to this protocol, the four null hypotheses to be tested in Run 0 of the I EEM were:

1. The term *buildbirds* has a regression coefficient equal to zero.
2. The three terms $avem^3$, $buildavem^3$ and $birdsavem^3$ have regression coefficients equal to zero.
3. The three terms $buildavem$, $buildavem^2$ and $buildavem^3$, representing the interaction between *build* and *avem*, have regression coefficients equal to zero.
4. The three terms $birdsavem$, $birdsavem^2$ and $birdsavem^3$, representing the interaction between *birds* and *avem*, have regression coefficients equal to zero.

The first column of Table 7-11 lists the mean trend variables involved in these four tests, and the second and third columns list the corresponding p-values for each test for the two runs in the backward-elimination process. The p-value is the probability that the estimated regression coefficients would have values as far from zero as the ones obtained merely by chance, even if the true values of the coefficients were zero. A small p-value is evidence that the regression coefficient is significantly different from zero, and therefore the corresponding mean trend term should remain in the EEM. To declare statistical significance, the EPA looked for p-values with an order of magnitude of $\alpha = 0.001$. This is a conservative value, much lower than the often-used $\alpha = 0.05$, to account for the fact that when many tests are performed, the actual significance level is much higher than the nominal significance level. Over the course of developing EEMs for all pollutants, many tests were performed.

Of the four tests, the EPA looked for the test that had the highest p-value. For the I EEM, Run 0, the test for *buildbirds* had a p-value 0.61, which indicates lack of significance. Therefore, the EPA eliminated that variable. Sometimes elimination of terms results in new mean trend variables being candidates for removal. For example, if all interactions with *birds* have been removed, then the main effect of *birds* becomes a candidate for removal. In the case of the I EEM, Run 1, following the first elimination, no additional terms became candidates for removal, so that tests 2 through 4 were the only relevant tests. Because the highest p-value of these, 0.0012, is of the order of magnitude of $\alpha = 0.001$, no further terms were eliminated.

Table 7-11. Hypothesis Tests for the I EEM, Runs 0 and 1

Mean Trend Variables	**Run 0[a]**	**Run 1**
	p-value	**p-value**
buildbirds	0.6109	-
avem^3 *buildavem*^{3} *birdsavem*^{3}	<0.0001	<0.0001
buildavem *buildavem*^{2} *buildavem*^{3}	0.0014	0.0012
birdsavem *birdsavem*^{2} *birdssavem*^{3}	0.0002	0.0002

[a] The EPA refers to the first run as Run 0 because none of the mean trend variables were eliminated at this step.

In addition to using p-values to determine what mean trend variables to keep in the EEM, with every EEM run (and thus with every elimination of a mean trend variable), the EPA examined the fit statistics listed in Table 7-12. The negative two log likelihood (-2LL) and the Bayesian information criterion (BIC), like the p-values, are calculated from the “likelihood function.”

The likelihood function of an EEM quantifies the probabilities that different sets of values of the parameters will reproduce NH_3 emissions in the NAEMS data. “Fitting the EEM” refers to finding the parameter estimates that maximize the likelihood function, which simply means finding those values of the parameters that result in accounting for the most variability in the data. Minimizing the function that is equal to -2LL is mathematically equivalent to maximizing the likelihood, and the required computations take less time. When comparing the values of -2LL for two different EEMs, the one with the lower -2LL better fits the data.

The BIC statistic is a function of -2LL, with a penalty added for the number of parameters in the EEM for situations in which fewer parameters are desirable. Lower values of the BIC statistic are also better; however there are instances where eliminating a term increases the -2LL while decreasing the BIC. The second column of Table 7-12 shows that elimination of *buildbirds* from the I EEM resulted in the -2LL increasing from 3,810 for Run 0 to 3,811 for Run 1, but the BIC decreased from 3,819 to 3,815. If both the -2LL and the BIC decrease, there is strong evidence that the resulting EEM is superior, but sometimes when the statistics disagree, other fit statistics must be considered, or it may be the case that the difference between two EEMs has little practical significance.

The remaining fit statistics quantify how well an EEM fits the cross-validation dataset. The EPA fit an EEM of the form given in Equation 7-1 to the base dataset. Using that EEM and the values of the predictor variables corresponding to the 217 values of NH_3 emissions in the cross-validation dataset, the EPA then produced point predictions, denoted with $\hat{Y}_{ht}$, and the lower and upper bounds of the 95 percent prediction intervals for the actual emissions, Y_{ht}. The fit statistics are different ways of assessing how well the 217 point predictions, $\hat{Y}_{ht}$, compare to the 217 actual values of NH_3 emissions, Y_{ht}, as well as how well the prediction intervals quantify uncertainty in the point predictions.

The row labeled “% in PI” gives the percent of cross-validation emissions, Y_{ht}, that fall inside the 95 percent prediction intervals for them. Values close to 95 indicate that the quantification of uncertainty is on target. For both runs of the I EEM, this value was 94 percent. The width of each prediction interval, in kg of NH_3 emissions, quantifies the uncertainty of the point prediction. For a given confidence level, narrower intervals are desirable. A 95 percent prediction interval that says the NH_3 emissions for a single date under a given set of conditions will fall between 0 and 36 kg is less useful than a prediction interval that says the emissions will fall between 15 and 30 kg. The width of the interval is a function of the natural variability in the deviations from the mean trend function as well as uncertainty regarding the point estimate due to using sample data. Including more relevant predictor variables, if possible, is one way to obtain narrower intervals, a fact that emphasizes the importance of the collinearity mitigation strategies of Section 7.3.1. The best of a set of candidate EEMs would be one that minimizes these widths, while at the same time ensuring that the statistic “% in PI” is close to 95. In other words, the best EEM minimizes uncertainty while at the same time quantifying it accurately. The average width of the prediction intervals produced by the I EEM, Run 0 was 14 kg, and this width did not change upon elimination of the predictor *buildbirds*.

Table 7-12. Backward Elimination Fit Statistics for the I EEM

Fit Statistic	I EEM Runs	
	0	**1**
-2LL	3,810	**3,811**
BIC	3,819	**3,815**
% in PI	94	-
Width (kg)	14	-
RMSE (kg)	3.8	-
R^2	0.81	-
Y_0 (kg)	-0.13✓	**-0.14✓**
Y_1	0.99✓	-
Eliminated	***buildbirds***	

Note: A dash indicates no change in the fit statistic from the previous EEM. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEMs for which a given statistic obtained its optimal value.

To obtain the next four fit statistics, RMSE, R^2, Υ_0, and Υ_1, the EPA performed an OLS regression of the cross-validation dataset of NH_3 emissions, Y_{ht}, on the predictions, $\hat{Y}_{ht}$, of the withheld cross-validation data. In other words, the EPA fit the OLS regression given by Equation 7-3, where the values of *h* and *t* correspond to those in the cross-validation dataset. In Equation 7-3, Υ_0 represents the intercept of the fit line and Υ_1 represents the slope.

$$Y_{ht} = \Upsilon_0 + \Upsilon_1 \hat{Y}_{ht} + e_{ht}$$

Equation 7-3

The root mean squared error (RMSE), in kg NH_3, is defined in Equation 7-4. The RMSE can be thought of as a measure of the average distance between the point predictions and the actual emissions. Smaller values indicate a better fit. For both runs of I EEM, the RMSE was 3.8 kg.

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{n}\left(Yht - \hat{Y}ht\right)^{(2)}}$$

Equation 7-4

The value of R^2 is interpreted as the proportion of variability in the cross-validation emissions, Y_{ht}, explained by the predictions of them, $\hat{Y}_{ht}$. As mentioned in Section 7.3.2, when R^2 is calculated from a regression of the base data emissions on mean trend variables, it is not a good indication of EEM fit because it is a mathematical certainty that R^2 will increase when mean trend variables are added. When R^2 is calculated based on a regression of the cross-validation dataset, Y_{ht}, on the predictions of the cross-validation dataset, $\hat{Y}_{ht}$, from a given EEM, it is not a mathematical certainty that adding mean trend variables to that EEM will increase R^2. Thus, values of R^2 closer to one indicate better fit of the EEM to the cross-validation data. The proportion of the variability in cross-validation emissions explained by both of the I EEMs is 0.81, or 81 percent.

If the EEM fit the cross-validation data perfectly, the intercept Υ_0 of the regression in Equation 7-3 would equal zero, and the slope Υ_1 would equal one. If the estimate of the intercept or slope, Υ_0 or Υ_1, is significantly different from 0 or 1, respectively, the EEM has systematic bias. A check ✓ beside either estimate indicates that the 95 percent confidence interval (CI) for it contains zero or one, and thus the estimate is not significantly different from zero or one. Both runs of I EEM were free from systematic bias.

Because elimination of *buildbirds* from the I EEM based on the regression coefficient p-value did not have a negative impact on the other fit statistics, the EPA chose the variables from Run 1 as the final mean trend variables for the I EEM.

7.5.2 Inventory and Ambient EEM

The hypotheses to be tested in Run 0 of IA EEM are listed in groups by type:

1. Any of the 7 individual variables that represent an interaction has a regression coefficient equal to zero. These variables are *buildbirds, buildta, buildha, buildpa, birdsta*, *birdsha* and *birdspa*.
2. All 5 variables containing $avem^3$ have regression coefficients equal to zero. These variables are $build\ avem^3$, $birds\ avem^3$, $avem^3\ ta$, $avem^3 ha$ and $avem^3 pa$.
3. All of the three regression coefficients corresponding to any of the five sets of triplets formed as the product of the terms $avem$, $avem^2$, $avem^3$ and another variable are equal to zero.

Table 7-13 gives the progression of fit statistics for each backward-elimination step, listing in the bottom row the variable eliminated.

Table 7-13. Backward Elimination Fit Statistics for the IA EEM

Fit Statistic	IA EEM Runs										
	0	1	2	3	4	5	6	7	8	9	**10**
-2LL	3,687	3,684	3,681	3,679	3,680	3,678	3,677	-	3,675	3,676	**-**
BIC	3,696	3,692	3,689	3,688	3,689	3,687	3,685	3,686	3,683	3,685	**3,684**
% in PI	97	-	-	-	96	-	-	-	97	-	**-**
Width (kg)	13	-	-	-	-	-	-	-	-	-	**-**
RMSE (kg)	3.2	-	-	-	-	-	3.3	-	-	-	**-**
R^2	0.86	-	-	-	-	-	-	-	-	-	**0.85**
γ_0 (kg)	-0.24✓	-0.25✓	-	-	-0.26✓	-0.27✓	-0.26✓	-0.24✓	-0.23✓	-0.24✓	**-0.23✓**
γ_1	0.99✓	-	-	-	-	-	-	-	-	-	**-**
Eliminated	-	*hapa*	*birdsha*	*buildha*	*buildbirds*	*birdspa*	*birdsta*	*buildta*	*taha*	*buildpa*	***tapa***

Note: A dash indicates no change in the fit statistic from the previous EEM. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEMs for which a given statistic obtained its optimal value.

For all runs of the IA EEM, both -2LL and BIC, which evaluate fit to the base data, were considerably better than for either run of the I EEM. As each variable was eliminated, the values of -2LL and BIC decreased, indicating improved fit, up through Run 8. When the final two variables were eliminated, -2LL increased by one and then held that value, while BIC increased by two, then decreased by one. The optimal value for both of these statistics occurred at Run 8.

At 97 percent, the "% in PI" for the IA EEM Runs 0-3 and 8-10 was farther from the optimal value of 95 than for either run of the I EEM, but for Runs 4 through 7, it was equally close, so that these four runs achieved the optimal value of that statistic for the IA EEM. For all runs of the IA EEM, the PI width was 13 kg, one kg narrower (thus better) than for the I EEM.

The RMSE for the IA EEM Runs 0 through 5 was 3.2 kg, increasing to 3.3 kg for Runs 6 through 10. Considering that these value represent averages over 217 observations, both represent a considerable improvement over the 3.8 kg for the I EEM. Runs 0 through 9 of the IA EEM explained 86 percent of the variability in the cross-validation data, while the final Run 10 explained 85 percent. Both numbers represent a considerable improvement over the value of 81 percent for the I EEM.

For all runs of the IA EEM, the intercepts Υ_0 were approximately one tenth of a kg farther from 0 than were those for the I EEM, although no intercept for any run of either EEM was significantly different from 0. For all runs of both EEMs, the slope Υ_1 were 0.99, and for all, the slope was not significantly different from 1.

The EPA chose the variables from Run 10 as the final mean trend function for the IA EEM. The EPA chose to use the statistical significance of the regression coefficients, which was the basis of variable elimination at each step, as the primary criterion for variable selection, but used the other fit statistics as back-up in case any lingering collinearity caused variance inflation, and thus p-value inflation, masking the significance of some regression coefficients. Although the -2LL and BIC were slightly less optimal for Run 10 than for Run 8, an increase of 1 in the value of -2LL with a removal of a single parameter did not represent a statistically significant worsening of fit according to a likelihood ratio test based on the χ^2 (chi-squared) distribution with one degree of freedom.

The increase from 96 to 97 percent coverage of the prediction intervals was not sufficiently extreme to warrant over-riding the p-value-based decision, nor was the increase by 0.1 kg in RMSE. A decrease in the variability in the cross-validation data explained from 86 percent to 85 percent was not of concern because any set of cross-validation data, like the base data, might have its own anomalies, so that over-riding p-values calculated from

994 observations in favor of statistics based on 217 would require a more dramatic difference. Finally, for the PI width, intercept Υ_0, and slope Υ_1, Run 10 had the optimal value.

7.5.3 Inventory, Ambient and Confinement EEM

Table 7-14 and Table 7-15 give the backward-elimination steps for the IAC EEM. The EPA chose variables from the p-value-based optimal Run 23 as the final mean trend function. Although Run 23 had the optimal value of only one fit statistic, the differences between the optimal values and those for Run 23 were not a concern. The EPA performed an additional formal hypothesis test to compare Run 23 with Run 16, which was the most recent run with the optimal value of -2LL. The difference of 18 between 3,504 and 3,522 is the value of a χ^2 (chi-squared) statistic for a likelihood ratio test. The null hypothesis is that the 7 eliminated variables had regression coefficients equal to zero, and thus were not needed in the model. The corresponding p-value was 0.01, which was not significant at the $\alpha = 0.001$ significance level; therefore, the EPA could not reject the hypothesis that those variables were not needed.

7.5.4 EEM Validation and Modification of Previous Versions

An important part of any statistical analysis is validation of results using a variety of techniques. Examination of the fit statistics described in Section 7.5.1 was not only used to validate backward-elimination decisions based on p-values, but also to assess other decisions. The EPA changed three major decisions as a result of validation analyses on previous versions of the EEMs. The first of these changes in decisions was the means of selecting the cross-validation dataset, described in Section 7.1.2. The other two are explained below.

In an earlier version of the EEM, the EPA did not include main effects of *birds** and *avem**, but instead used total live bird mass, calculated as *mass** = (*birds**)(*avem**). The underlying assumption was that the total live bird mass was the most important factor determining the amount of manure produced. Because a graph of NH_3 emissions versus *mass** showed curvature similar to that in Figure 7-5, the EPA used a cubic polynomial function of *mass* (i.e., the centered and scaled version of *mass**). When the statistics Υ_0 and Υ_1 were significantly different from 0 and 1, the EPA considered the variables *birds** and *avem** separately, producing the plots in Figure 7-5 and Figure 7-11. The EPA realized that cubing *mass* was equivalent to cubing both *birds* and *avem*, but it was only appropriate to cube *avem* because Figure 7-11 gave no indication that a cubic function of *birds** would be appropriate. The result was use of a linear function as the main effect of *birds**, a cubic polynomial as the main effect of *avem**, and the three terms *birdsavem*, $birdsavem^2$ and $birdsavem^3$ for the interaction.

Table 7-14. Backward Elimination Fit Statistics (Runs 0 – 11) for IAC EEM

Fit Statistic	**IAC EEM Runs**											
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
-2LL	3,526	-	3,525	3,522	3,520	3,518	3,516	3,514	-	3,511	3,510	3,508
BIC	3,524	3,535	3,533	3,531	3,528	3,526	3,524	3,522	-	3,520	3,519	3,516
% in PI	96	-	-	-	-	-	-	-	-	-	-	-
Width (kg)	13	-	-	-	-	-	-	-	-	-	-	-
RMSE (kg)	3.4	-	-	-	-	-	-	-	-	-	-	-
R^2	0.85	-	-	-	-	-	-	-	-	-	0.84	-
Υ_0 (kg)	0.06✓	-	-	0.07✓	-	-	-	-	0.06✓	0.05✓	0.04✓	0.05✓
Υ_1	0.97✓	-	-	-	-	-	-	-	-	-	-	-
Eliminated	-	*buildta*	*tapa*	*taha*	*tatc*	*pahc*	*birdspa*	*taha*	*buildtc*	*hatc*	*paavem* paavem^2 paavem^3	*patc*

Note: A dash indicates no change in the fit statistic from the previous run. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEM runs for which a given statistic obtained its optimal value.

Table 7-15. Backward Elimination Fit Statistics (Runs 12 – 23) for IAC EEM

Fit Statistic	IAC EEM Runs											
	12	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
-2LL	-	3,506	3,504	3,505	3,504	3,509	3,511	3,513	3,516	3,519	3,520	**3,522**
BIC	-	3,515	3,512	3,514	3,512	3,517	3,520	3,522	3,525	3,528	3,529	**3,531**
% in PI	-	-	-	-	-	97	-	-	-	-	-	**-**
Width (kg)	-	-	-	-	-	-	-	-	-	-	-	**-**
RMSE (kg)	-	-	-	-	-	3.5	-	-	-	-	-	**-**
R^2	-	0.85	-	-	0.84	-	-	-	-	0.83	0.84	**-**
Υ_0 (kg)	0.02✓	-0.004✓	-0.009✓	-0.02✓	-0.03✓	-0.11✓	-0.09✓	-	-0.07✓	-0.05✓	-0.03✓	**-0.04✓**
Υ_1	-	-	-	-	-	0.98✓	-	-	-	0.97✓	-	**-**
Eliminated	*buildpa*	*hapa*	*pa*	*buildha*	*buildhc*	*buildbirds*	*birdsha*	*birdstc*	*birdsta*	*birdshc*	*hahc*	***tchc***

Note: A dash indicates no change in the fit statistic from the previous run. A check mark (✓) indicates that the 95 percent confidence interval (CI) for the intercept (slope) contains zero (one) and the estimate is not significantly different from zero (one). Highlighting emphasizes the EEM runs for which a given statistic obtained its optimal value.

In another early version of the EEM considered as an alternative to the one in the previous paragraph, instead of using a cubic polynomial as the functional form through which *mass** would enter the model, the EPA used a function known as the Gompertz growth curve to capture the curvature in NH_3 emissions as a function of *mass**. The difference between the Gompertz curve and the cubic polynomial is that the Gompertz curve flattened out as a function of *mass**, while the cubic polynomial captured the decrease in NH_3 emissions as a function of *mass** at the end of the grow-out period. Curvature in plots of cross-validation residuals vs. *mass** from the Gompertz EEM led the EPA to further investigate the downturn in emissions at the end of the grow-out period. This investigation, and reaching the conclusions described in the previous paragraph, happened at the same time so that the EPA never considered a Gompertz growth curve as the functional form through which *avem** would enter the EEM. Investigation of the downturn in emissions at the end of the grow-out period led to producing the disaggregated plots in Figure 7-8, Figure 7-9 and Figure 7-10. This investigation resulted in use of the cubic polynomial as the functional form through which *avem** would enter the EEM.

7.5.5 Summary of Final Results for the I, IA and IAC EEMs

The fit statistics in Table 7-12, Table 7-13, Table 7-14 and Table 7-15 show that adding ambient meteorological predictor variables *ta*, *ha* and *pa* to inventory-based predictors *build*, *birds* and *avem* considerably improved the ability of the EEM to predict NH_3 emissions in both the base and cross-validation datasets. Adding confinement-based predictor variables *tc* and *hc* improved the ability to predict NH_3 emissions in the base dataset, and allowed all terms involving *pa*, some of which had been significant in the IA EEM, to be eliminated. The IAC EEM had less optimal values of cross-validation statistics RMSE and R^2 than did IA EEM, but only by 0.2 kg and 1 percent, respectively. Because the mean trend variables for the final IAC EEM were not a superset of those in the IA EEM, a likelihood ratio test comparing the differences in -2LL was not appropriate.

After selecting final I, IA and IAC EEMs, the EPA refitted each EEM to the full dataset to obtain the final regression coefficient estimates for use in estimating emissions. After selecting the final mean trend variables, the EPA refit the EEM using the full dataset. Re-fitting the final EEM to the full dataset allowed for more accurate estimation of the variance parameter, which quantifies both variability and uncertainty, manifested as prediction interval widths.

Table 7-16 lists the final mean trend variables and the estimated regression coefficients for each EEM, and Table 7-17 lists the final covariance parameter estimates for each EEM.

Table 7-16. Regression Coefficient Estimates for NH_3 EEMS

p	x_p	$\hat{\beta}_p$		
		I EEM	**IA EEM**	**IAC EEM**
0	Intercept	10.4845	10.3695	9.9947
1	*build*	2.3812	2.2340	2.5626
2	*birds*	3.0668	3.3263	3.0839
3	*avem*	14.9106	14.4635	16.5926
4	$avem^2$	1.4911	1.1737	2.6695
5	$avem^3$	-3.4083	-3.4425	-4.0508
6	*buildavem*	-4.7227	-4.4761	-5.0093
7	$buildavem^2$	-1.0359	-0.7518	-1.1414
8	$buildavem^3$	1.3166	1.3052	1.4978
9	*birdsavem*	-0.8076	-0.09837	-1.0318
10	$birdsavem^2$	-1.7600	-1.5965	-2.0927
11	$birdsavem^3$	0.8944	0.6744	0.7855
12	*ta*	-	1.6982	1.1261
13	*ha*	-	0.3647	0.3841
14	*pa*	-	0.06279	-
15	*avemta*	-	1.2416	-0.5759
16	$avem^2ta$	-	0.1117	-1.0748
17	$avem^3ta$	-	0.02461	0.06863
18	*avemha*	-	0.3230	-0.1160
19	$avem^2ha$	-	0.1217	-0.3436
20	$avem^3ha$	-	0.06174	-0.06470
21	*avempa*	-	0.5491	-
22	$avem^2pa$	-	0.4662	-
23	$avem^3pa$	-	-0.01466	-
24	*tc*	-	-	1.9043
25	*hc*	-	-	0.02233
26	*avemtc*	-	-	2.7732
27	$avem^2tc$	-	-	0.5435
28	$avem^3tc$	-	-	-0.4688
29	*avemhc*	-	-	0.7263

Table 7-16. Regression Coefficient Estimates for NH_3 EEMS

p	x_p	$\hat{\beta}_p$		
		I EEM	IA EEM	IAC EEM
30	$avem^2hc$	-	-	0.5292
31	$avem^3hc$	-	-	0.06077

Note: Each main effect variable was centered and scaled prior to creating higher-order terms and interactions.

Table 7-17. Covariance Parameter Estimates for Final NH_3 EEMs

Covariance Parameter	Covariance Parameter Estimate		
	I EEM	IA EEM	IAC EEM
$\hat{\rho}$	0.9232	0.9306	0.9414
$\hat{\sigma}^2$	14.6086	13.5434	14.0816

7.6 Producing Point and Interval Predictions

This section uses an example based on the I EEM to show how point (i.e., mean) and interval predictions of NH_3 emissions are obtained for a single confinement house on two separate days, using the values of the predictor variables available for each day. These two example days are also used to show how to obtain a point and interval prediction for the sum of two days. For the point prediction of the sum of the two days, the point predictions for each day are simply added. The prediction interval for the sum of the two days is calculated using the variances of each day, as will be demonstrated below. The method used to obtain point and interval predictions of the sum of emissions for an entire year or for multiple houses on the same farm are simply expansions of that used to get the sum of two days.

As an example, suppose that on day 15 of a given flock, the house contains 24,147 birds with average bird mass 0.41 kg, and suppose that on day 46 of the same flock, the house contains 23,795 birds with average bird mass 2.4 kg. Suppose this is the third flock introduced into the house since the last full litter cleanout. Table 7-18 summarizes the values of the predictor variables resulting from this information.

Table 7-18. Values of Predictor Variables for the Example Calculation

Day	*buildup*	*birds**	*avem**
15	3	24.147	0.41
46	3	23.795	2.4

Note: The unit of measure for *birds** is thousands of birds and the unit of measure for *avem** is kg. The asterisk (*) denotes that these are the centered and scaled values of the original predictor variables.

The values of the mean trend variables can now be obtained from the values of the predictor variables as follows.

- *build*: The mean trend variable *build* was chosen to be the functional form that represents the discrete predictor variable *buildup*. Whenever there is any buildup of litter in the house, the value of *build* = 1. Otherwise, the value of *build* = 0. For both days 15 and 46, *build* = 1.

- *birds*: The house contained 24,147 birds on day 15 and 23,795 on day 46, but because the EPA used thousands of birds as the unit of measure, *birds** = 24.147 and 23.795, respectively. To get the value of *birds*, this value must be centered and scaled by subtracting from it the “centering value” for *birds* and dividing by the “scaling value” for *birds*, both of which are in presented in Table 7-5. The results are 0.859 and 0.718, for days 15 and 46, respectively.

- *avem*: The values of *avem** must also be centered and scaled using the values in Table 7-5. The centered and scaled values for days 15 and 46 are -0.793 and 1.49, respectively.

- $avem^2$: These centered and scaled values are the squares of the values of *avem* and are equal to 0.629 and 2.23, for days 15 and 46, respectively.

- $avem^3$, etc: The centered and scaled values are the cubic values of *avem* and are equal to -0.499 and 3.34, for days 15 and 46, respectively. The values above for *build, birds* and *avem* can be used to obtain the remaining mean trend variables, the values of which are listed in Table 7-19.

Table 7-19. Values of Mean Trend Variables for Example Days 15 and 46

p	**Name of x_p**	**Value of x_p**		$\hat{\beta}_p$
		Day 15	**Day 46**	

Table 7-19. Values of Mean Trend Variables for Example Days 15 and 46

p	**Name of x_p**	**Value of x_p**		$\hat{\beta}$
0	Intercept	Not applicable	Not applicable	10.4845
1	*build*	1	1	2.3812
2	*birds*	0.859	0.718	3.0668
3	*avem*	-0.793	1.49	14.9106
4	*avem*^{2}	0.629	2.23	1.4911
5	*avem*^{3}	-0.499	3.31	-3.4083
6	*buildavem*	-0.793	1.49	-4.7227
7	*buildavem*^{2}	0.629	2.23	-1.0359
8	*buildavem*^{3}	-0.499	3.34	1.3166
9	*birdsavem*	-0.681	1.07	-0.8076
10	*birdsavem*^{2}	0.540	1.60	-1.7600
11	*birdsavem*^{3}	-0.428	2.40	0.8944

To obtain the point estimate for each day, the values of the mean trend variables (x_p) and the estimated regression coefficients from Table 7-16 are inserted into Equation 7-5.

$$\hat{Y} = \widehat{\beta_0} + \widehat{\beta_1}\, x_1 + \cdots + \widehat{\beta_{11}} x_{11} + \hat{e}$$

Equation 7-5

For the point prediction (i.e., the mean), the value of $\hat{e}$ is zero. Thus, the point estimates for NH_3 emissions for days 15 and 46 are, respectively, 7.97 kg and 22.8 kg. The point estimate for the sum of the two days is simply the sum of the two point estimates (7.97 kg + 22.8 kg = 30.77 kg).

The uncertainty in the predicted emissions values, $\hat{Y}$, can be expressed as the 95 percent prediction interval, which is calculated as $\hat{Y} \pm 1.96\, \widehat{se}(\hat{Y})$. The symbol $\widehat{se}(\hat{Y})$ represents the "estimated prediction standard error," which is the square root of the "estimated prediction error variance," denoted as $\hat{V}ar\,(\hat{Y})$. The estimated prediction error variance has two components, as shown in Equation 7-6 and Figure 7-16.

$$\hat{V}ar\big(\hat{Y}\big) = \hat{\sigma}^2 + \boldsymbol{x}^T\, \widehat{\Omega}\boldsymbol{x}$$

Equation 7-6

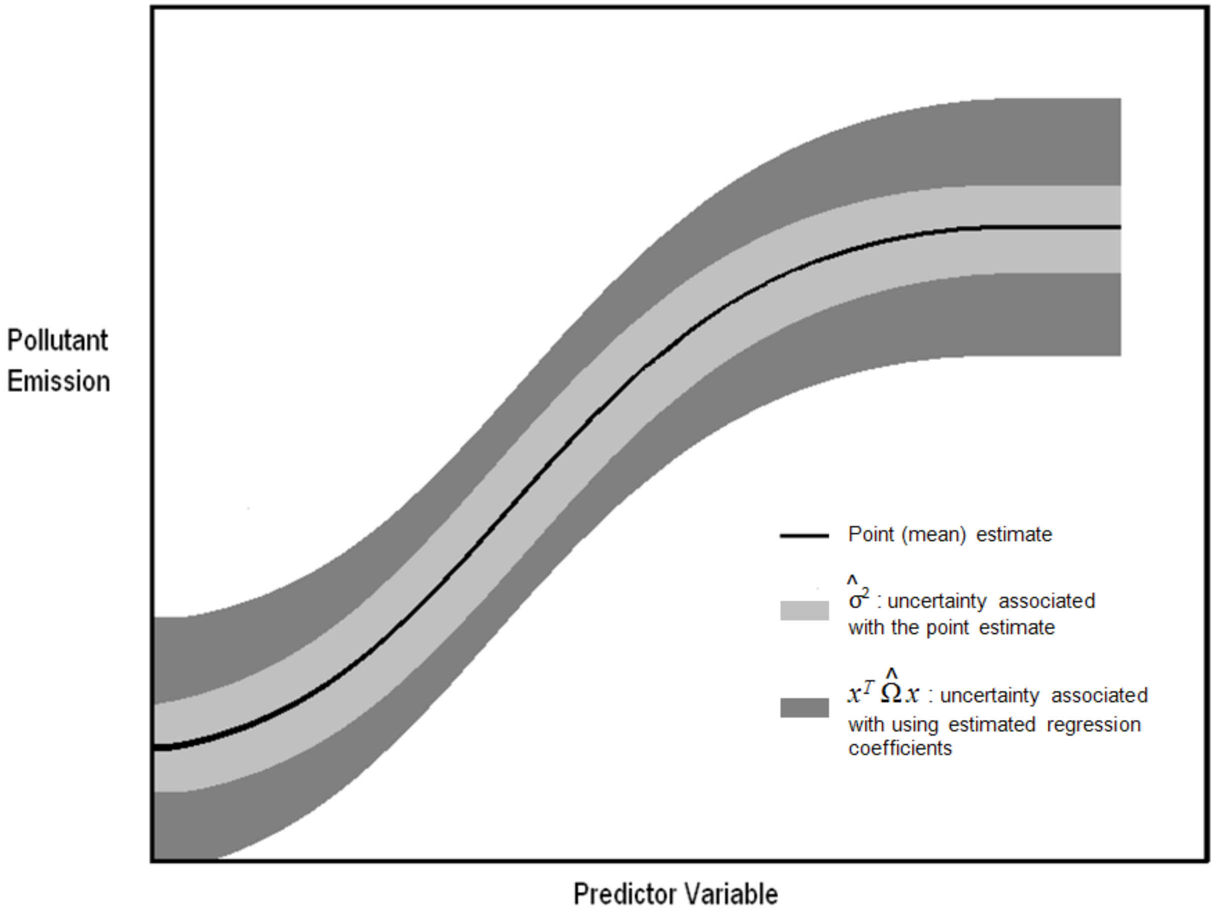


Figure 7-16. Illustration of the Relationship Between the Point Estimate and the Prediction Interval

The first component $\hat{\sigma}^2$, quantifies the uncertainty attributable to the deviation of emissions from the mean trend function. It is the estimated variance $\hat{\sigma}^2$, of the e_{ht}. The $\hat{\sigma}^2$ values for each EEM are presented in Table 7-17. For the I EEM, $\hat{\sigma}^2 = 14.6$.

The second component is the product of three terms, $\boldsymbol{x}^T\hat{\Omega}\boldsymbol{x}$. This component quantifies the uncertainty attributable to using estimated regression coefficients $\hat{\beta}_p$ in place of the true values β_p. The symbol $\boldsymbol{x}$ represents the 12×1 vector (column matrix) that contains the intercept (using 1 as a place holder) and the values of the 11 mean trend variables. The bold print indicates that $\boldsymbol{x}$ is a vector as opposed to a scalar (a single number). For the example of day 46, $\boldsymbol{x}^T$ = (1.0, 1.0, 0.72, 1.49, 2.23, 3.34, 1.07 1.60, 2.40). The symbol $\boldsymbol{x}^T$ represents the 1×12 transpose of this matrix. The matrix $\hat{\Omega}$ is the 12×12 covariance matrix for the intercept and regression coefficients, which are random variables. The covariance matrix accounts for the covariance of each mean trend term coefficient with the coefficient of every other mean trend term, and is standard output by software that produces regression coefficient estimates. Unlike the value of the first component, $\hat{\sigma}^2$ which is constant for a given EEM, the value of the second component varies for combinations of the predictor variables. The uncertainty is related to the number and range of data values available for developing the coefficient for a predictor variable. For example, if the number of NAEMS observations for a house with 20,000 birds is large and the range of emissions values was very narrow, the prediction interval at 20,000 birds will be relatively small. The prediction interval, therefore, will vary for different bird populations and for other mean trend terms (such as temperature if the IA EEM is used). Because the product $\boldsymbol{x}^T \widehat{\Omega}\, \boldsymbol{x}$ includes values of the predictor variables, there also will be differing levels of certainty for different sets of inputs. For example, if the user enters as an input to the EEM an extreme value for *birds* relative to the mean value of *birds* in the NAEMS data that were used to develop the EEM, this component of the estimated prediction error variance would be relatively large. Using matrix multiplication, the product $\boldsymbol{x}^T\Omega\boldsymbol{x}$ for days 15 and 46 is respectively, 0.517 and 0.848.

The estimated prediction error variance for the two days can now be calculated as $\hat{\sigma}^2 + \boldsymbol{x}^T\widehat{\Omega}\, \boldsymbol{x}$ = 14.6 + 0.517 = 15.1 kg^2 for day 15, and 14.6 + 0.848 = 15.4 kg^2 for day 46, where $\hat{\sigma}^2$ is from Table 7-16. The prediction standard errors are calculated as the square root of these values, such that $\widehat{se}(\hat{Y})$ = 3.89 kg and 3.93 kg, respectively. The 95 percent prediction interval for day 15 is calculated as 7.97 ± 1.96(3.89). Thus, the 95 percent confidence interval for NH_3 emissions for day 15 falls between 0.34 kg and 15.6 kg. Similarly, for day 46, the formula is 22.8 ± 1.96(3.93) and results in a 95 percent confidence interval of between 15.1 kg and 30.5 kg.

The point estimate for the sum of the emissions on days 15 and 46 is obtained by adding the two point estimates, which yields 30.77 kg. To obtain the lower (or upper) bound of the 95 percent prediction interval for the sum of daily emissions, however, it is not appropriate to add the two lower (or upper) bounds. Instead, the estimated prediction error variance of the sum of the two days is calculated as the sum of the prediction error variances for the two days, plus the estimated covariance between the two days. The covariance is calculated from the second line of Equation 7-1 using $\hat{\sigma}^2$and $\hat{\rho}$: $Cov(\hat{Y}_{15}, \hat{Y}_{46}) = \hat{\sigma}^2\, \hat{\rho}^{46-15}$ =14.6(0.9232)^{31} = 1.23.

Therefore, for the example, the estimated prediction error variance for the sum of day 15 and day 46 is 15.1 + 15.4 + 1.23 = 31.73 kg^2. The square root of this value (5.63 kg) is the prediction standard error for the sum of days 15 and 46. The 95 percent prediction interval is calculated as 30.77 ± 1.96(5.63). Thus, the 95 percent confidence interval for the sum of NH_3 emissions on days 15 and 46 has a lower bound of 19.7 kg and an upper bound of 41.8 kg.

8.0 RESULTS OF GROW-OUT PERIOD EEM DEVELOPMENT

This section describes the development of the grow-out period EEMs for H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs. The EEMs for each pollutant were developed using the methodology discussed in Section 7. Sections 8.1 through 8.5 present the development of the EEMs for H_2S, PM_{10}, $PM_{2.5}$, TSP and VOCs, respectively. These sections summarize the decisions regarding the functional forms of the predictor variables, interaction terms included as candidate mean trend variables, selection of final mean trend variables, and the final form of the EEMs. For those components of the EEMs not discussed in detail in this section (e.g., the covariance function), the decision-making process and final decisions regarding the functional form were the same as those presented in Section 7.

8.1 EEMs for H_2S

8.1.1 Selecting Datasets

Table 8-1 shows the H_2S emissions observations available for each monitoring site after exclusion of the negative emissions and the records where the bird inventory remained constant over consecutive days late in the grow-out period (see Section 7.1). For example, the total number of grow-out period days for site CA1B H10 is 642 and the number of days for which an H_2S emissions value is available is 499. Therefore, the H_2S data availability is approximately 78 percent.

Of the 1,463 H_2S emissions values available, 68 lacked at least one of the inventory, ambient or confinement predictor variables needed for EEM development. After these missing data records were removed, the full dataset available for developing the H_2S EEMs consisted of 1,395 observations.

As one means of evaluating EEM performance, the EPA used fit statistics based on a cross-validation dataset (see Section 7.1.2). The EPA ultimately randomly withheld 266 (approximately 19 percent) of the 1,395 observations in the full dataset to serve as the cross-validation dataset.

Table 8-1. Data Completeness for H_2S EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days H_2S data available	499	501	260	203	1,463
	Percent complete	78%	77%	90%	76%	79%
Winter	Number of grow-out days	150	153	87	74	464
	Days H_2S data available	141	146	80	72	439
	Percent complete	94%	95%	92%	97%	95%
Spring	Number of grow-out days	157	158	83	55	453
	Days H_2S data available	134	134	82	19	369
	Percent complete	85%	85%	99%	35%	81%
Summer	Number of grow-out days	156	157	55	74	442
	Days H_2S data available	148	146	35	53	382
	Percent complete	95%	93%	64%	72%	86%
Fall	Number of grow-out days	179	179	63	64	485
	Days H_2S data available	76	75	63	59	273
	Percent complete	42%	42%	100%	92%	56%

8.1.2 Choosing the Probability Distribution

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed H_2S daily emissions to determine whether using the normal distribution was appropriate (see Section 7.2). The histogram in Figure 8-1 shows that many of the H_2S observations correspond to lower emissions values, with a single peak at emissions values less than 15 g. Also, the figure shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-2, for example, shows histograms of H_2S emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2 and 3 are skew right while those for bins 4, 5 and 6 are symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern was by no means a consistent pattern. There are not enough observations under any specific set of conditions (e.g., bird mass and range of humidity) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

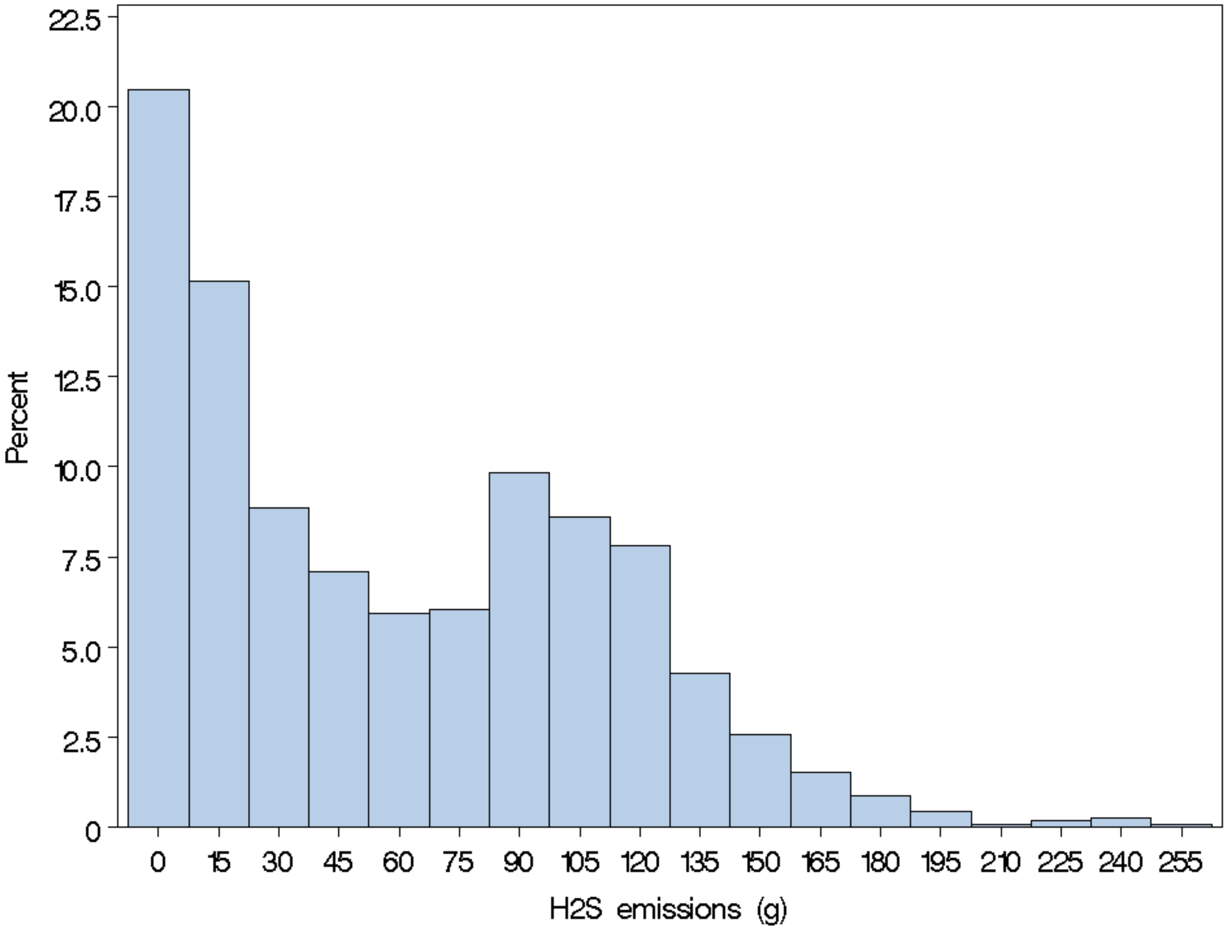


Figure 8-1. Histogram of H_2S Emissions in the Base Dataset

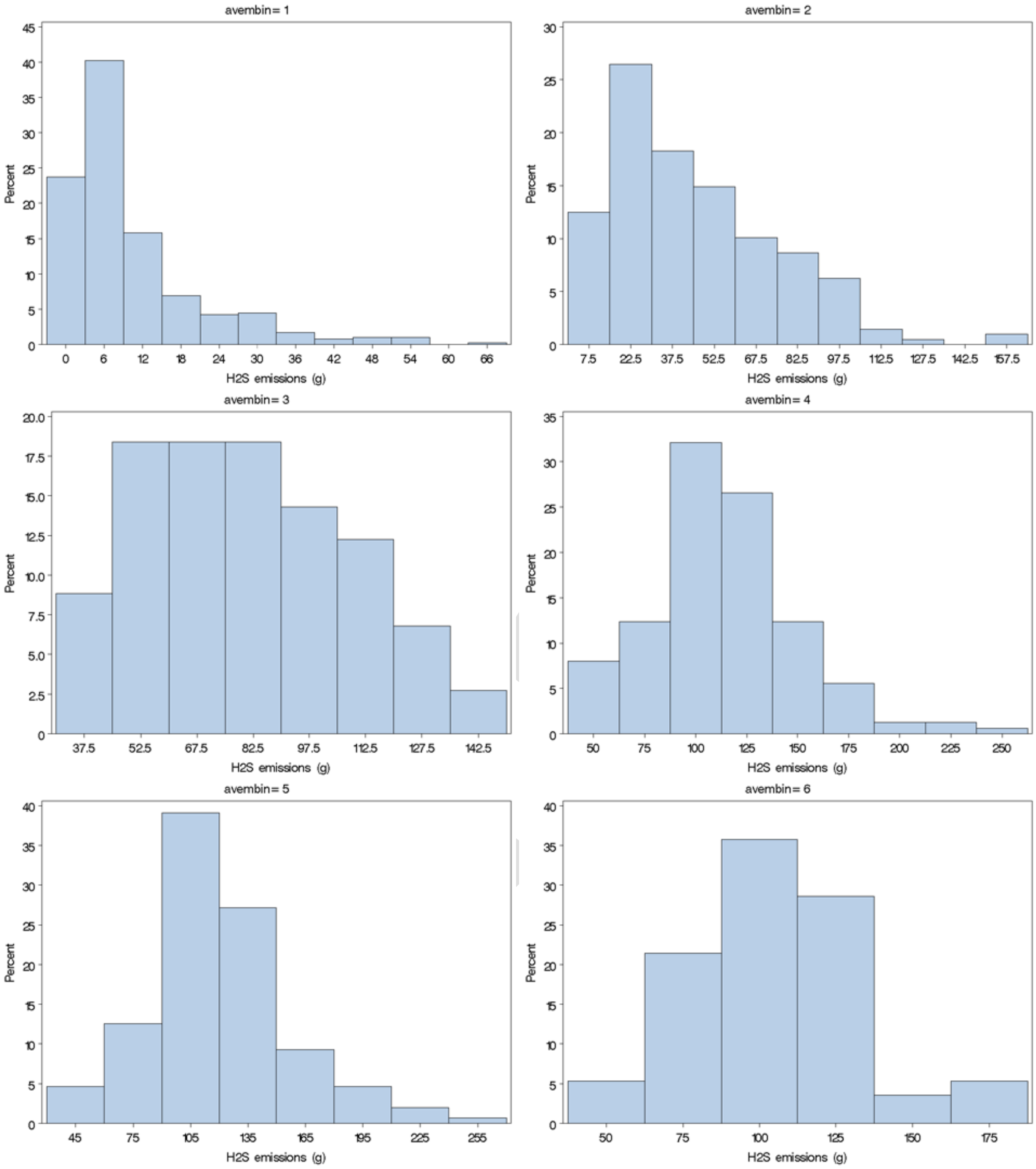


Figure 8-2. Histograms of H_2S Emissions by *avem Bins**

8.1.3 Developing Candidate Mean Trend Variables for H_2S

8.1.3.1 *Choosing Predictor Variable Functional Forms*

The plot of H_2S emissions for all houses display a flattened “S” shape over the grow-out period. The plot of H_2S emissions versus average mass for all flocks is shown in Figure 8-3. To provide a reference for determining the functional form, the figure also depicts overlays of the linear, quadratic, and cubic regressions. The “S” trend is not as obvious in the aggregated plot due to high variability, especially for higher average bird mass values. However, when the plots are disaggregated by house (Figure 8-4), the trend becomes more apparent, especially in the CA1B houses. It appears that the increased variance in KY1B-1 H5 seen in Figure 8-4 masks the curvature when all house and flocks are plotted together. The trend is further evident in all houses when the H_2S emissions are plotted versus average mass by flock (see Appendix F). Due to this curvature, the EPA determined that a cubic form of average mass was appropriate to characterize H_2S emissions.

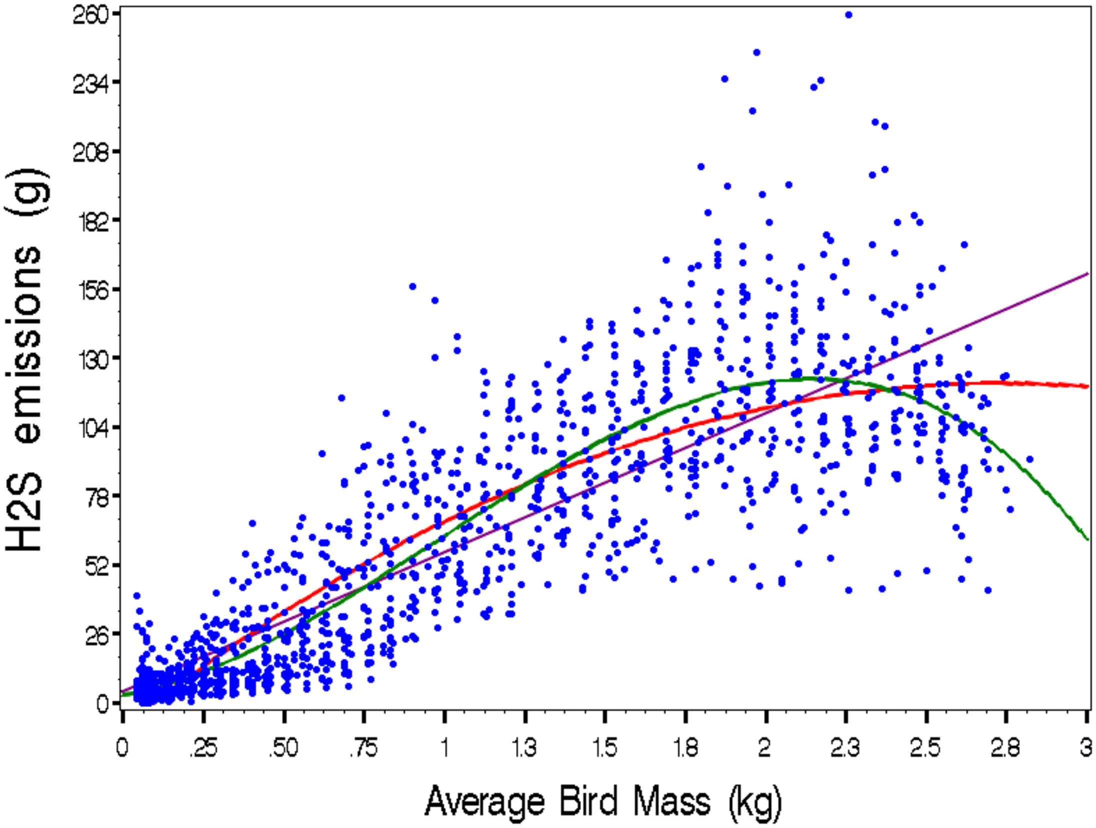


Figure 8-3. H_2S Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

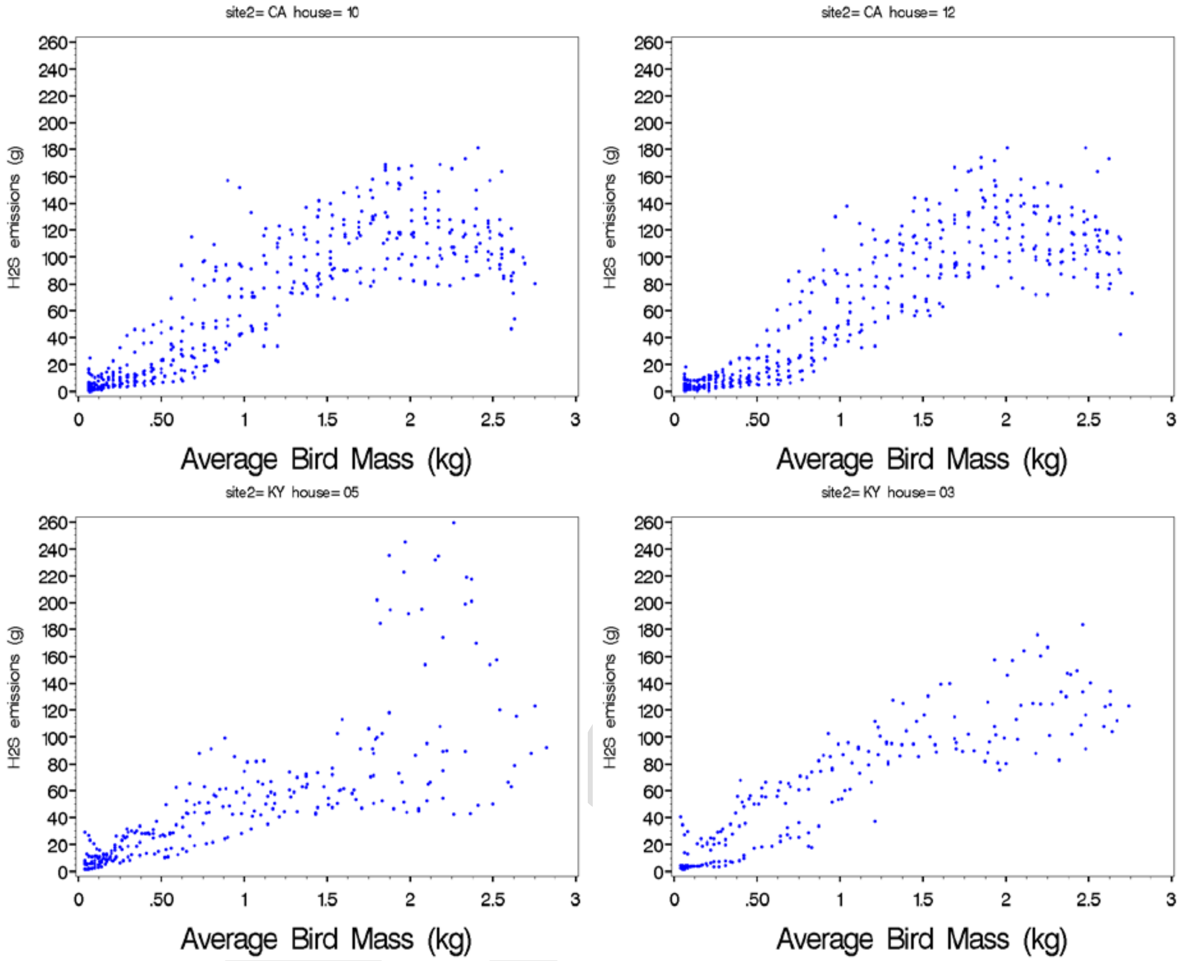


Figure 8-4. H_2S Emissions vs. Average Bird Mass, by House

With regard to the effect of accumulated litter (*buildup*) on H_2S emissions (see Section 7.3.1), the EPA did not discern a relationship between H_2S emissions and the degree of litter accumulation, based on a visual review of the data. The scatter plot of H_2S emissions versus average mass in Figure 8-5 shows very low variability in emissions during periods of low bird mass. The plot also shows that there is very little difference between the levels of litter condition, as the flocks of each *buildup* level are evenly distributed through the scatter plot. The EPA also created box plots (Figure 8-6) of the *buildup* variable to determine if the effect of accumulated litter should be included in the candidate mean trend variables for EEM development. The box plots, which depict the emissions for new bedding (*build* = 0) and any degree of accumulated litter (*build* = 1), show little difference in H_2S emissions when flocks were raised on new bedding or on built-up litter.

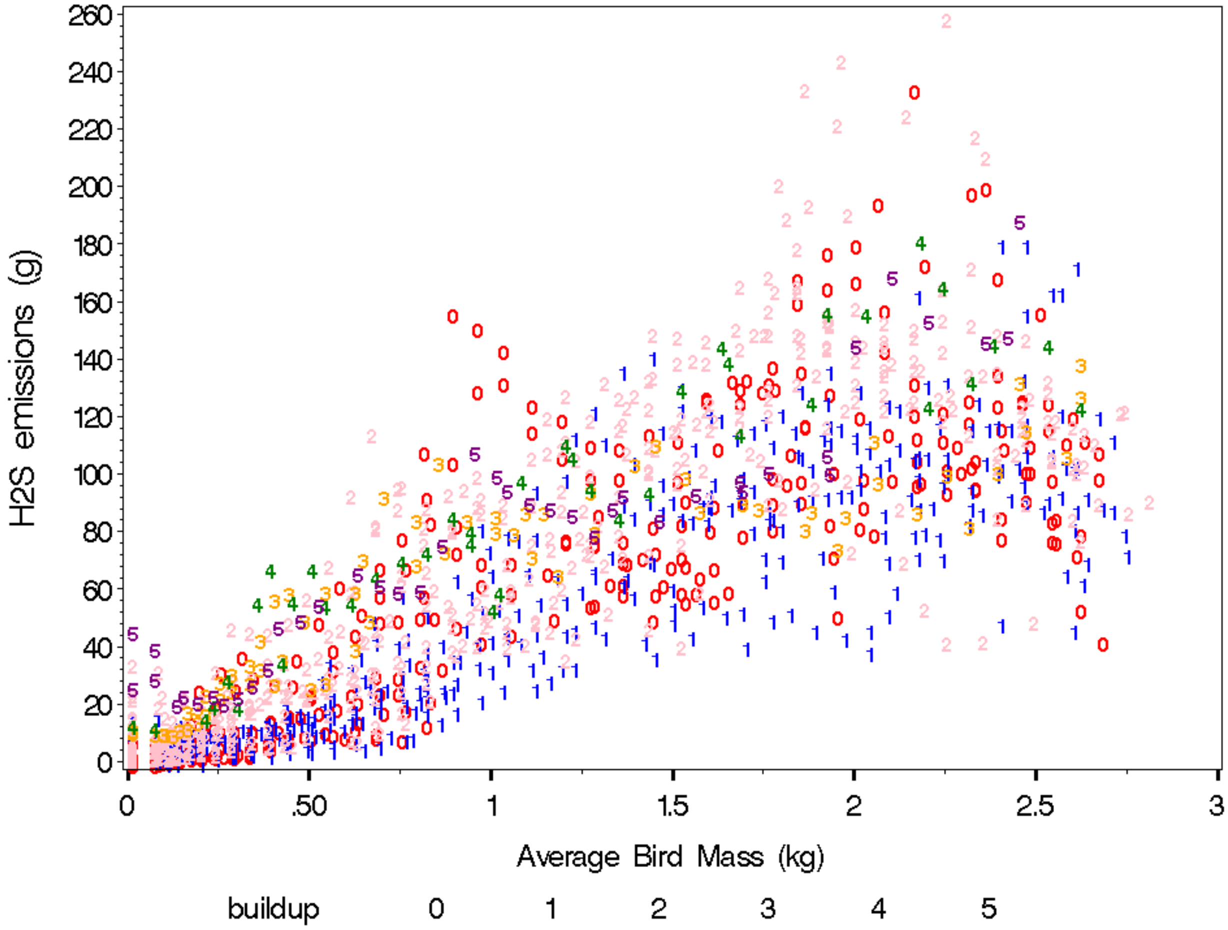


Figure 8-5. Overlay of *buildup* on H_2S Emissions vs. Average Live Bird Mass

Although the visual analysis of the data indicated that litter condition should not be included in the candidate mean trend, the EPA examined the effect of litter condition further by plotting emissions based on two additional build-up indicators: *build* and *bld*. As described in Section 7.3.1, these two indicators note how many flocks were raised on the litter since the previous full litter clean-out was conducted. Examining these box plots (Figure 8-6) shows that there is an increase in average H_2S emissions for flocks raised on litter that had been decaked and replenished for two or more grow-out periods. Therefore, the EPA used the variable *build*, which indicates the presence or absence of built-up litter, as the functional form through which the variable *buildup* entered the mean trend function.

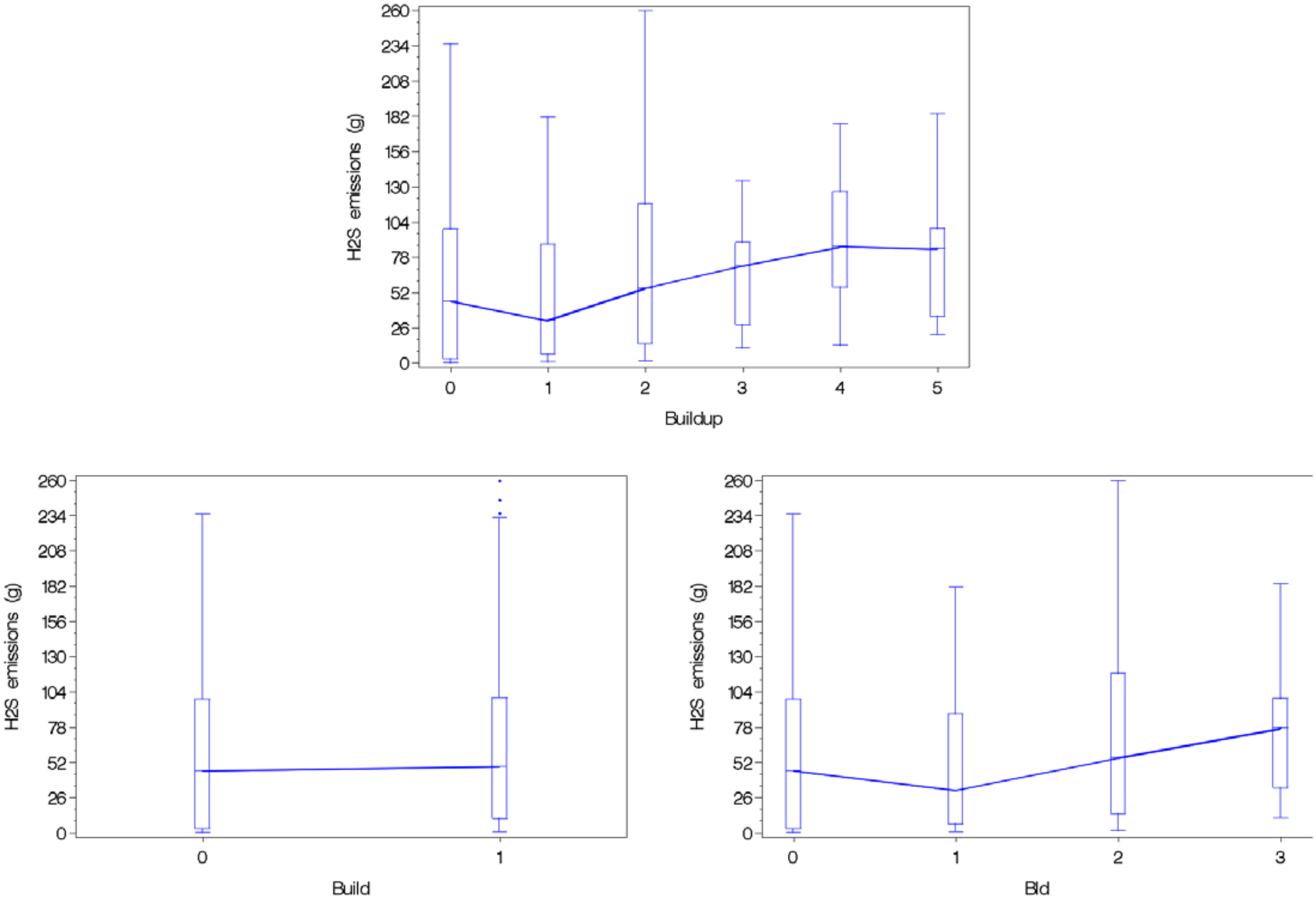


Figure 8-6. Box Plots of H_2S Emissions vs. Categorical Variables for *buildup*

Figure 8-7, Figure 8-8 and Figure 8-9 show the scatter plots of H_2S emissions by the remaining predictor variables (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, the EPA chose a linear functional form for all variables except average bird mass in developing the H_2S EEMs.

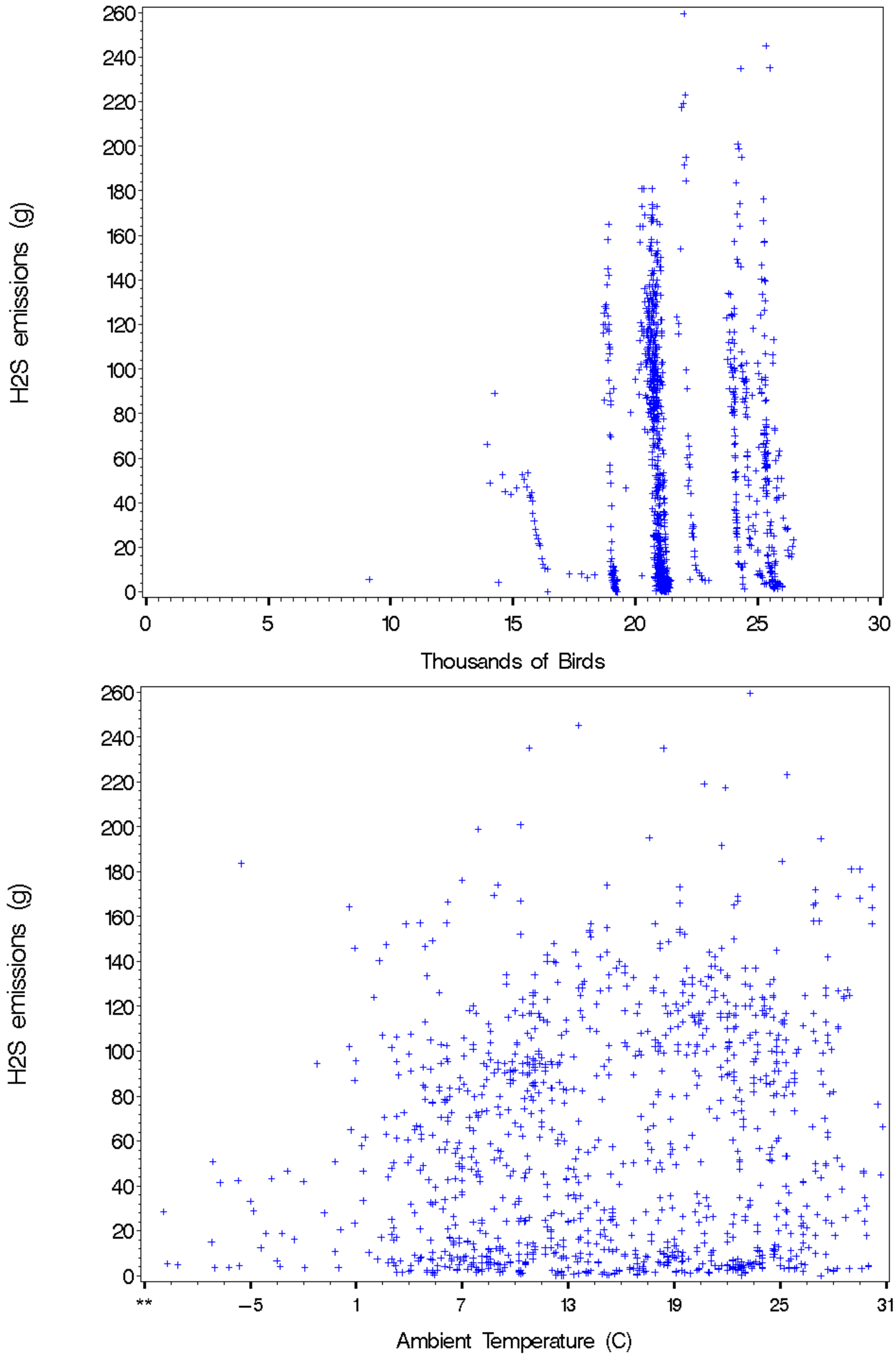


Figure 8-7. H_2S Emissions vs. Predictor Variables *birds and *ta****

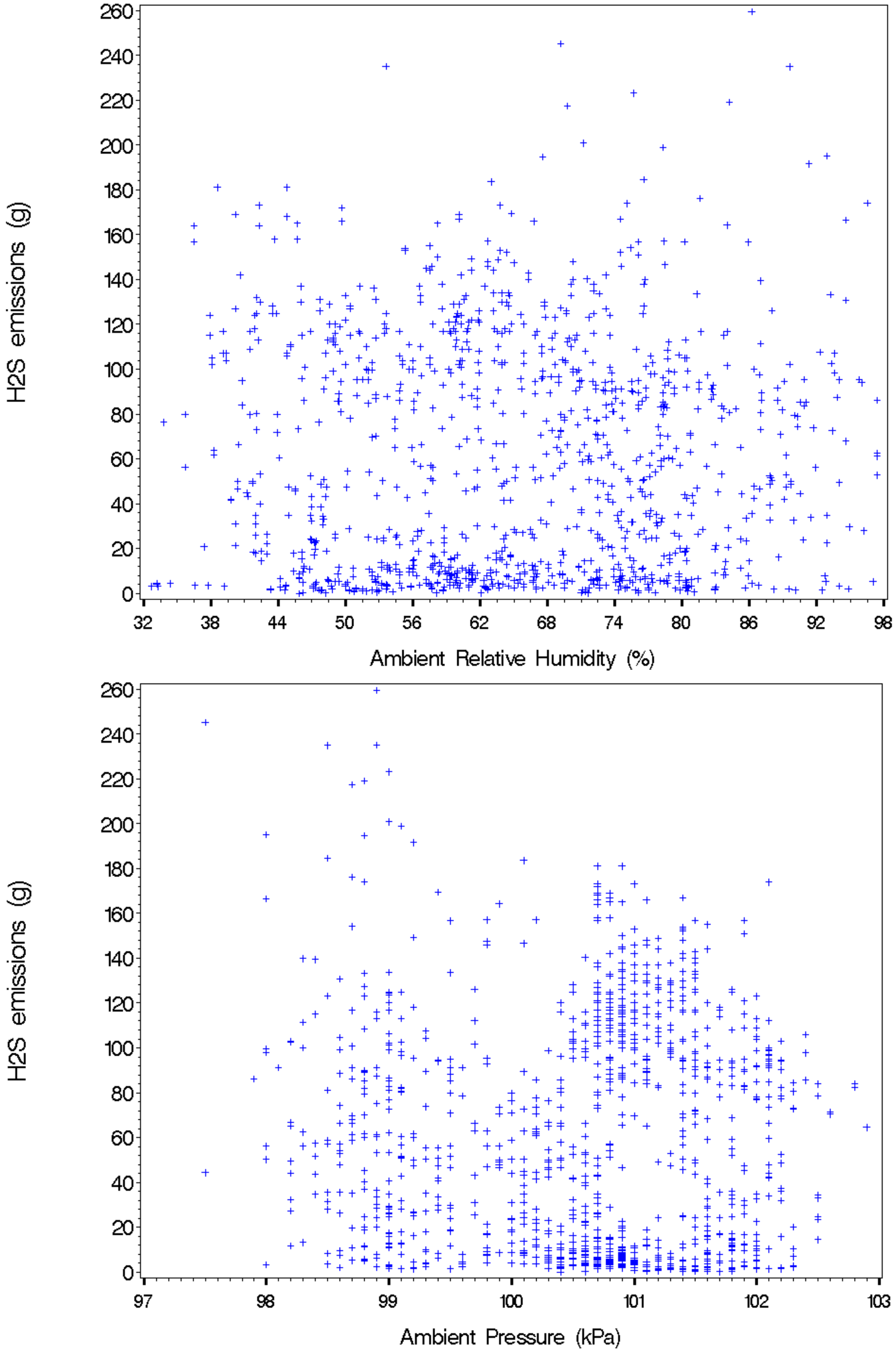


Figure 8-8. H_2S Emissions vs. Predictor Variables *ha and *pa***

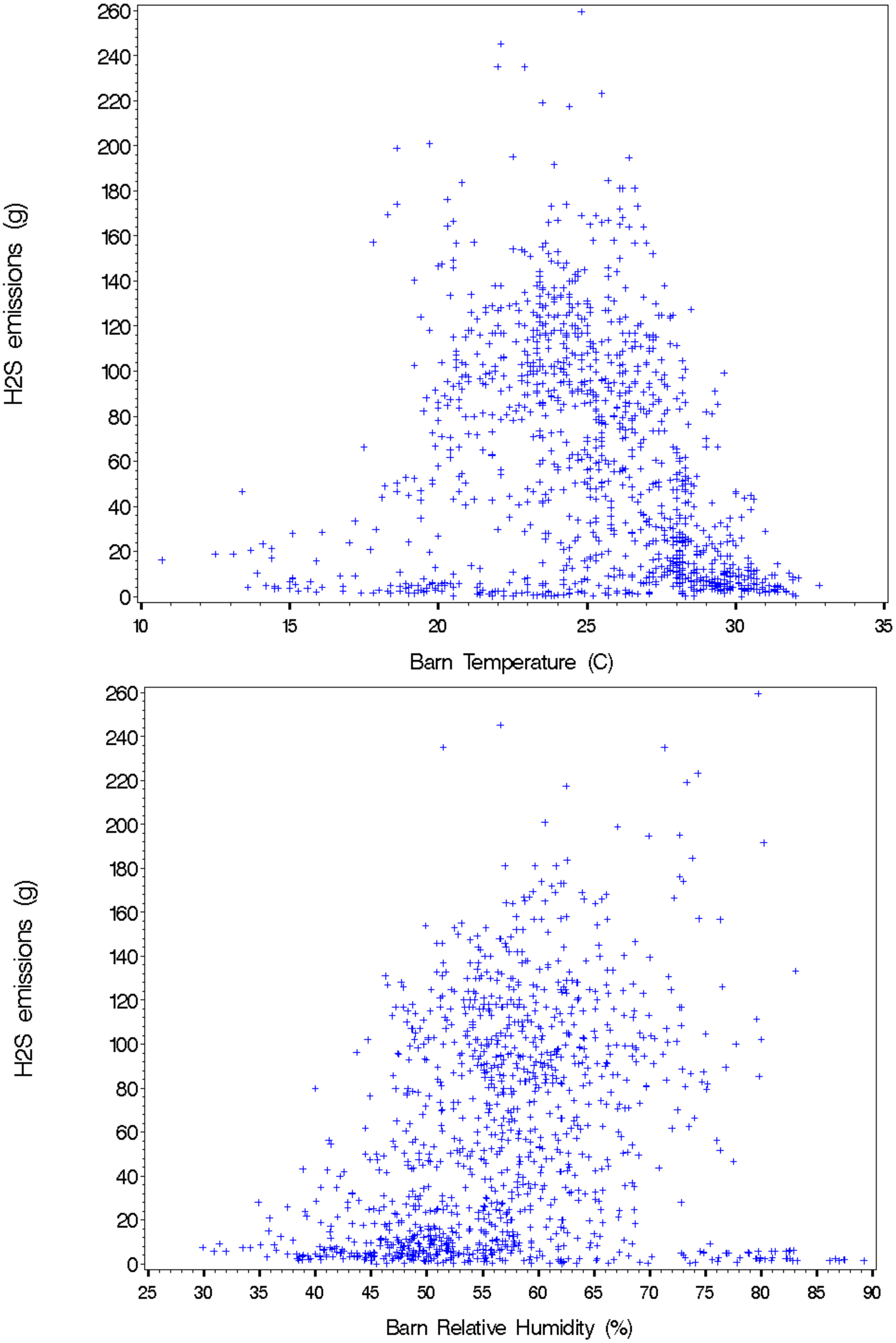


Figure 8-9. H_2S Emissions vs. Predictor Variables *tc and *hc***

Table 8-2 summarizes the mean trend variables that describe the dependence of H_2S emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable *build*. For *avem**, the linear, quadratic and cubic terms were collectively considered the main effect.

Table 8-2. Summary of Main Effect Mean Trend Variables for H_2S

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	$avem$, $avem^2$, $avem^3$
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.1.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-2. Initial testing of the R^2 of two-way and three-way terms suggested that consideration of two-way interactions was appropriate for development of H_2S EEMs. The main effects and interaction terms for the three EEMs tested are presented in Table 8-3.

Table 8-3. Candidate Mean Trend Variables for the I, IA and IAC H_2S EEMs

EEM (Form)	Main Effects	Two-Way Interaction Terms
I, Cubic (I EEM_C)	*birds, build, avem,* $avem^2$, $avem^3$	*buildbirds, buildavem,* $buildavem^2$, $buildavem^3$, *birdsavem,* $birdsavem^2$, $birdsavem^3$
IA, Cubic (IA EEM_C)	Same as I EEM_C plus: *ta, ha, pa*	Same as I EEM_C plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta,* $avem^2ta$, $avem^3ta$, *avemha,* $avem^2ha$, $avem^3ha$, *avempa,* $avem^2pa$, $avem^3pa$, *taha, tapa, hapa*
IAC, Cubic (IAC EEM_C)	Same as IA EEM_C plus: *tc, hc*	Same as IA EEM_C plus: *buildtc, buildhc, birdstc, birdshc, avemtc,* $avem^2tc$, $avem^3tc$, *avemhc,* $avem^2hc$, $avem^3hc$, *tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.1.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating higher order terms and interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variables for the H_2S final EEMs are presented in Table 8-4.

Table 8-4. Centering and Scaling Reference Values for Continuous H_2S Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	22	2.2
*avem**	1.0	0.83
*ta**	15	8
*ha**	65	14
*pa**	101	1.1
*tc**	25	3.7
*hc**	57	9.5

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or $avem^2$) and the creation of interaction terms (e.g., *avemta*).

8.1.4 Selecting Final Mean Trend Variables for H_2S

Table 8-5 contains the final mean trend variables for the selected form of each EEM after backward elimination of mean trend variables (see Section 7.5). Table 8-6 shows the fit statistics for each EEM. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether the estimate is significantly different from one.

Table 8-5. Final I, IA and IAC EEM Mean Trend Variables for H_2S EEMs

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, avem,* $avem^2$, $avem^3$	*buildbirds, buildavem,* $buildavem^2$, $buildavem^3$, *birdsavem,* $birdsavem^2$, $birdsavem^3$
IA	*build, birds, avem,* $avem^2$, $avem^3$, *ta, ha, pa*	*buildavem,* $buildavem^2$, $buildavem^3$, *buildpa, birdsta, birdsha, birdspa, avemta,* $avem^2ta$, $avem^3ta$, *avemha,* $avem^2ha$, $avem^3ha$, *avempa,* $avem^2pa$, $avem^3pa$, *taha, tapa, hapa*
IAC	*build, birds, avem,* $avem^2$, $avem^3$, *ta, ha, pa, tc, hc*	*buildavem,* $buildavem^2$, $buildavem^3$, *buildta, buildha, buildpa, buildtc, buildhc, birdspa, birdshc, avemta,* $avem^2ta$, $avem^3ta$, *avemtc,* $avem^2tc$, $avem^3tc$, *avemhc,* $avem^2hc$, $avem^3hc$, *hapa, tatc, tahc, hatc, tchc*

For all EEMs, the intercept, γ_0, was significantly different from 0 at the $\alpha = 0.05$ significance level. For the IA EEM, the slope, γ_1, was significantly different from 1. These differences in γ_0 and γ_1 from 0 and 1 may indicate systematic bias, but the phrase "significantly different" refers to statistical significance, which is not the same as practical significance. The estimates of γ_0 and γ_1 mean that the relationship between the value of H_2S emissions, Y_{ht}, in the cross-validation data to the point prediction produced by the EEM, $\hat{Y}_{ht}$, is given by $Y_{ht} = \gamma_0 + \gamma_1\hat{Y}_{ht}$. Using the IA EEM as an example, this relationship is $Y_{ht} = 6.4 + 0.94\hat{Y}_{ht}$. That means that instead of the H_2S emissions being equal to the point prediction, on average, they are equal to 6.4 grams plus 0.94 times the prediction of them. The practical significance of adding 6.4 grams is small, and it is offset by the fact that the multiplier 0.94 is less than 1, which reduces the predicted value of emissions.

Table 8-6. Final I, IA and IAC EEM Fit Statistics for H_2S

EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0 (g)	γ_1
I	9,143	9,152	98	91	23	0.80	4.7 x	1.0 ✓
IA	8,945	8,954	97	89	23	0.80	6.4 x	0.94 x
IAC	8,759	8,767	95	85	23	0.80	6.3 x	0.95 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the α = 0.05 significance level.

8.1.5 Summary of Final Results for the I, IA and IAC EEMs for H_2S

The covariance parameters for the final EEMs are listed in Table 8-7. The coefficients for the EEM mean trend variables are listed in Table 8-8. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling constants for the predictor variables of the H_2S EEMs are presented in Table 8-4.

Table 8-7. Covariance Parameters for Final H_2S EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.8628	0.8683	0.8876
$\hat{\sigma}^2$	577.84	534.28	522.84

Table 8-8. Regression Coefficients for Final H_2S EEMs

p	x_p	$\hat{\beta}_p$		
		I	IA	IAC
0	*Intercept*	56.75	55.23	51.53
1	*birds*	2.85	1.31	1.04
2	*build*	4.36	5.43	5.43
3	*avem*	64.99	69.23	73.93
4	$avem^2$	0.71	1.89	9.44
5	$avem^3$	-11.95	-14.43	-14.80
6	*ta*	a	8.03	-2.25
7	*ha*	a	5.61	-2.36
8	*pa*	a	0.24	-3.84
9	*tc*	a	a	15.09
10	*hc*	a	a	10.58
11	*buildbirds*	-0.32	a	a
12	*buildavem*	-0.45	-1.35	-3.72
13	$buildavem^2$	1.86	0.95	0.99
14	$buildavem^3$	0.65	0.82	2.15
15	*buildta*	a	a	2.87
16	*buildha*	a	a	2.28
17	*buildpa*	a	3.70	4.70
18	*birdsavem*	-4.04	a	a
19	$birdsavem^2$	-1.03	a	a
20	$birdsavem^3$	3.36	a	a
21	*birdsta*	a	-3.35	a
22	*birdsha*	a	0.07	a
23	*birdspa*	a	-1.25	-0.71
24	*avemta*	a	14.54	1.15
25	$avem^2ta$	a	2.97	-0.35
26	$avem^3ta$	a	-5.18	-2.95
27	*avemha*	a	4.83	a
28	$avem^2ha$	a	-0.34	a
29	$avem^3ha$	a	-0.57	a
30	*avempa*	a	8.46	a
31	$avem^2pa$	a	0.28	a
32	$avem^3pa$	a	-4.14	a
33	*taha*	a	1.52	a
34	*tapa*	a	-0.91	a
35	*hapa*	a	0.16	-0.16
36	*avemtc*	a	a	18.41
37	$avem^2tc$	a	a	3.13
38	$avem^3tc$	a	a	-1.99
39	*avemhc*	a	a	9.12
40	$avem^2hc$	a	a	0.06
41	$avem^3hc$	a	a	-1.41
42	*birdshc*	a	a	-0.32
43	*buildhc*	a	a	-2.23
44	*buildtc*	a	a	-1.85
45	*tahc*	a	a	1.77
46	*tatc*	a	a	0.82
47	*hatc*	a	a	1.04
48	*tchc*	a	a	-0.84

Note: Each main effect variable was centered and scaled prior to creating higher-order terms and interactions.
[a] This mean trend variable is not included in the EEM.

8.2 EEMs for PM_{10}

8.2.1 Selecting Datasets

Data was available for PM_{10} was 66 percent of the grow-out period days (Table 8-9). Particulate matter was monitored on a rotating schedule at the CA1B houses, which limited the number of PM_{10} observations collected at that site. Table 8-9 shows that PM_{10} emissions values were available for just over 50 percent of the time for the CA1B houses. The Kentucky sites had better completeness with seasonal completeness ranging from 84 to 98 percent. The available data are evenly distributed across the seasons.

Of the 1,219 PM_{10} emission readings, 45 did not have values for the inventory, ambient and confinement predictor variables necessary for the EEM development. After these data records were removed, the base dataset for PM_{10} EEM development consisted of 1,174 records. The EPA then randomly withheld 233 observations (approximately 20 percent of the 1,174 observations) to serve as the cross-validation dataset.

Table 8-9. Data Completeness for PM_{10} EEMs

Season	**Description**	**CA1B**		**KY1B-1**	**KY1B-2**	**All Houses**
		House 10	**House 12**	**House 5**	**House 3**	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days PM_{10} data available	333	365	274	247	1,219
	Percent complete	52%	56%	95%	93%	66%
Winter	Number of grow-out days	150	153	87	74	464
	Days PM_{10} data available	80	92	83	68	323
	Percent complete	53%	60%	95%	92%	70%
Spring	Number of grow-out days	157	158	83	55	453
	Days PM_{10} data available	72	109	77	46	304
	Percent complete	46%	69%	93%	84%	67%
Summer	Number of grow-out days	156	157	55	74	442
	Days PM_{10} data available	101	89	52	70	312
	Percent complete	65%	57%	95%	95%	71%
Fall	Number of grow-out days	179	179	63	64	485
	Days PM_{10} data available	80	75	62	63	280
	Percent complete	45%	42%	98%	98%	58%

8.2.2 Choosing the Probability Distribution for PM_{10}

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed PM_{10} daily emissions to determine whether using the normal distribution could be justified. The histogram in Figure 8-10 shows that many of the PM_{10} observations correspond to lower values, with a single peak at emissions values less than 0.3 kg. Also, the figure shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-11, for example, shows histograms of PM_{10} emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2 and 5 are skew right while those for bins 3, 4 and 6 are symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern is by no means ubiquitous. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

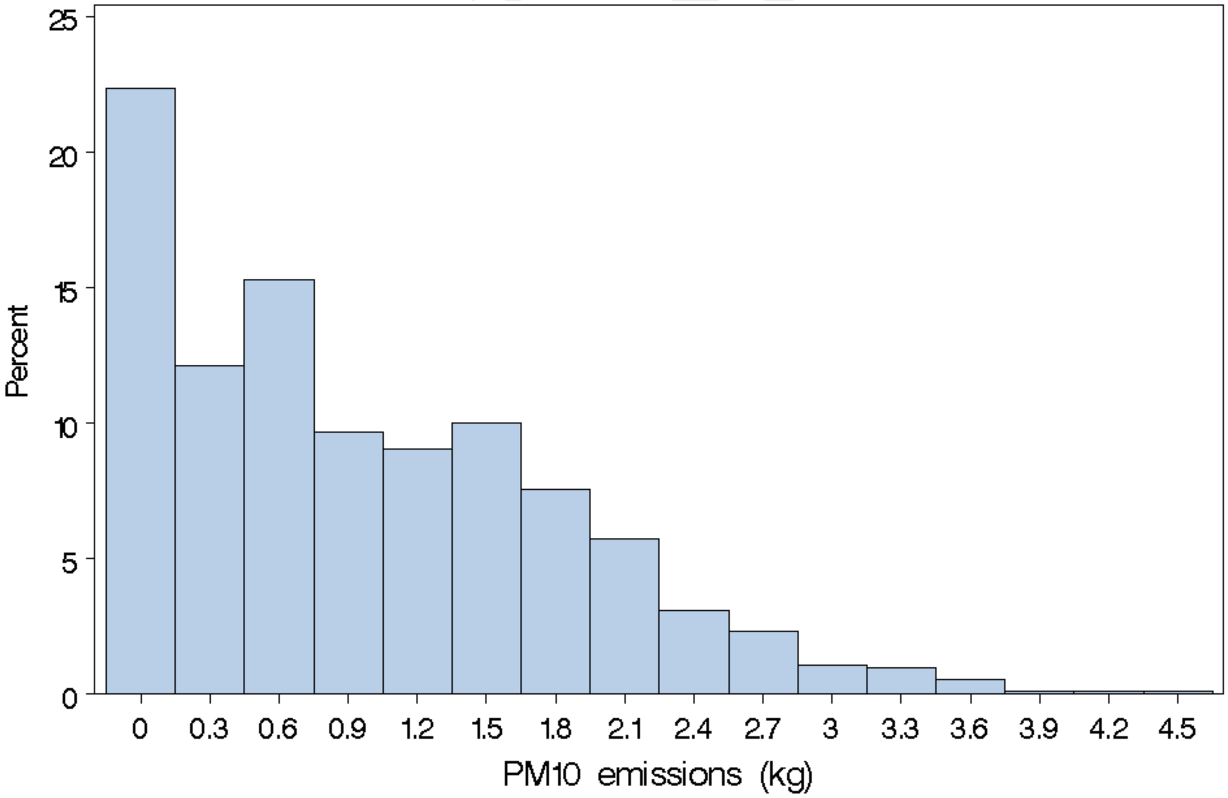


Figure 8-10. Histogram of PM_{10} Emissions in the Base Dataset

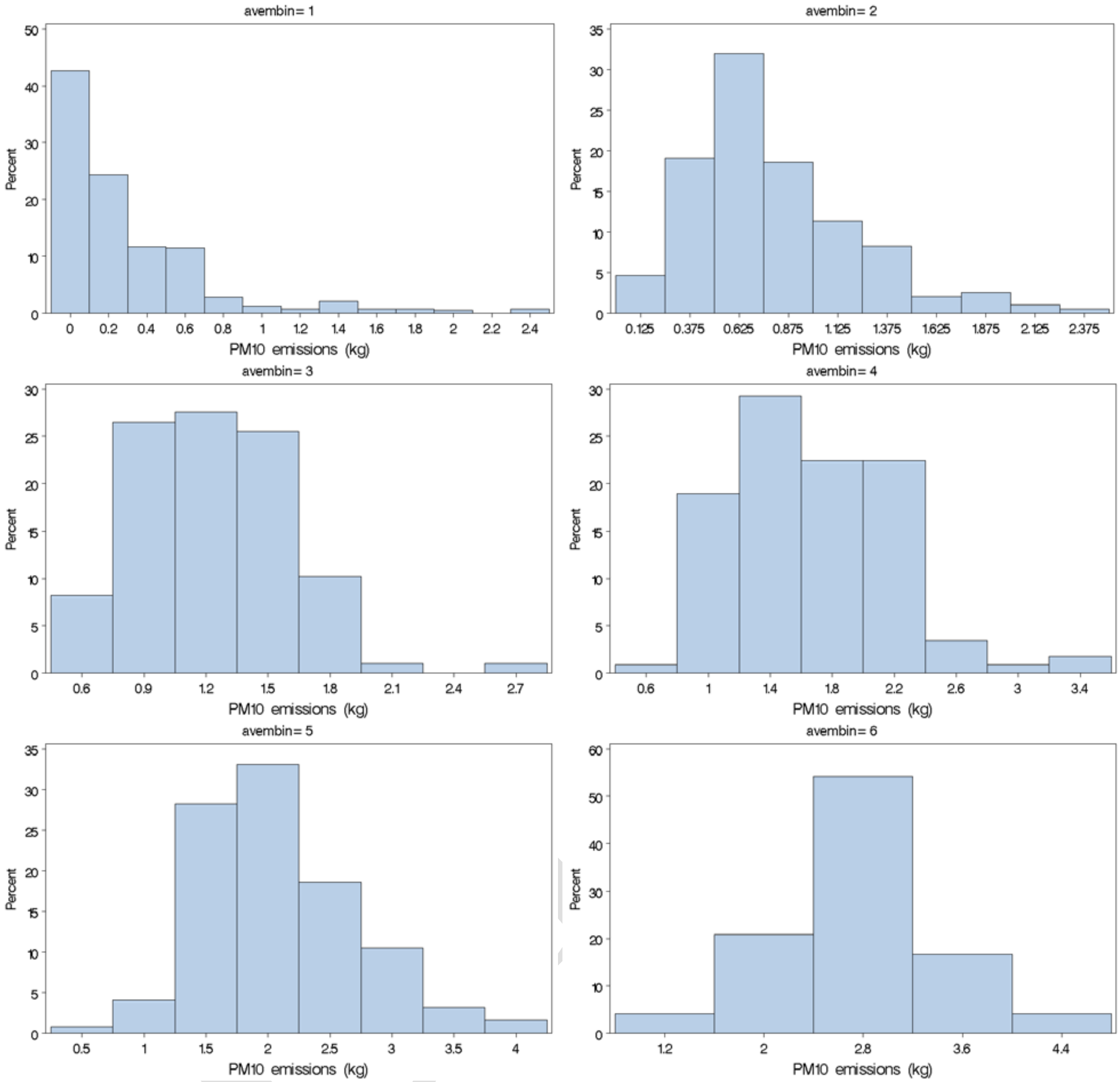


Figure 8-11. Histograms of PM_{10} Emissions by *avem Bins**

8.2.3 Developing Candidate Mean Trend Variables for PM_{10}

8.2.3.1 *Choosing Predictor Variable Functional Forms for PM_{10}*

Plots of PM_{10} emissions versus average bird mass, for all houses, suggested a positive relationship, with a slight upward curvature. Figure 8-12 shows a scatter plot of PM_{10} emissions versus average mass, with overlays of linear, quadratic and cubic regressions. The gradual increasing trend suggested either a quadratic or exponential relationship between PM_{10} emissions and average bird mass. Accordingly, the EPA tested two forms of the EEMs: an EEM based on a quadratic relationship with average mass (*avem and avem*^{2}), and an EEM based on an exponential relationship (*eavem*).

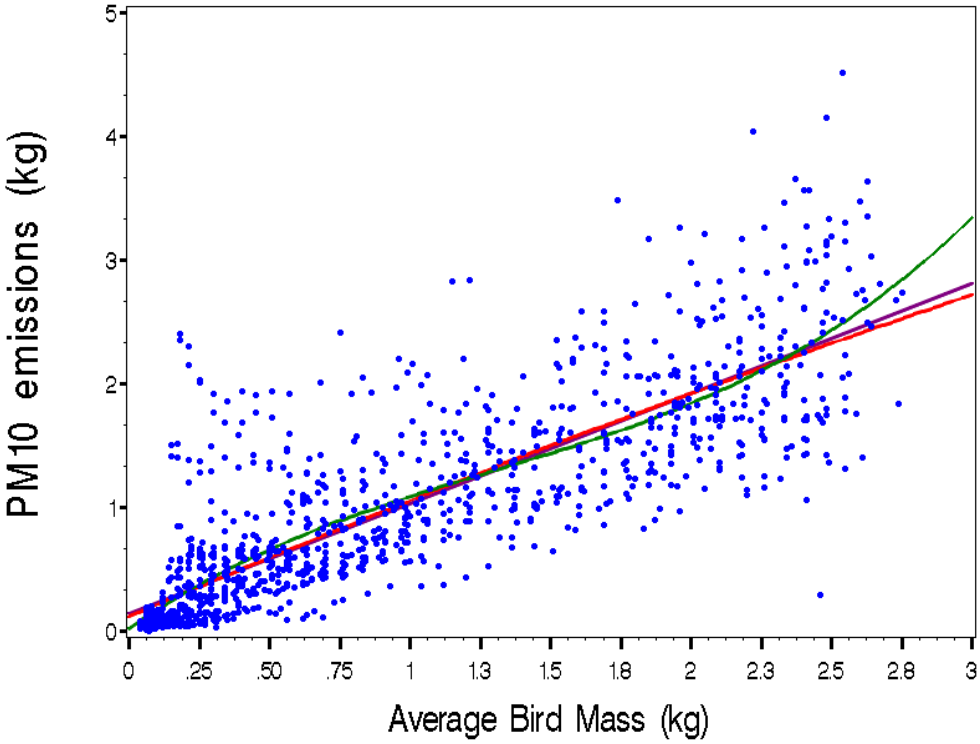


Figure 8-12. PM_{10} Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on PM_{10} emissions (see Section 7.3.1), the EPA discerned a relationship between PM_{10} emissions and the degree of litter accumulation, based on the variance in PM_{10} emissions values for lower bird weights (see Figure 8-13). When PM_{10} emissions are plotted by average mass and color-coded to indicate the level of *buildup*, there is some indication that higher emissions correspond to built-up litter at lower animal mass. Further investigations showed that the increased variance was due to two flocks at each of the CA1B houses (Figure 8-14). Both of these flocks (6 and 7) were raised in the summer on built-up litter.

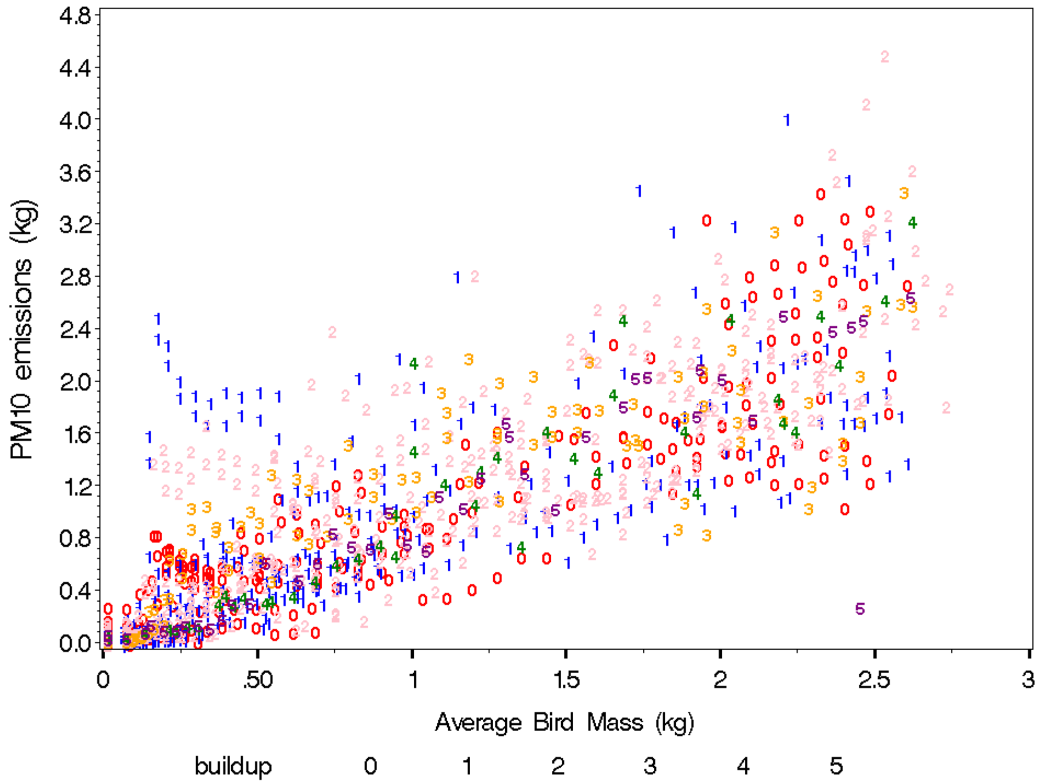


Figure 8-13. Overlay of ***buildup*** on PM_{10} Emissions vs. Average Live Bird Mass

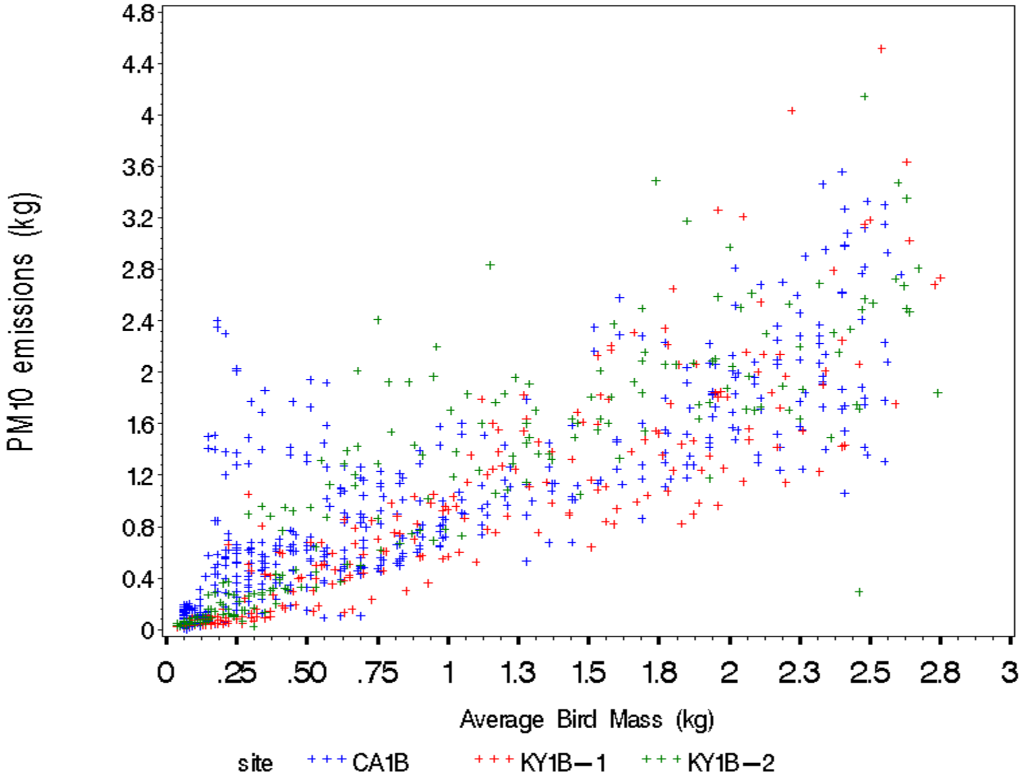


Figure 8-14. PM_{10} Emissions vs. Average Bird Mass, Color-coded by Site

Plots of the build-up indicator parameters (i.e., *buildup*, *build*, *bld*) suggested average PM_{10} emissions do not increase for flocks raised on built-up litter, because there is little difference in the minimum emissions levels between the litter conditions (Figure 8-15), and only a slight difference in average values. The EPA decided to include *build* as the functional form through which the variable *buildup* enters the mean trend function and test its significance using the p-value analysis to determine the final mean trend variables.

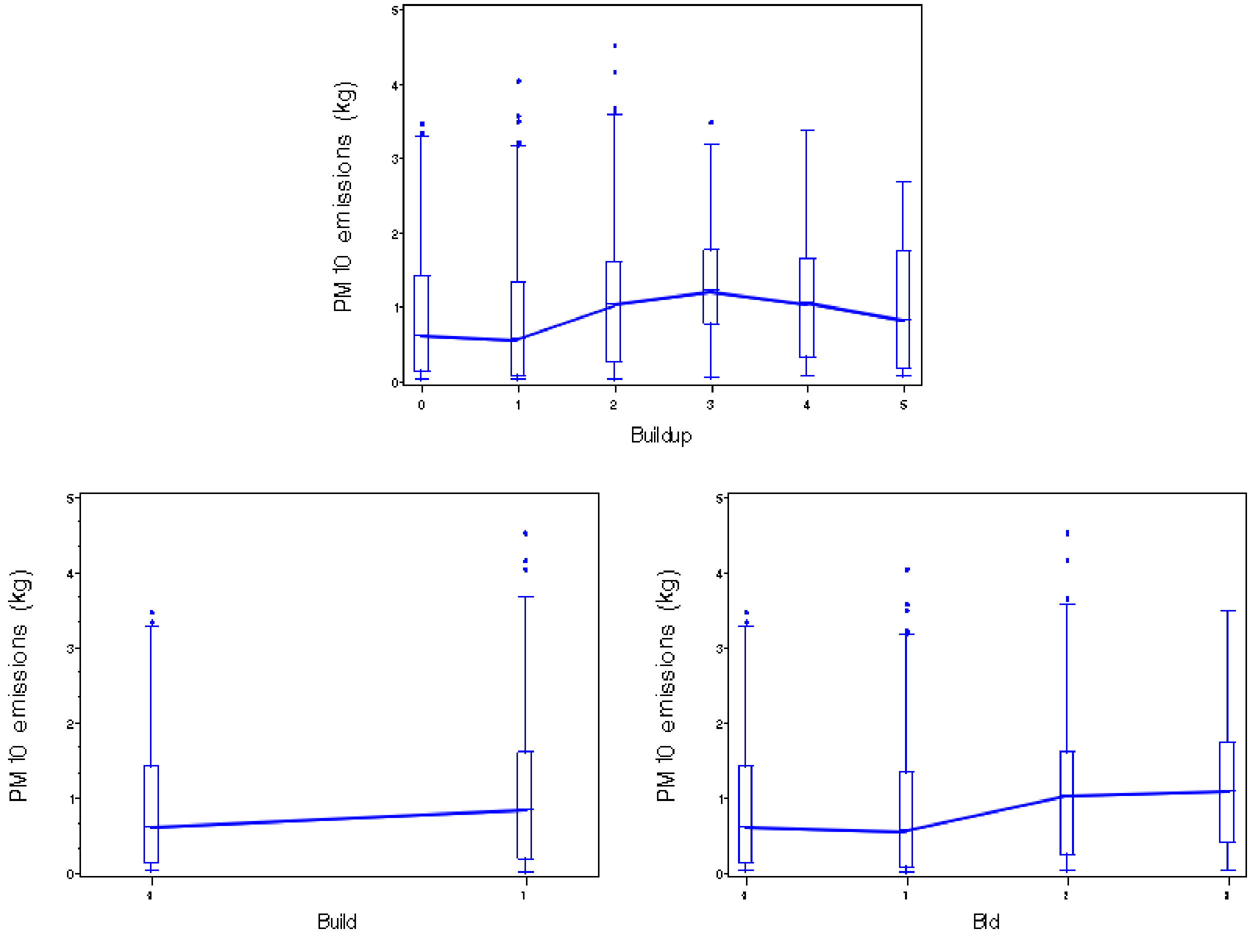


Figure 8-15. Box Plots of PM_{10} Emissions vs. Categorical Variables for *buildup*

Figure 8-16, Figure 8-17, and Figure 8-18 show the scatter plots of PM_{10} emissions versus the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear for all variables other than *avem*. Based on this visual analysis, and the absence of a process-based reason to do otherwise, the EPA chose a linear functional form for all variables except average bird mass in developing the PM_{10} EEMs.

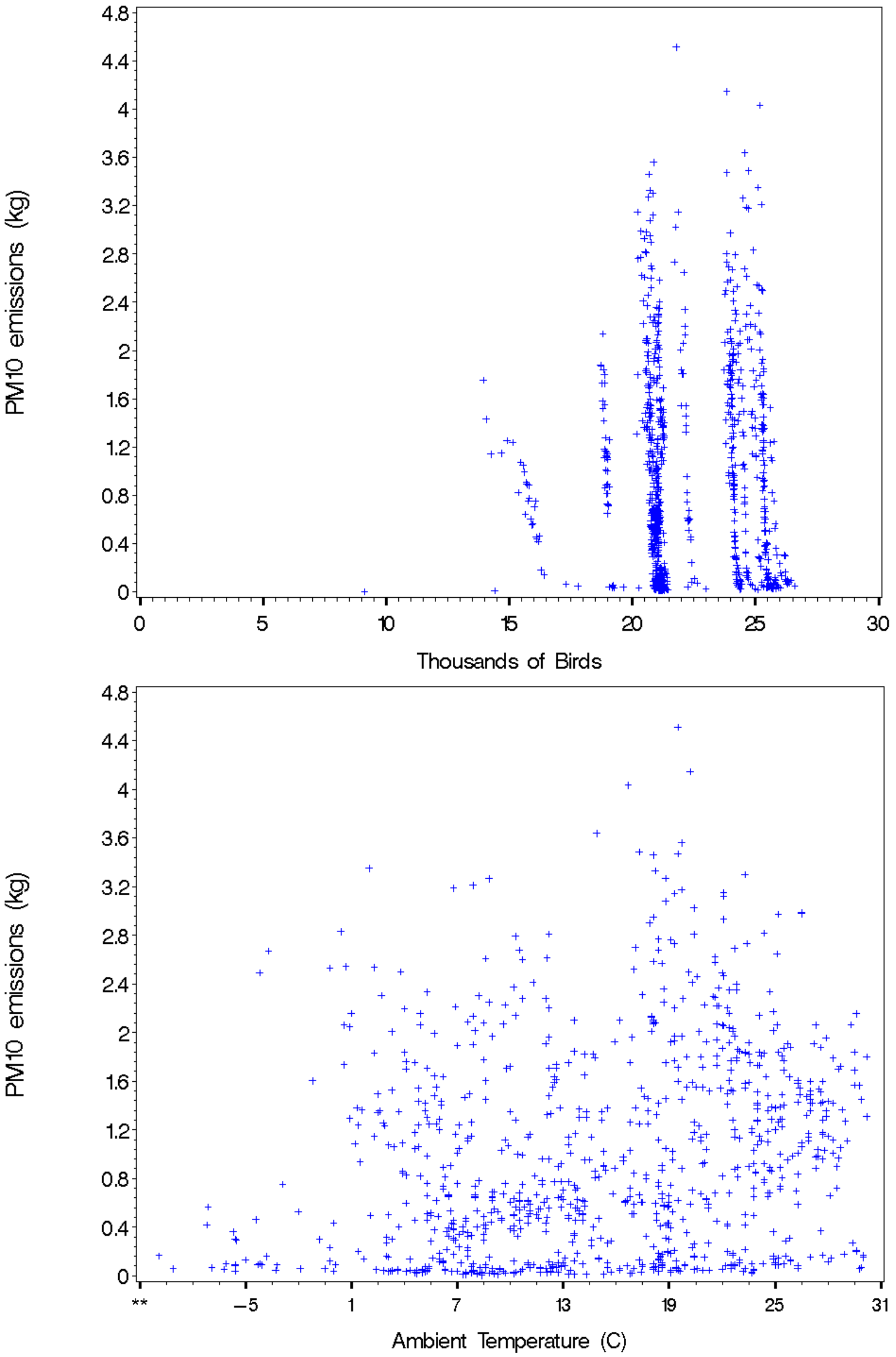
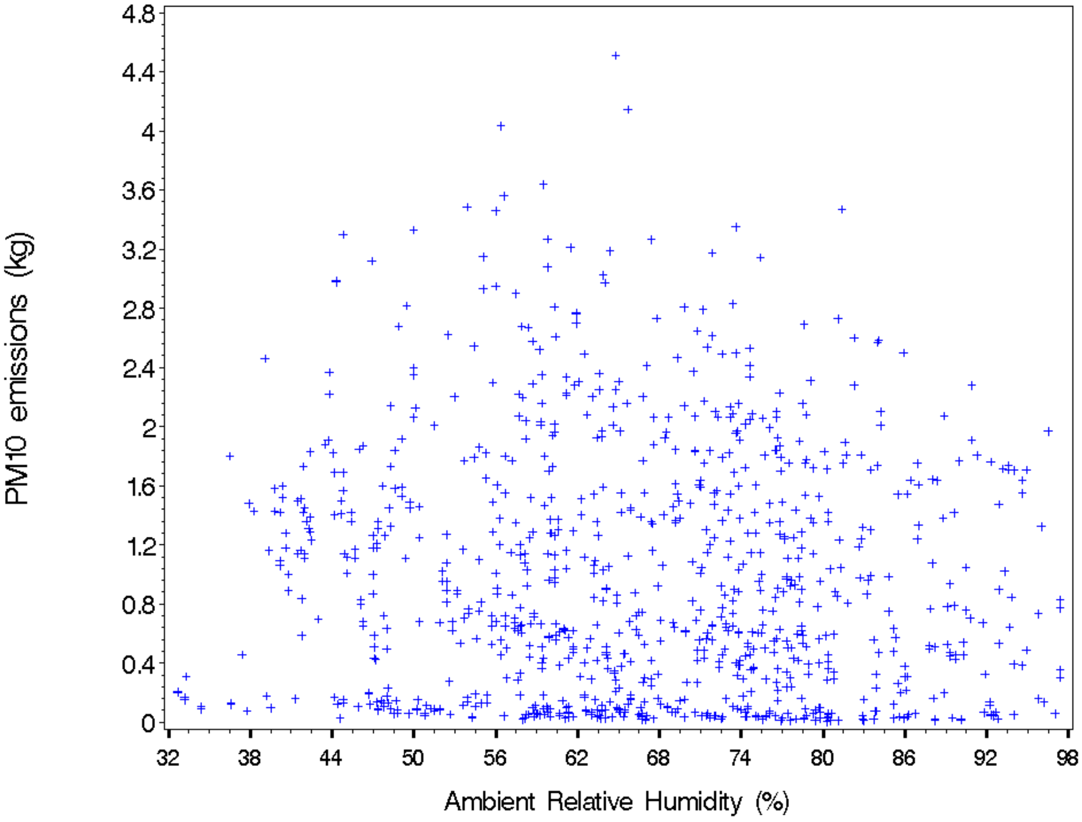


Figure 8-16. PM$_{10}$ Emissions vs. Predictor Variables *birds and *ta****



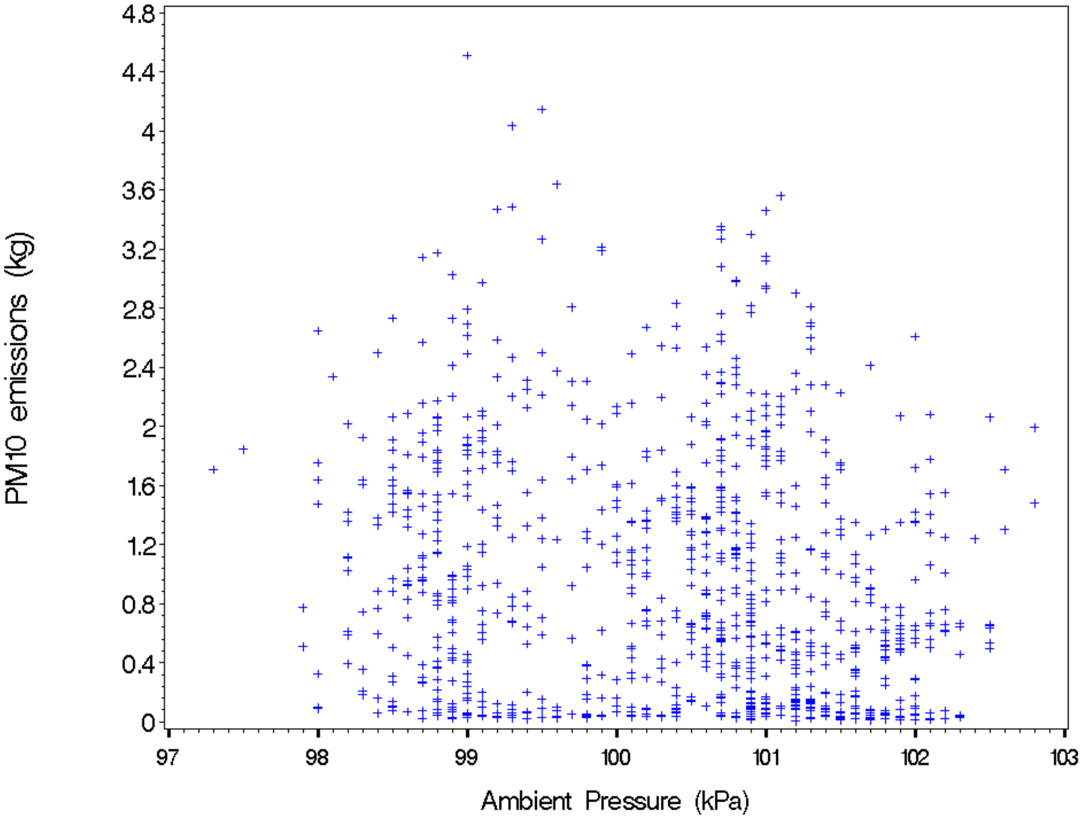


Figure 8-17. PM$_{10}$ Emissions vs. Predictor Variables *ha and *pa***

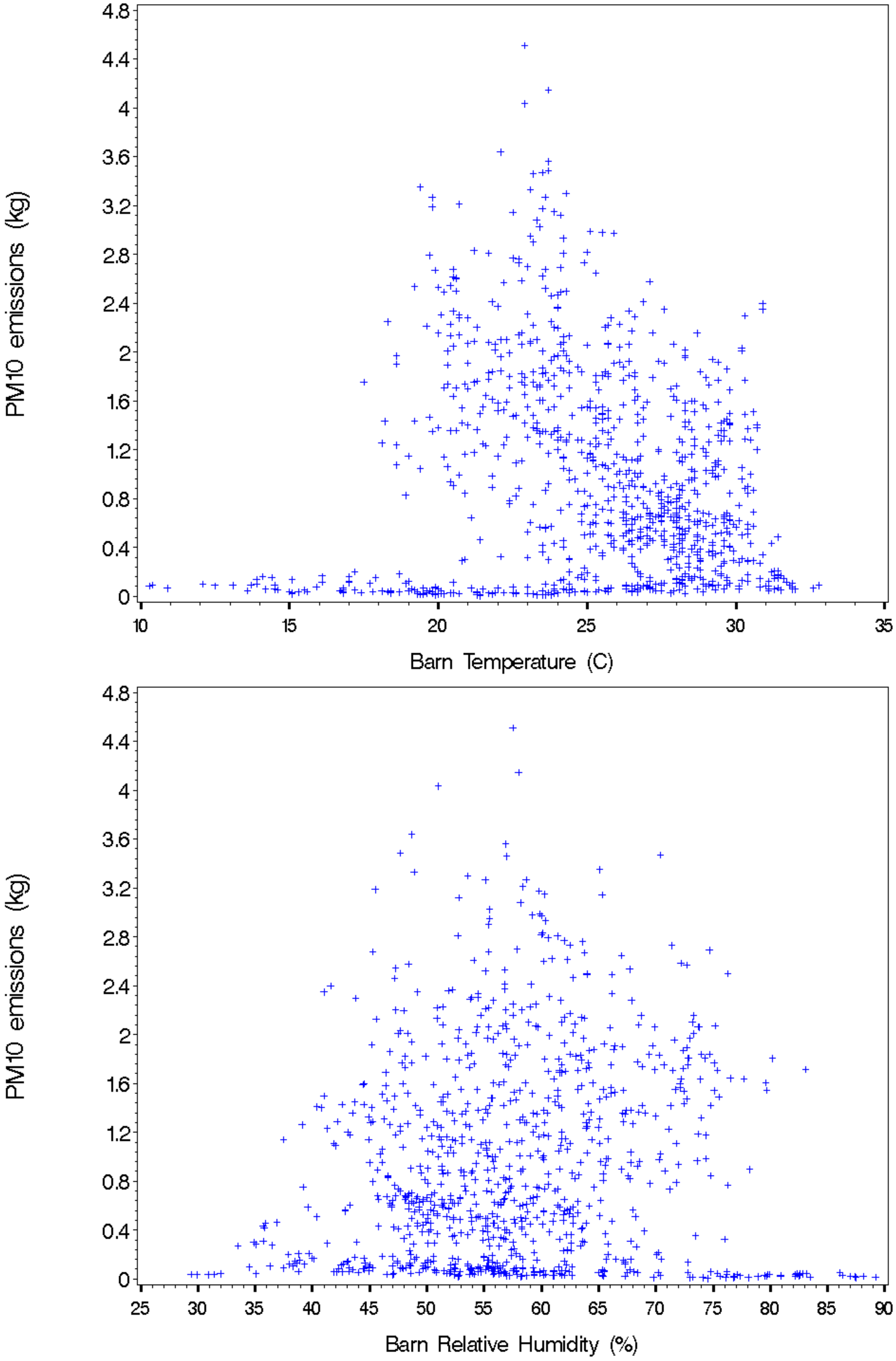


Figure 8-18. PM_{10} Emissions vs. Predictor Variables *tc and *hc***

Table 8-10 summarizes the mean trend variables that describe the dependence of PM_{10} emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable, *build*. For *avem**, the linear and quadratic terms were collectively considered the main effect for one version of the EEM tested, and the exponential of average bird mass (*eavem*) was considered in a second version of the EEM.

Table 8-10. Summary of Main Effect Mean Trend Variables for PM_{10}

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$ *eavem*
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.2.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-10. Initial testing of the R^2 of two-way and three-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of PM_{10} EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-11.

Table 8-11. Candidate Mean Trend Variables for the I, IA and IAC PM_{10} EEMs

EEM	Main Effects	Two-Way Interaction Terms
I, Quadratic (I EEM_Q)	*build, birds, avem,* $avem^2$	*buildbirds, buildavem,* $buildavem^2$*, birdsavem,* $birdsavem^2$
I, Exponential (I EEM_E)	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA, Quadratic (IA EEM_Q)	Same as I EEM_Q plus: *ta, ha, pa*	Same as I EEM_Q plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta,* $avem^2ta$*, avemha,* $avem^2ha$*, avempa,* $avem^2pa$*, taha, tapa, hapa*
IA, Exponential (IA EEM_E)	Same as I EEM_E plus: *ta, ha, pa*	Same as I EEM_E plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*
IAC, Quadratic (IAC EEM_Q)	Same as IA EEM_Q plus: *tc, hc*	Same as IA EEM_Q plus: *buildtc, buildhc, birdstc, birdshc, avemtc,* $avem^2tc$*, avemhc,* $avem^2hc$*, tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC, Exponential (IAC EEM_E)	Same as IA EEM_E plus: *tc, hc*	Same as IA EEM_E plus: *buildtc, buildhc, birdstc, birdshc, eavemtc, eavemhc, tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.2.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the PM_{10} final EEMs are presented in Table 8-12.

Table 8-12. Centering and Scaling Reference Values for Continuous PM_{10} Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	22	2.5
*avem**	1.1	0.87
*ta**	15	8.2
*ha**	66	14
*pa**	100	1.1
*tc**	25	3.8
*hc**	58	9.9

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or $avem^2$) and the creation of interaction terms (e.g., *avemta*).

8.2.4 Selecting Final Mean Trend Variables for PM_{10}

8.2.4.1 Inventory EEM

The EPA tested two forms of the I EEM; a quadratic and an exponential form (Table 8-13). Predictions based on the quadratic form of the EEM (I EEM_Q) always had systematic bias for the intercept, γ_0, regardless of the number of parameters eliminated. Predictions based on the exponential form of the EEM (I EEM_E) demonstrated systematic bias after initial backward elimination steps.

The selected form of the I EEM_Q contains all of the initial interaction terms. This EEM displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2); however, the EEM still exhibited systematic bias. The best form of the I EEM_E also included all the initial interaction terms. This version of the I EEM_E had the best fit-statistics against the cross-validation dataset, as well as the coverage percentage (% in PI) closest to 95 percent, without exhibiting systematic bias. The fit statistics for the selected I EEM_Q and I EEM_E are presented in Table 8-14. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Because the I EEM_Q always exhibited systematic bias, the EPA retested the I EEM_Q using different versions of the base and cross-validation datasets to verify that the systematic bias was not due to random selection of an improper cross-validation dataset. Examples of an improper cross-validation dataset include a dataset where the values are skewed to one end of the distribution, or a dataset that contains too many extreme values. In these examples, the fit statistics would be biased for the extreme values of the dataset. Based on the results of the retest, the systematic bias for the I EEM$_Q$ could not be attributed to improper selection of a cross-validation dataset. Therefore, the EPA selected the I EEM$_E$ (highlighted in gray) because it did not display systematic bias.

Table 8-13. Final Candidate I EEM Mean Trend Variables for PM$_{10}$

EEM	Main Effects	Two-Way Interaction Terms
I EEM$_Q$	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
I EEM$_E$	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*

Table 8-14. Final Candidate I EEM Fit Statistics for PM$_{10}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
I EEM$_Q$	646	654	93	2.1	0.51	0.65	0.16 ×	0.92 ✓
I EEM$_E$	621	630	91	2.0	0.52	0.63	-0.12 ✓	1.1 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.2.4.2 *Inventory and Ambient EEM*

The selected form of IA EEM$_Q$ and IA EEM$_E$ are presented in Table 8-15. Similar to the I EEM, the quadratic form of the EEM (IA EEM$_Q$) always demonstrated systematic bias for the slope, γ_0, regardless of the number of parameters eliminated. The initial eliminations produced minor systematic bias, with the range of estimates for γ_0 failing to cover zero by only 0.001. Predictions based on the exponential form of the EEM (IA EEM$_E$) demonstrated systematic bias after the third backward elimination steps. The selected version of the IA EEM$_E$ occurs prior to the development of systematic bias and displays the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) and the smallest confidence interval width and best coverage percentage of the backward elimination steps.

Although both selected EEMs had similar fit statistics (Table 8-16), the IA EEM$_Q$ had persistent systematic bias. This systematic bias could not be contributed to improper selection of a cross-validation data set. Therefore, the EPA selected the IA EEM$_E$ (highlighted in gray), which retains the terms listed in Table 8-15.

Table 8-15. Final Candidate IA EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-Way Interaction Terms
IA EEM_Q	*build, birds, avem,* $avem^2$	*buildbirds, buildavem,* $buildavem^2$*, buildta, buildha, buildpa, birdsavem,* $birdsavem^2$*, birdsta, birdsha, birdspa, avemta,* $avem^2ta$*,avemha* $avem^2ha$*, avempa,* $avem^2pa$
IA EEM_E	*build, birds, eavem, ta, ha, pa*	*buildbirds, buildeavem, birdseavem, eavemha, eavempa,*

Table 8-16. Final Candidate IA EEM Fit Statistics for PM_{10}

EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IA EEM_Q	614	622	94	1.9	0.46	0.71	0.10 x	0.95 ✓
IA EEM_E	579	587	91	1.9	0.50	0.67	-0.11 ✓	1.1 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.2.4.3 *Inventory, Ambient and Confinement EEM*

With the addition of confinement variables, IAC EEM_Q no longer had systematic bias for predictions. The IAC EEM_E produced systematic bias prior to completing the backward elimination process. The selected version of the IAC EEM_E is the version of the model with the best fit statistics against the cross-validation dataset (highest R^2), the smallest confidence interval width and the best coverage percentage compared to the other elimination steps. This version also occurs prior to the development of systematic bias. The selected versions of the mean trend variables for the EEMs are presented in Table 8-17.

In general, the two final candidate EEMs had similar fit statistics (Table 8-18). The IAC EEM_E did a slightly better job at fitting the base dataset (smaller BIC and -2LL values), with the IAC EEM_Q providing a slightly better fit to the cross-validation dataset and a slightly better confidence interval width. Consequently, the EPA selected the IAC EEM_Q (highlighted in gray) as the final version of the EEM.

Table 8-17. Final Candidate IAC EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-way Interaction Terms
IAC EEM_Q	*build, birds, avem,* $avem^2$*, ta, ha, pa, tc, hc*	*buildbirds, buildavem,* $buildavem^2$*, buildta, buildha, buildpa, buildtc, buildhc, birdsavem,* $birdsavem^2$*, birdsta, birdsha, birdspa, birdstc, birdshc, avemta,* $avem^2ta$*, avemha,* $avem^2ha$*, avempa,* $avem^2pa$*, avemtc,* $avem^2tc$*, avemhc,* $avem^2hc$*, taha, tapa, hapa, tatc, tahc, tchc*
IAC EEM_E	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildbirds, buildeavem, buildta, buildha, buildpa, buildtc, buildhc, birdseavem, eavemta, eavemha, eavempa, eavemtc, eavemhc, taha, tapa, hapa, tatc, tahc, hatc, hahc, patc, pahc, tchc*

Table 8-18. Final Candidate IAC EEM Fit Statistics for PM_{10}

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IAC EEM_Q	519	526	94	1.7	0.40	0.79	0.03 ✓	1.0 ✓
IAC EEM_E	507	515	93	1.8	0.45	0.73	-0.09 ✓	1.08 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.2.5 Summary of Final Results for the I, IA and IAC EEMs for PM_{10}

A summary of the final mean trend variables for the three EEMs is provided in Table 8-19. The covariance parameters for the final forms of the EEMs are listed in Table 8-20. The coefficients for the EEM mean trend variables are listed in Table 8-21. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling factors for the predictor variables used in the final PM_{10} EEMs are presented in Table 8-12.

Table 8-19. Final EEM Mean Trend Variables for PM_{10}

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA	*build, birds, eavem, ta, ha, pa*	*buildbirds, buildeavem, birdseavem, eavemha, eavempa,*
IAC	*build, birds, avem,* $avem^2$*, ta, ha, pa, tc, hc*	*buildbirds, buildavem,* $buildavem^2$*, buildta, buildha, buildpa, buildtc, buildhc, birdsavem,* $birdsavem^2$*, birdsta, birdsha, birdspa, birdstc, birdshc, avemta,* $avem^2ta$*, avemha,* $avem^2ha$*, avempa,* $avem^2pa$*, avemtc,* $avem^2tc$*, avemhc,* $avem^2hc$*, taha, tapa, hapa, tatc, tahc, tchc*

Table 8-20. Covariance Parameter for Final PM_{10} EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.7486	0.7513	0.6984
$\hat{\sigma}^2$	0.2131	0.1977	0.1404

Table 8-21. Regression Coefficient for Final PM_{10} EEMs

p	x_p	$\hat{\beta}_p$		
		I	**IA**	**IAC**
0	*Intercept*	-0.9544	-0.9162	0.821
1	*build*	0.2722	0.263	0.3658
2	*birds*	-0.174	-0.1874	0.1941
3	*eavem*	1.1093	1.0842	a
4	*avem*	a	a	0.7447
5	*avem*^{2}	a	a	0.08099
6	*ta*	a	0.07748	0.3429
7	*ha*	a	0.1404	0.1763
8	*pa*	a	-0.03434	0.1246
9	*tc*	a	a	-0.1338
10	*hc*	a	a	-0.3531
11	*buildbirds*	0.05141	0.03733	0.03798
12	*birdseavem*	0.1119	0.1503	a
13	*birdsavem*	a	a	0.176
14	*birdsavem*^{2}	a	a	-0.08347
15	*buildeavem*	-0.1199	-0.1149	a
16	*buildavem*	a	a	0.06747
17	*buildavem*^{2}	a	a	-0.1888
18	*buildta*	a	a	-0.12
19	*buildha*	a	a	-0.07546
20	*buildpa*	a	a	-0.1342
21	*birdsta*	a	a	0.05334
22	*birdsha*	a	a	0.005728
23	*birdspa*	a	a	0.04285
24	*eavemha*	a	-0.1407	a
25	*eavempa*	a	0.0229	a
26	*avemta*	a	a	0.1749
27	*avem*^{2}*ta*	a	a	0.05689
28	*avemha*	a	a	0.03161
29	*avem*^{2}*ha*	a	a	-0.01245
30	*avempa*	a	a	0.03111
31	*avem*^{2}*pa*	a	a	0.01967
32	*taha*	a	a	0.0631
33	*tapa*	a	a	-0.02629
34	*hapa*	a	a	0.0337
35	*avemhc*	a	a	-0.2287
36	*avem*^{2}*hc*	a	a	-0.02424
37	*avemtc*	a	a	-0.1866
38	*avem*^{2}*tc*	a	a	-0.109
39	*buildtc*	a	a	0.1014
40	*buildhc*	a	a	0.05585
41	*birdstc*	a	a	-0.08495
42	*birdshc*	a	a	-0.01929
43	*tahc*	a	a	-0.0308
44	*tatc*	a	a	0.03133
45	*tchc*	a	a	-0.04071

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.

[a] This variable is not included in the EEM.

8.3 EEMs for $PM_{2.5}$

8.3.1 Selecting Datasets

The majority of the data available for developing the $PM_{2.5}$ EEMs were from the Kentucky broiler sites. The CA1B site had an abbreviated collection schedule for $PM_{2.5}$. For $PM_{2.5}$ sampling at the California site, the goal of the NAEMS was to collect data for one week in the winter and summer to represent extreme temperature chemistry. As a result, the CA1B site has a higher percent of missing data (see Table 8-22) when compared to the total number of monitoring days for the grow-out periods.

Table 8-22 shows relatively good completeness for $PM_{2.5}$ emissions for the Kentucky sites, ranging from 69 to 95 percent over the seasons. Data completeness at KY1B-1 House 5 for summer is the lowest data completeness at 69 percent. However, when considered with the data from the CA1B houses, there are a substantial number of observations over all the seasons for EEM development.

Of the 593 $PM_{2.5}$ emissions values available, 14 lacked all of the inventory, ambient and confinement predictor variables needed for EEM development. After these missing data records were removed, the base dataset available for developing the $PM_{2.5}$ EEMs consisted of 579 observations. The EPA then randomly withheld 116 observations (approximately 20 percent of the 579 observations in the base dataset) for the cross-validation data set.

Table 8-22. Data Completeness for $PM_{2.5}$ EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days $PM_{2.5}$ data available	53	43	254	243	593
	Percent complete	8%	7%	88%	91%	32%
Winter	Number of grow-out days	150	153	87	74	464
	Days $PM_{2.5}$ data available	28	28	83	66	205
	Percent complete	19%	18%	95%	89%	44%
Spring	Number of grow-out days	157	158	83	55	453
	Days $PM_{2.5}$ data available	0	0	79	46	125
	Percent complete	0%	0%	95%	84%	28%

Table 8-22. Data Completeness for $PM_{2.5}$ EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
Summer	Number of grow-out days	156	157	55	74	442
	Days $PM_{2.5}$ data available	15	15	38	70	138
	Percent complete	10%	10%	69%	95%	31%
Fall	Number of grow-out days	179	179	63	64	485
	Days $PM_{2.5}$ data available	10	0	54	61	125
	Percent complete	6%	0%	86%	95%	26%

8.3.2 Choosing the Probability Distribution for $PM_{2.5}$

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed $PM_{2.5}$ daily emissions to determine whether using the normal distribution could be justified (see Section 7.2). The histogram in Figure 8-19 shows that many of the $PM_{2.5}$ observations correspond to lower emissions values, with a single peak at emission values less than 40 g. The figure also shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-20 shows histograms of $PM_{2.5}$ emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2, 3, and 4 are skew right, while bin 5 is symmetric and 6 is skew left, though it has fewer data points than the other bins. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew patterns were by no means a consistent pattern. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity ranges) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

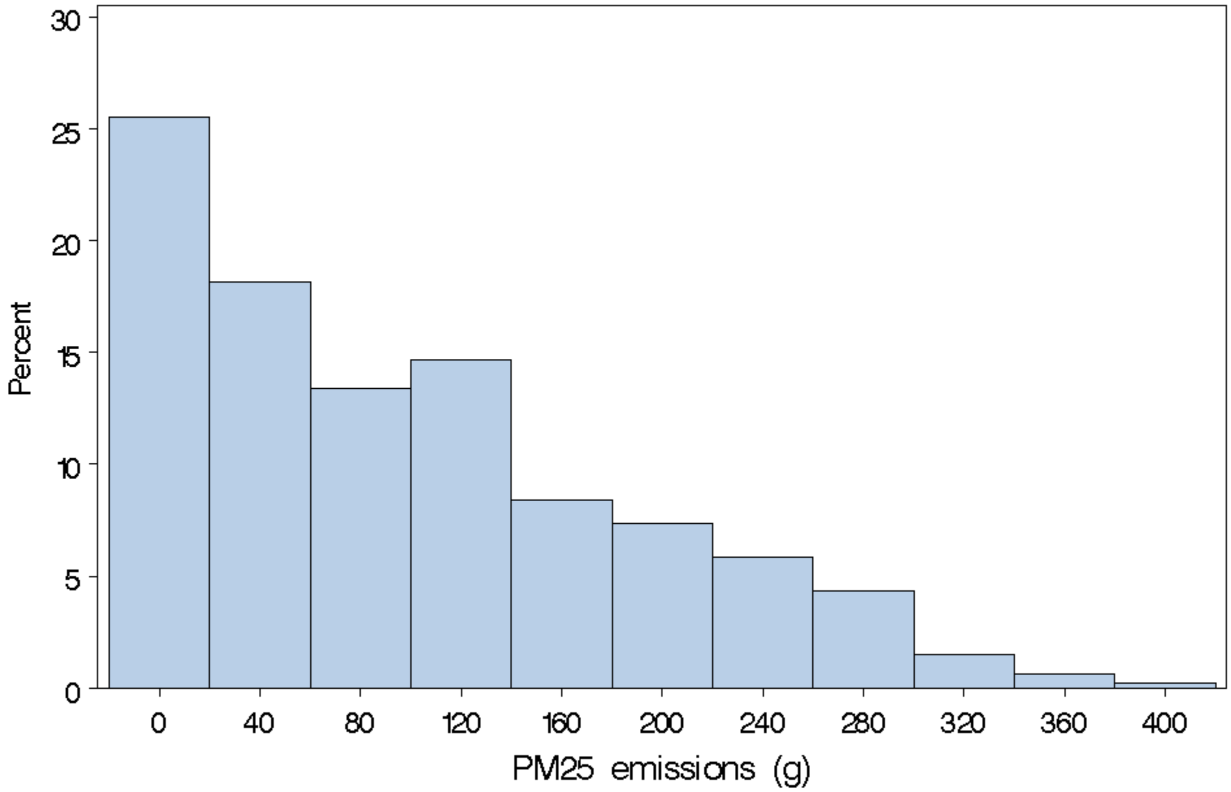


Figure 8-19. Histogram of $PM_{2.5}$ Emissions in the Base Dataset

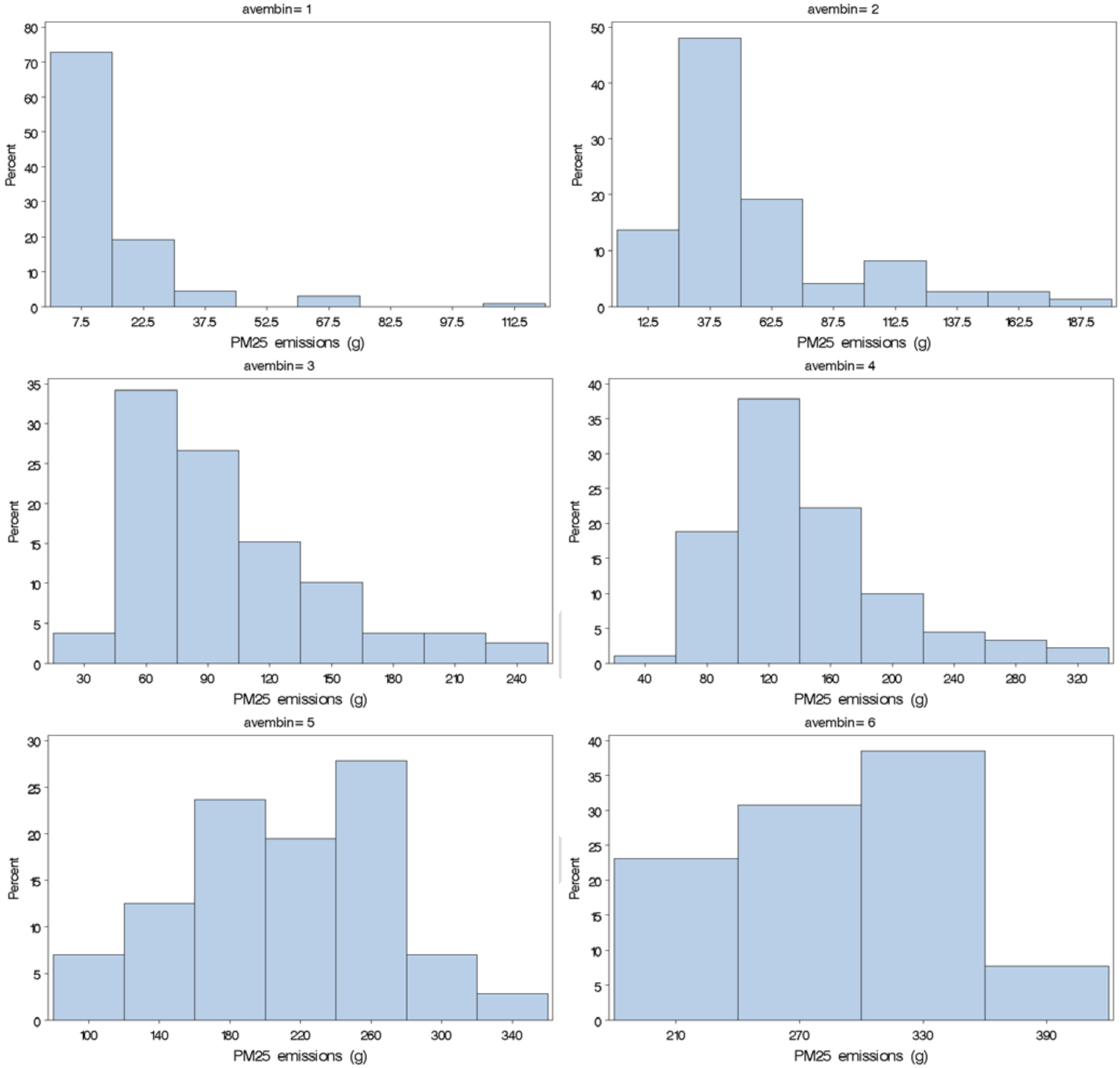


Figure 8-20. Histograms of $PM_{2.5}$ Emissions by *avem Bins**

8.3.3 Developing Candidate Mean Trend Variables for $PM_{2.5}$

8.3.3.1 Choosing Predictor Variable Functional Forms for $PM_{2.5}$

Similar to PM_{10}, plots of $PM_{2.5}$ emissions versus average bird mass, for all houses (Figure 8-21), suggested a positive relationship, with a slight upward curvature. The gradual increasing trend suggested either a quadratic or exponential relationship between $PM_{2.5}$ emissions and the average bird mass. For the $PM_{2.5}$ analysis, the EPA tested two functional forms of average mass: one form based on a quadratic relationship with average mass (*avem* and $avem^2$), and the second form based on an exponential relationship (*eavem*).

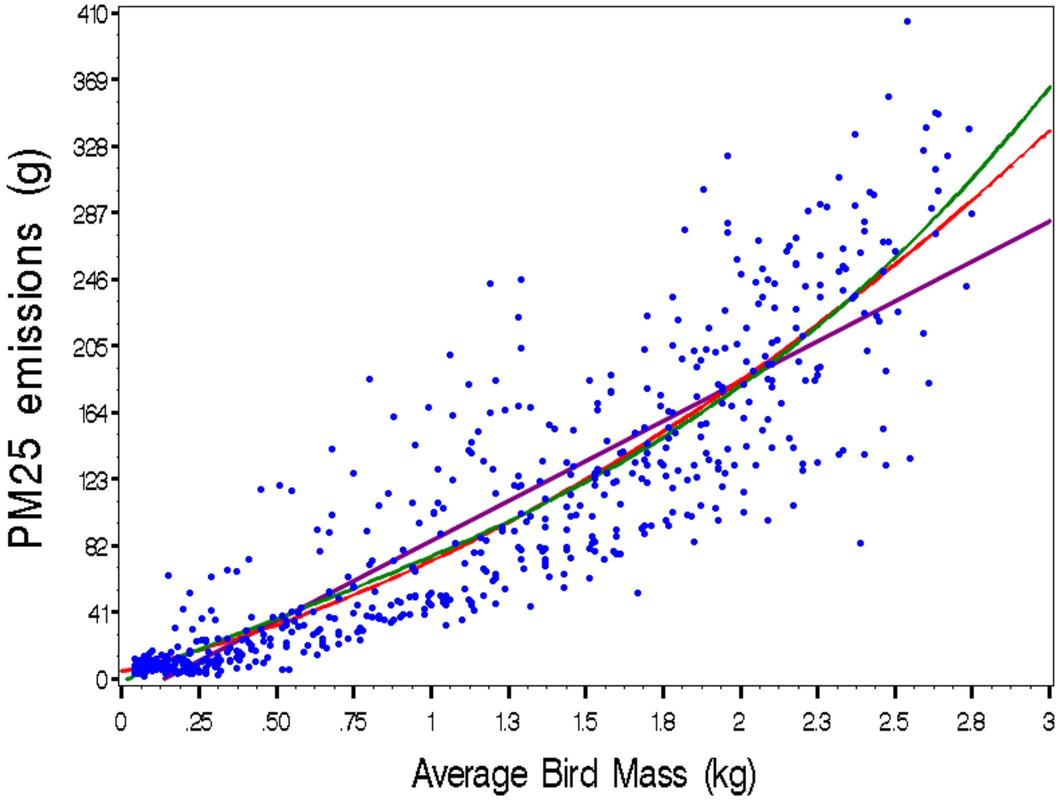


Figure 8-21. $PM_{2.5}$ Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on $PM_{2.5}$ emissions (see Section 7.3.1), the EPA discerned a relationship between $PM_{2.5}$ emissions and the degree of litter accumulation, based on the variance in $PM_{2.5}$ emissions values for lower bird weights (see Figure 8-22). Plots of $PM_{2.5}$ emissions by average mass that are color-coded to indicate the level of *buildup* (Figure 8-22) suggested built-up litter correspond to higher emissions. However, the EPA was unable to draw a definitive conclusion from the scatter plot because only one full flock was raised on fresh bedding between the California and Kentucky sites due to the design of the study.

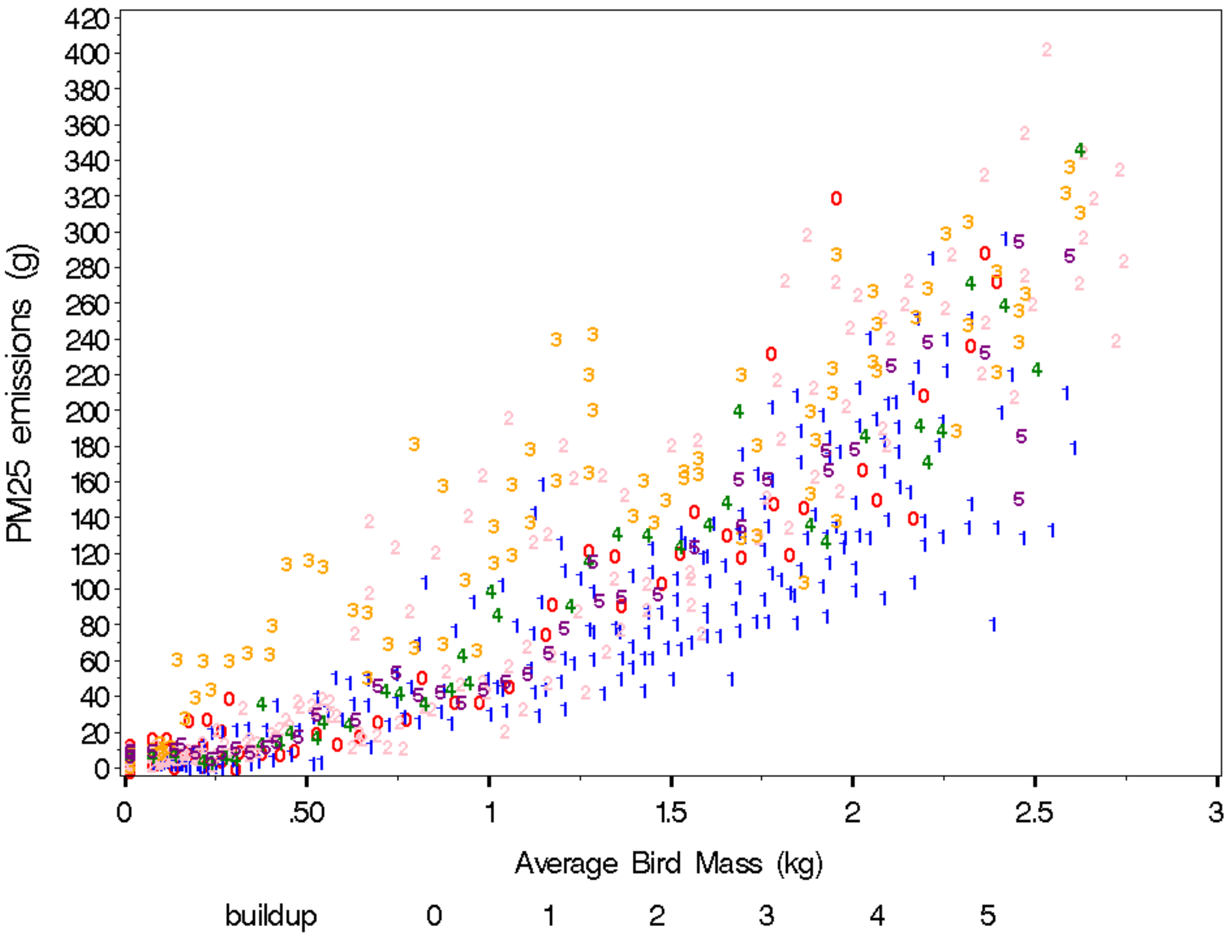


Figure 8-22. Overlay of *buildup* on $PM_{2.5}$ Emissions vs. Average Live Bird Mass

Plots of the build-up indicator parameters (i.e., *buildup*, *build* and *bld*) suggested that the average $PM_{2.5}$ emissions increase for flocks raised on built-up litter. The trend is not as strong as with other pollutants, as there is little difference between the minimum emissions levels between the litter conditions (Figure 8-23), although the average emissions for the litter conditions does vary greatly. Initial test runs without the inclusion of a representation of build-up displayed systematic bias. Because $PM_{2.5}$ is a subset of PM_{10}, the EPA conducted a revised development run was conducted that included *build*, the same representation used in the PM_{10} EEM, to determine if a build-up variable would correct the systematic bias. Initial tests including *build* showed improved results. Therefore, EEM development process for $PM_{2.5}$ proceeded with the inclusion of *build* as the functional form through which the variable *buildup* enters the mean trend function and test its significance using the p-value analysis to determine the final mean trend variables.

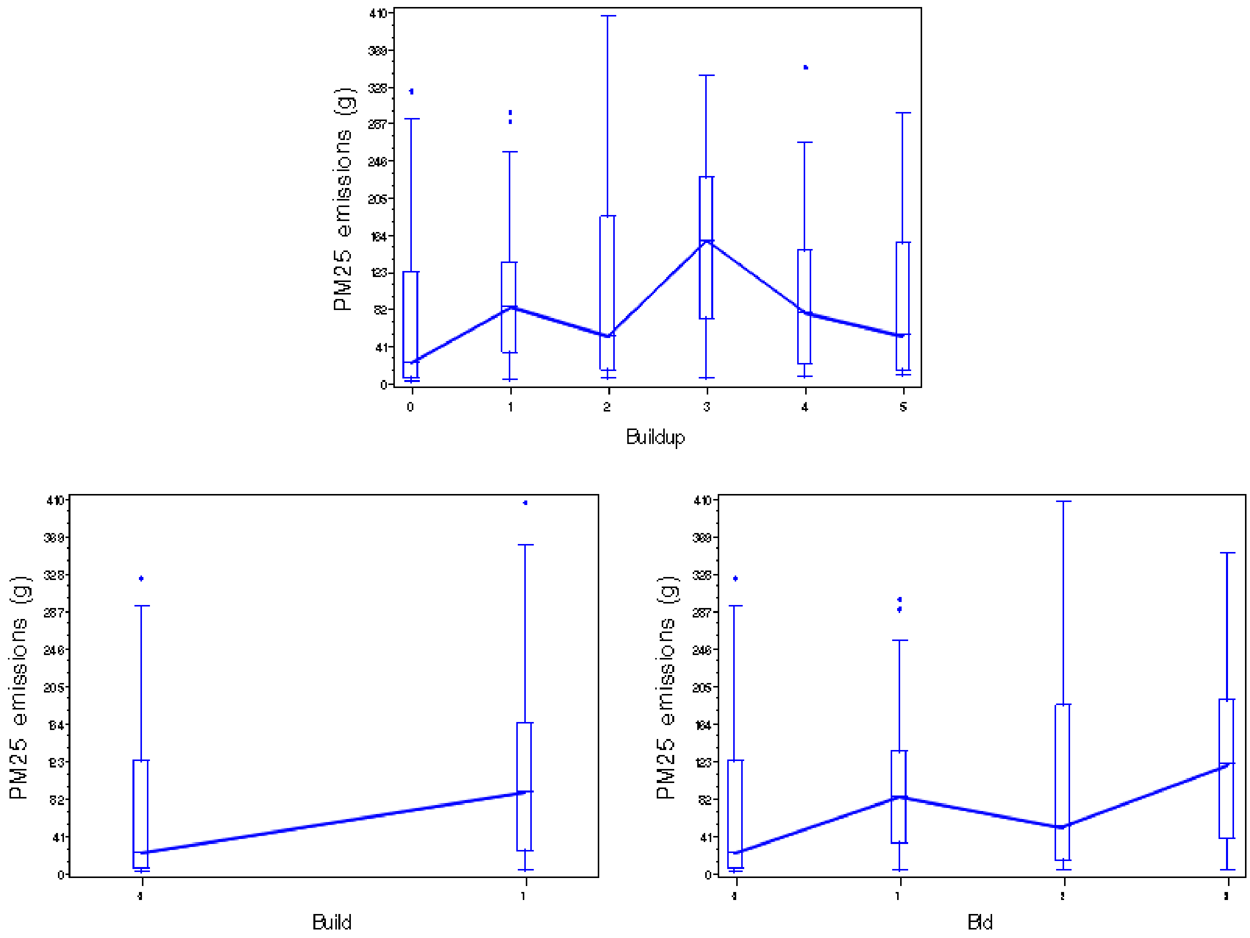
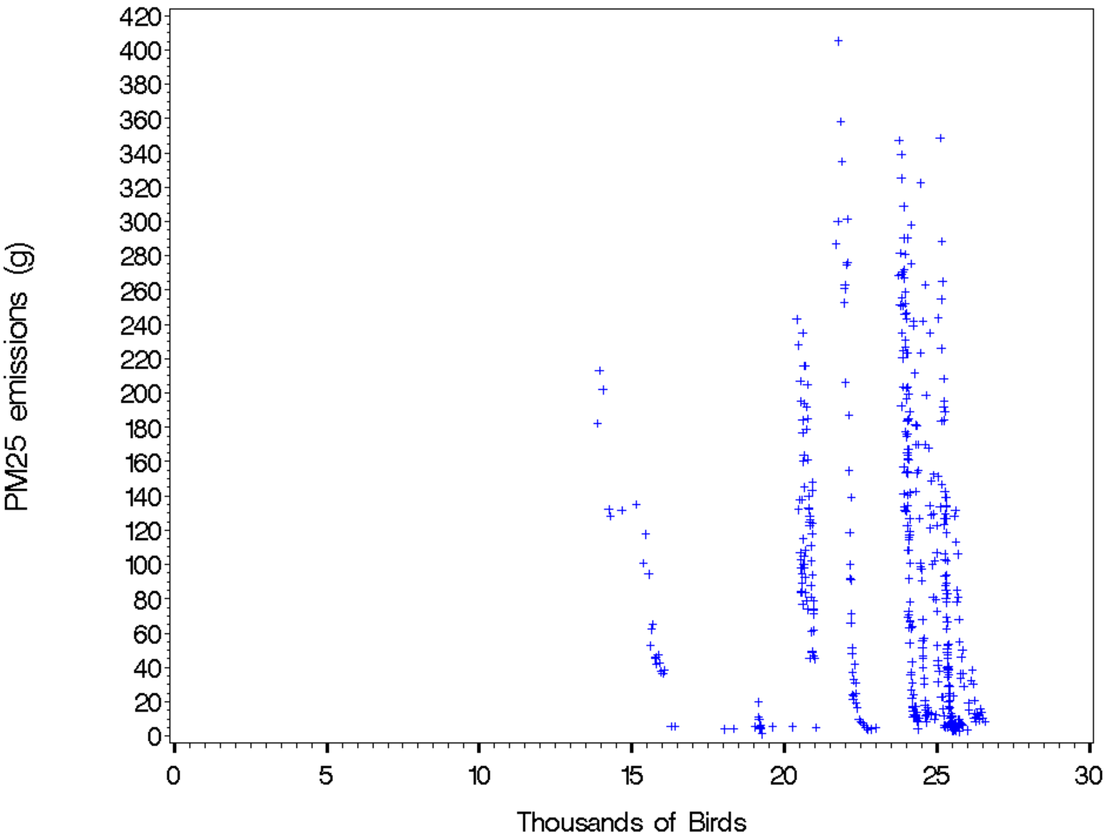


Figure 8-23. Box Plots of $PM_{2.5}$ Emissions vs. Categorical Variables for *buildup*

Figure 8-24**,** Figure 8-25 and Figure 8-26 show the scatter plots of $PM_{2.5}$ emissions by the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, the EPA chose a linear functional form for all variables except average bird mass in developing the $PM_{2.5}$ EEMs.



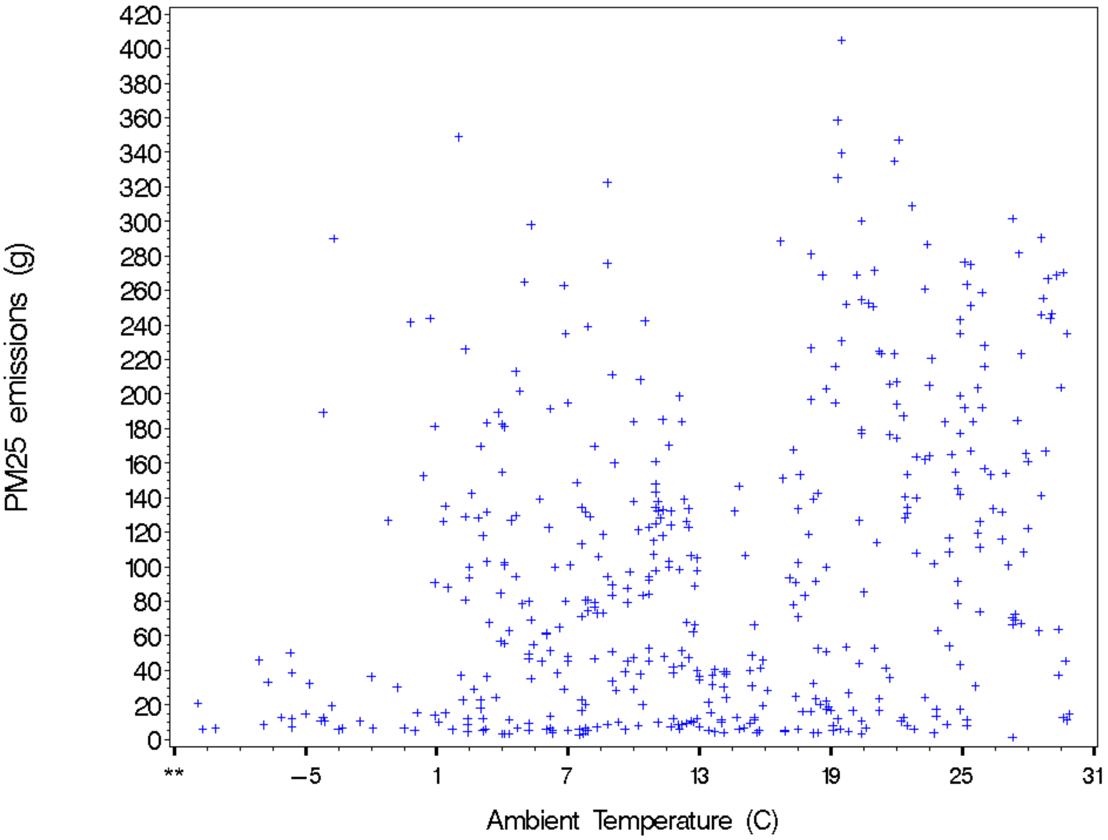


Figure 8-24. PM$_{2.5}$ Emissions vs. Predictor Variables *birds and *ta***

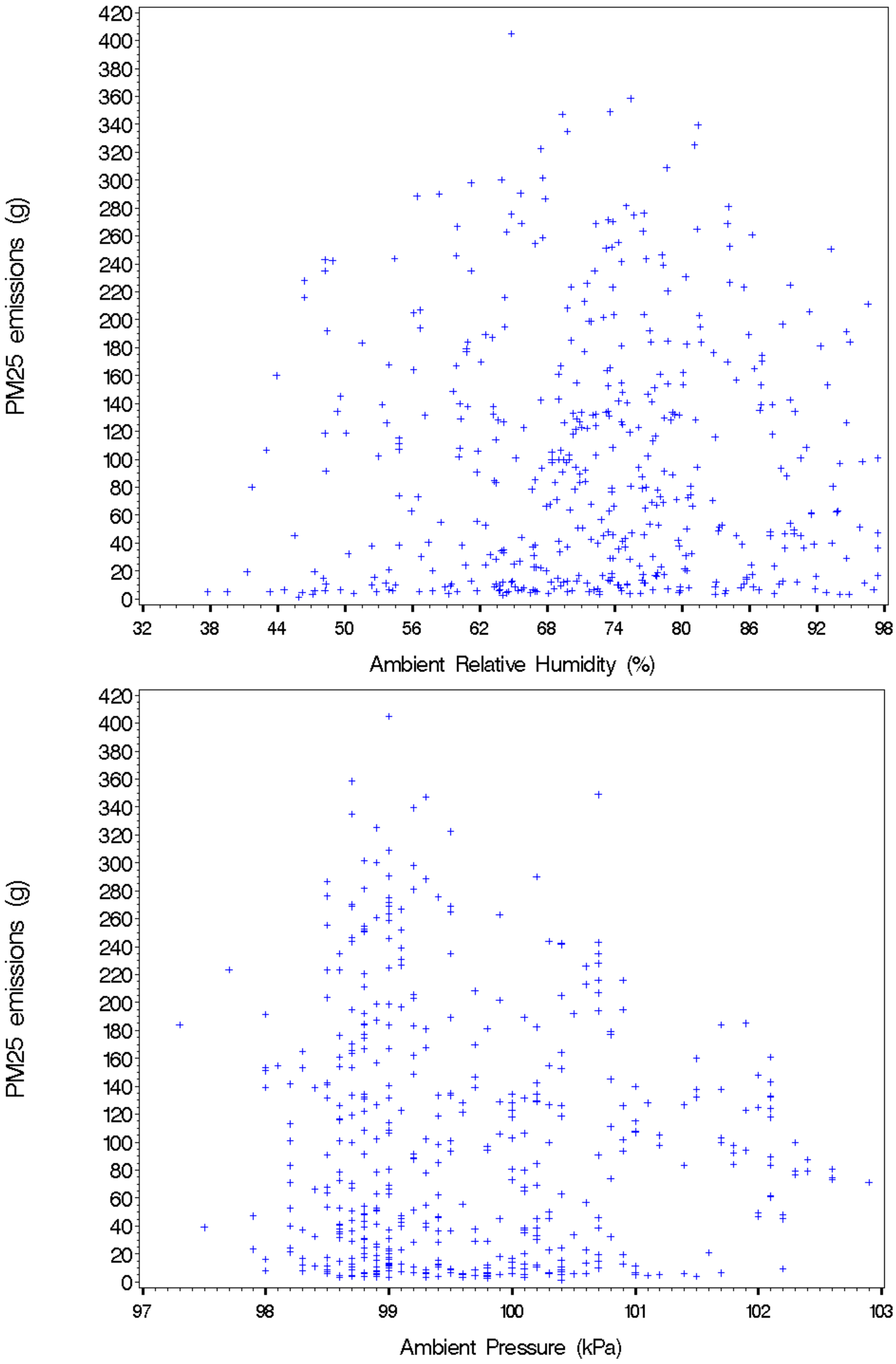


Figure 8-25. $PM_{2.5}$ Emissions vs. Predictor Variables *ha and *pa***

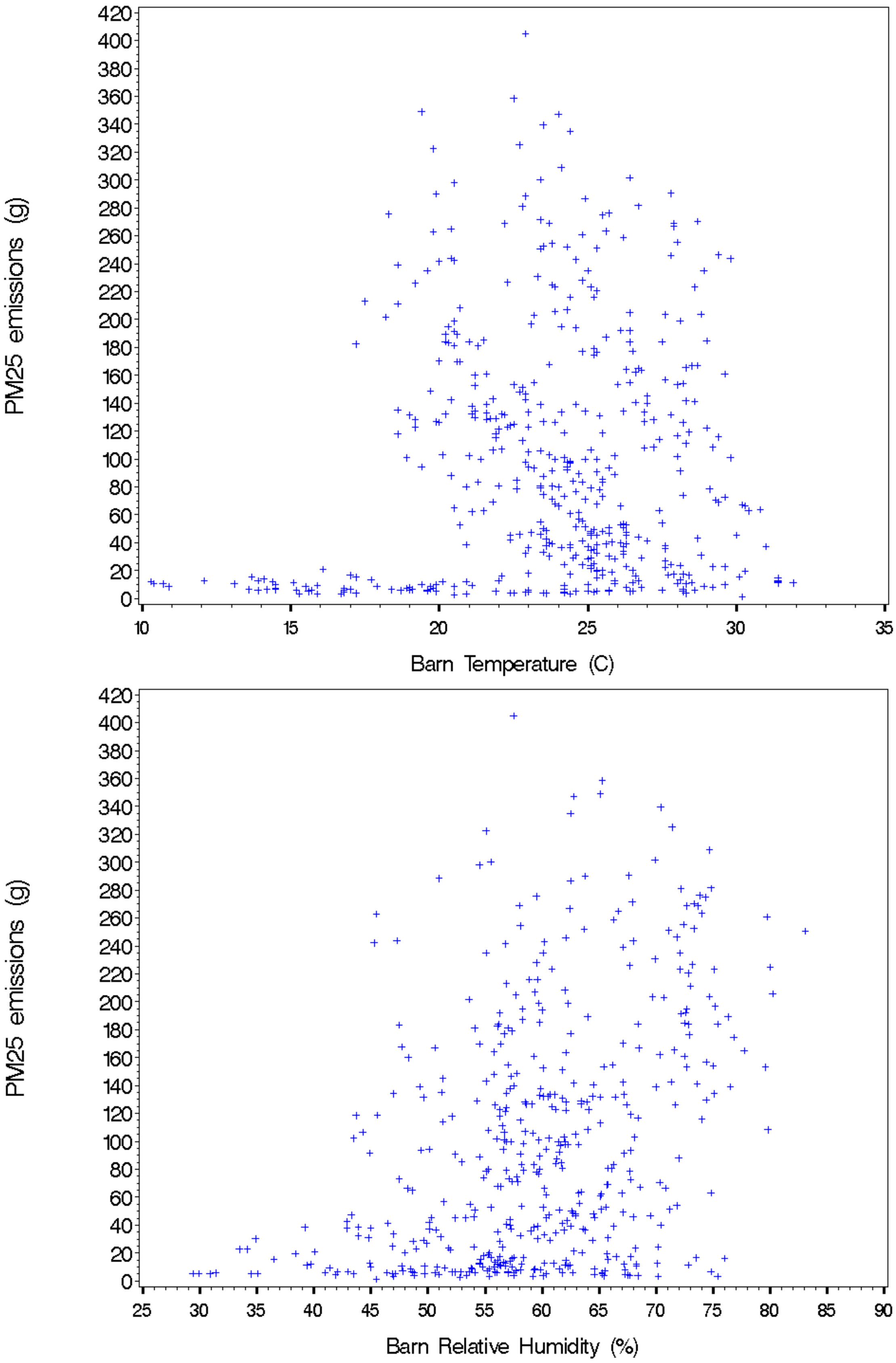


Figure 8-26. PM$_{2.5}$ Emissions vs. Predictor Variables *tc and *hc***

Table 8-23 summarizes the mean trend variables that describe the dependence of $PM_{2.5}$ emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable, *build*. For *avem**, the linear and quadratic terms were collectively considered the main effect for one version of the EEM tested, and the exponential of average bird mass (*eavem*) was considered in a second version of the EEM.

Table 8-23. Summary of Main Effect Mean Trend Variables for $PM_{2.5}$

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$ *eavem*
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.3.3.2 *Creating Mean Trend Variables from Main Effects and Interactions for $PM_{2.5}$*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-23. Initial testing of the R^2 of two-way and three-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of $PM_{2.5}$ EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-24.

Table 8-24. Candidate Mean Trend Variables for the I, IA and IAC $PM_{2.5}$ EEMs

EEM	Main Effects	Two-Way Interaction Terms
I, Quadratic (I EEM_Q)	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
I, Exponential (I EEM_E)	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA, Quadratic (IA EEM_Q)	Same as I EEM_Q plus: *ta, ha, pa*	Same as I EEM_Q plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avempa, avem*^{2}*pa,taha, tapa, hapa*
IA, Exponential (IA EEM_E)	Same as I EEM_E plus: *ta, ha, pa*	Same as I EEM_E plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*
IAC, Quadratic (IAC EEM_Q)	Same as IA EEM_Q plus: *tc, hc*	Same as IA EEM_Q plus: *buildtc, buildhc, birdstc, birdshc, avemtc, avem*^{2}*tc, avemhc, avem*^{2}*hc, tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC, Exponential (IAC EEM_E)	Same as IA EEM_E plus: *tc, hc*	Same as IA EEM_E plus: *buildtc, buildhc, birdstc, birdshc, eavemtc, eavemhc, tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.3.3.3 *Centering and Scaling Predictors for $PM_{2.5}$*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the $PM_{2.5}$ final EEMs are presented in Table 8-25.

Table 8-25. Centering and Scaling Reference Values for Continuous $PM_{2.5}$ Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	24	2.8
*avem**	1.1	0.76
*ta**	13	8.8
*ha**	72	12
*pa**	99	0.73
*tc**	27	3.5
*hc**	58	9.7

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem or avem*^{2}) and the creation of interaction terms (e.g., *avemta*).

8.3.4 Selecting Final Mean Trend Variables for $PM_{2.5}$

8.3.4.1 Inventory EEM for $PM_{2.5}$

Predictions based on the I EEM_Q developed systematic bias for the slope, γ_0, prior to completing the backwards elimination process. Predictions based on the I EEM_E completed the backward elimination process without developing any systematic bias.

The selected form of the I EEM_Q contained all the initial interaction terms (Table 8-26). This EEM displayed the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (lowest RMSE and highest R^2), without exhibiting systematic bias.

The selected form of the I EEM_E occurred after one backward elimination step, the removal of the interaction term *buildbirds*. The selected version of the I EEM_E had the best fit-statistics against the base dataset and good fit statistics versus the cross-validation dataset. The fit statistics for the final candidate I EEMs are presented in Table 8-27. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Overall, the I EEM_Q has slightly better fit statistics against both the base and cross-validation dataset. Therefore, the EPA selected the quadratic version of the I EEM for $PM_{2.5}$ emissions.

Table 8-26. Final Candidate I EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-Way Interaction Terms
I EEM_Q	*build, birds, avem,* $avem^2$	*buildbirds, buildavem,* $buildavem^2$*, birdsavem,* $birdsavem^2$
I EEM_E	*build, birds, eavem*	*buildeavem, birdseavem*

Table 8-27. Final Candidate I EEM Fit Statistics for $PM_{2.5}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0 (g)	γ_1
I EEM_Q	4,320	4,327	97	168	36	0.84	9.6 ✓	0.95 ✓
I EEM_E	4,355	4,363	99	201	43	0.77	3.4 ✓	0.96 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.3.4.2 *Inventory and Ambient EEM for $PM_{2.5}$*

The IA EEM_Q developed systematic bias for the slope, γ_0, prior to completing the backwards elimination process, and IA EEM_E completed the backward elimination process without any systematic bias.

The selected forms of the IA EEM_Q and IA EEM_E are presented in Table 8-28. The best version of the IA EEM_Q displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) and the smallest confidence interval width and best coverage percentage, without exhibiting systematic bias. The mean trend variables for the selected version of the IA EEM_E included all the interaction terms. This version of the IA EEM_E had the best fit-statistics against the base dataset (lowest BIC and -2LL values, and smallest confidence interval width) and the cross-validation dataset (lowest RMSE and highest R^2). The fit statistics for the selected IA EEM_Q and IA EEM_E are presented in Table 8-29.

The IA EEM_Q generally had better fit statistic than the IA EEM_E version. The IA EEM_E version did have slightly better base dataset fit (smaller -2LL and BIC); however, the IA EEM_Q version was better with respect to all other fit statistics. Therefore, the EPA selected the quadratic version of the IA EEM for $PM_{2.5}$ emissions.

Table 8-28. Final Candidate IA EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-way Interaction Terms
IA EEM_Q	*build, birds, avem, avem^2, ta, ha, pa*	*buildavem, buildavem^2, buildpa, birdsavem, birdsavem^2, birdsta, birdspa, avemta, avem^{2}ta, avemha, avem^{2}ha, avempa, avem^{2}pa, taha, tapa, hapa*
IA EEM_E	*build, birds, eavem, ta, ha, pa*	*buildbirds, buildeavem, buildta, buildha, buildpa, birdseavem, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*

Table 8-29. Final Candidate IA EEM Fit Statistics for $PM_{2.5}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0(g)	γ_1
IA EEM_Q	4,208	4,216	97	144	28	0.90	7.6 ✓	0.96 ✓
IA EEM_E	4,210	4,217	99	196	39	0.80	1.4 ✓	0.98 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.3.4.3 *Inventory, Ambient and Confinement EEM for $PM_{2.5}$*

The IAC EEM_Q regularly developed systematic bias for γ_0 prior to completing the backwards elimination process. The IAC EEM_Q also developed systematic bias for the intercept, γ_1, just prior to completing the backward elimination process. The IAC EEM_E completed the backward elimination process without any systematic bias.

The mean trend variables for the selected version of the IAC EEM_Q and IAC EEM_E are presented in Table 8-30. The IAC EEM_Q displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) coupled with a small confidence interval width and approximately 95 percent inclusion in the confidence interval, without displaying systematic bias. The IAC EEM_E displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) coupled with one of the smallest confidence interval widths and approximately 95 percent inclusion in the confidence interval. The fit statistics for both the selected IAC EEM_Q and IAC EEM_E are presented in Table 8-31. Overall, the IAC EEM_Q had slightly better fit statistics than the IAC EEM_E. Therefore, the EPA selected the quadratic version of the IAC EEM for $PM_{2.5}$ emissions.

Table 8-30. Final Candidate IAC EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-way Interaction Terms
IAC EEM_Q	*build, birds, avem, avem^2, ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem^2, buildta, buildha, buildpa, buildtc, buildhc, birdsavem, birdsavem^2, birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem^{2}ta, avemtc, avem^{2}tc, avemhc, avem^{2}hc, taha, tapa, hapa, tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC EEM_E	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildeavem, buildtc, birdseavem, birdsta, birdspa, eavemta, eavempa, eavemtc, eavemhc, taha, hapa, tatc, tahc*

Table 8-31. Final Candidate IAC EEM Fit Statistics for $PM_{2.5}$

Candidate EEM	Fit Statistics							
	-2LL	BIC	% in PI	Width (g)	RMSE (g)	R^2	γ_0 (g)	γ_1
IAC EEM_Q	4,086	4,091	97	142	27	0.90	7.6 ✓	0.95 ✓
IAC EEM_E	4,169	4,176	98	165	32	0.87	-2.5 ✓	1.0 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.3.5 Summary of Final Results for the I, IA and IAC EEMs for $PM_{2.5}$

A summary of the final mean trends terms for the $PM_{2.5}$ EEMs are provided in Table 8-32. The covariance parameters for the final forms of the EEMs are listed in Table 8-33.The coefficients for the EEM mean trend variables are listed in Table 8-34. The value of each main effect variable (x_p) must be centered and scaled when using the terms in Equation 7-1. The centering and scaling factors for the predictor variable for the final $PM_{2.5}$ EEMs are presented in Table 8-25.

Table 8-32. Final EEM Mean Trend Variables for $PM_{2.5}$

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
IA	*build, birds, avem, avem*^{2}*, ta, ha, pa*	*buildavem, buildavem*^{2}*, buildpa, birdsavem, birdsavem*^{2}*, birdsta, birdspa, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avempa, avem*^{2}*pa, taha, tapa, hapa*
IAC	*build, birds, avem, avem*^{2}*, ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem*^{2}*, buildta, buildha, buildpa, buildtc, buildhc, birdsavem, birdsavem*^{2}*, birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem*^{2}*ta, avemtc, avem*^{2}*tc, avemhc, avem*^{2}*hc, taha, tapa, hapa, tatc, tahc, hatc, hahc, patc, pahc, tchc*

Table 8-33. Covariance Parameter for Final $PM_{2.5}$ EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.7640	0.6833	0.6941
$\hat{\sigma}^2$	1,504.72	1031.15	981.22

Table 8-34. Regression Coefficient for Final $PM_{2.5}$ EEMs

p	x_p	$\hat{\beta}_p$		
		I	**IA**	**IAC**
0	*Intercept*	73.69	57.76	78.21
1	*build*	15.64	28.45	9.22
2	*birds*	5.66	15.35	-14.10
3	*avem*	75.14	72.83	73.25
4	$avem^2$	17.2	28.31	-5.81
5	*ta*	a	27.22	29.64
6	*ha*	a	-5.20	12.39
7	*pa*	a	11.23	0.19
8	*tc*	a	a	-8.24
9	*hc*	a	a	-41.36
10	*buildbirds*	7.27	a	38.69
11	*buildavem*	-0.27	0.50	-3.01
12	$buildavem^2$	-6.31	-15.31	3.79
13	*buildta*	a	a	-2.80
14	*buildha*	a	a	-13.78
15	*buildpa*	a	-7.14	4.74
16	*buildtc*	a	a	9.99
17	*buildhc*	a	a	30.48
18	*birdsavem*	7.81	10.44	9.35
19	$birdsavem^2$	0.44	-2.30	2.03
20	*birdsta*	a	9.23	-2.40
21	*birdsha*	a	a	-0.56
22	*birdspa*	a	3.61	2.72
23	*birdstc*	a	a	6.35
24	*birdshc*	a	a	6.54
25	*avemta*	a	8.81	7.05
26	$avem^2ta$	a	-9.62	0.78
27	*avemha*	a	-3.40	a
28	$avem^2ha$	a	-0.06	a
29	*avempa*	a	1.48	a
30	$avem^2pa$	a	-2.82	a
31	*avemtc*	a	a	-6.23
32	$avem^2tc$	a	a	-10.27
33	*avemhc*	a	a	-8.14
34	$avem^2hc$	a	a	1.07
35	*taha*	a	-3.34	-4.27
36	*tapa*	a	-2.31	-2.01
37	*hapa*	a	1.06	1.35
38	*tatc*	a	a	3.28
39	*tahc*	a	a	13.00
40	*hatc*	a	a	0.46
41	*hahc*	a	a	-1.36
42	*patc*	a	a	2.35
43	*pahc*	a	a	2.89
44	*tchc*	a	a	-1.83

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.

[a] This variable is not included in the EEM.

8.4 EEMs for TSP

8.4.1 Selecting Datasets

The majority of the data available for developing the TSP EEMs were from the Kentucky broiler sites. The CA1B site had an abbreviated collection schedule for TSP. For TSP sampling at the California site, the goal of the NAEMS was to collect data for one week every eight weeks.

As a result, the CA1B site has a higher percent of missing data (see Table 8-35) when compared to the total number of monitoring days for the grow-out periods.

Overall data completeness for TSP was 33 percent of the grow-out period days. Table 8-35 shows that TSP emissions values were available for just over 5 percent of the study period for the CA1B houses. The Kentucky sites had better completeness with seasonal completeness ranging from 84 to 98 percent. The available data are evenly distributed across the seasons.

Of the 601 TSP emission readings, 16 did not have values for the inventory, ambient and confinement predictor variables necessary for the EEM development. After these data records were removed, the base dataset for TSP EEM development consisted of 585 records. The EPA then randomly withheld 107 observations (approximately 18 percent of the 585 observations) to serve as the cross-validation data set.

Table 8-35. Data Completeness for TSP EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days TSP data available	37	39	278	247	601
	Percent complete	6%	6%	97%	93%	33%
Winter	Number of grow-out days	150	153	87	74	464
	Days TSP data available	7	7	83	68	165
	Percent complete	5%	5%	95%	92%	36%
Spring	Number of grow-out days	157	158	83	55	453
	Days TSP data available	8	15	79	46	148
	Percent complete	5%	9%	95%	84%	33%
Summer	Number of grow-out days	156	157	55	74	442
	Days TSP data available	10	12	54	70	146
	Percent complete	6%	8%	98%	95%	33%
Fall	Number of grow-out days	179	179	63	64	485
	Days TSP data available	12	5	62	63	142
	Percent complete	7%	3%	98%	98%	29%

8.4.2 Choosing the Probability Distribution for TSP

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed daily TSP emissions to determine whether using the normal distribution could be justified. The histogram in Figure 8-27 shows that many of the TSP observations correspond to lower values, with a single peak at emissions values less than 0.8 kg. Also, the figure shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-28, for example, shows histograms of TSP emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1 and 2 are skew right while those for bins 3, 4, 5 and 6 are more symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew-right pattern is by no means ubiquitous. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

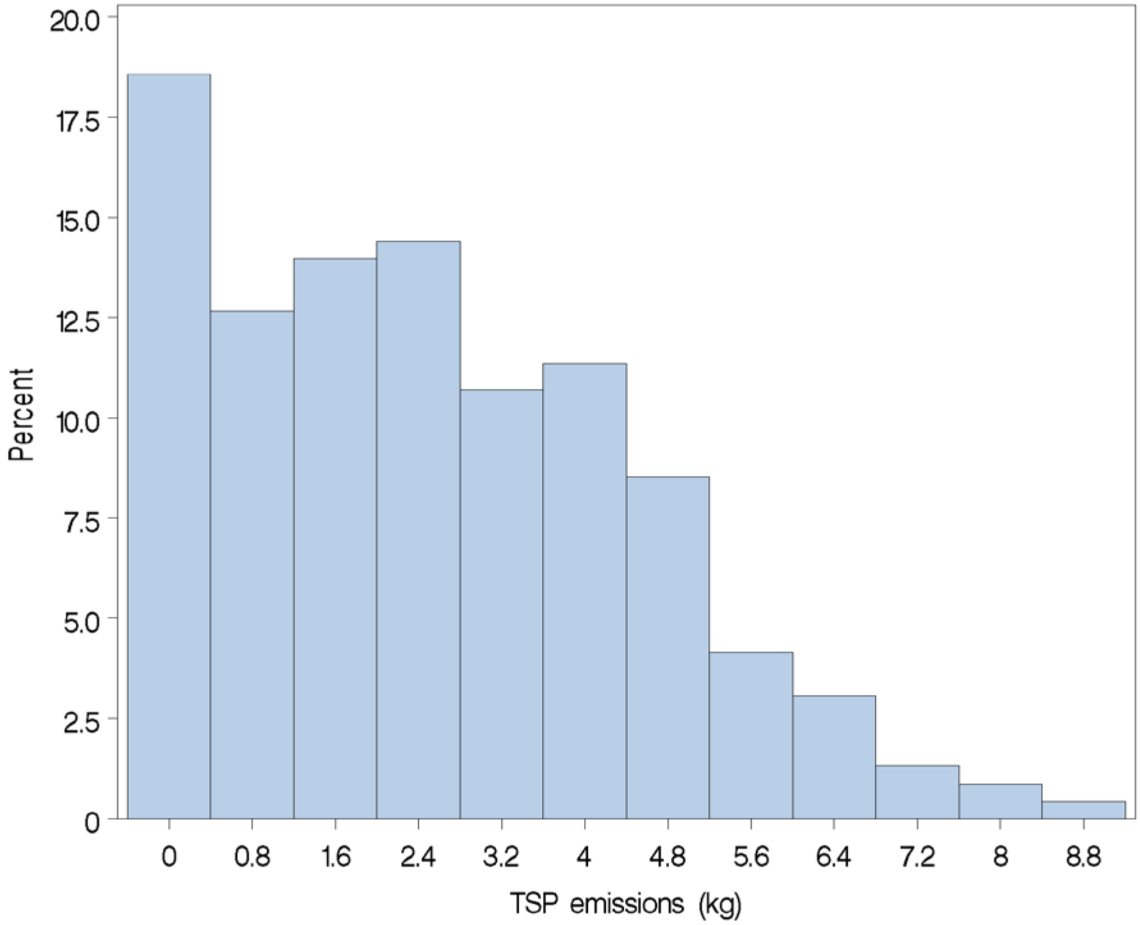


Figure 8-27. Histogram of TSP Emissions in the Base Dataset

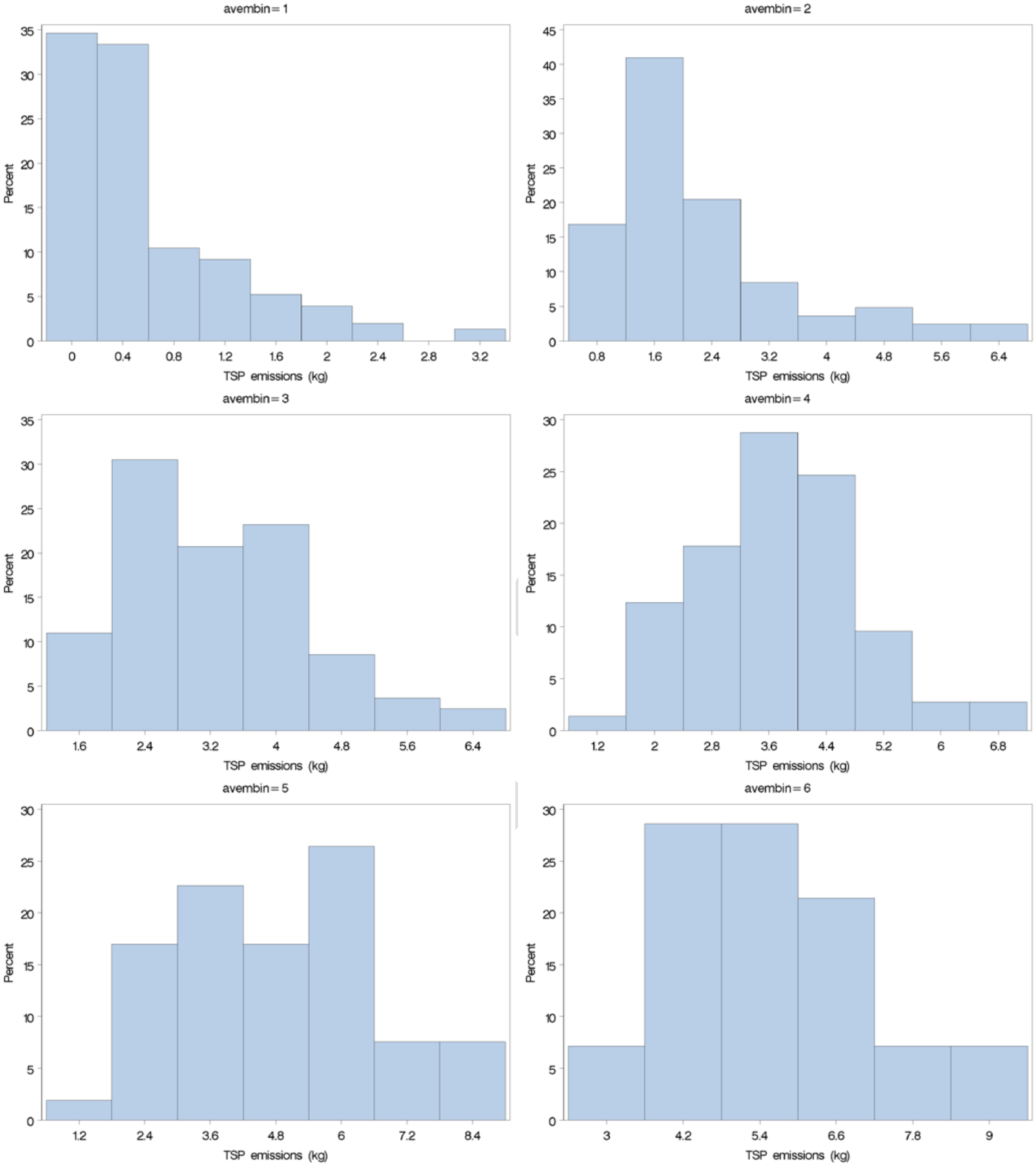


Figure 8-28. Histograms of TSP Emissions by *avem Bins**

8.4.3 Developing Candidate Mean Trend Variables for TSP

8.4.3.1 Choosing Predictor Variable Functional Forms for TSP

Plots of TSP emissions versus average bird mass, for all houses, suggested a positive relationship, with a slight curvature that levels off at higher average bird masses. Figure 8-29 shows a scatter plot of TSP emissions versus average mass, with overlays of linear, quadratic and cubic regressions. The gradual increasing trend suggested a quadratic relationship between TSP emissions and the average bird mass. Accordingly, the EPA tested one form of the EEM based on a quadratic relationship with average mass (*avem and avem*^{2}).

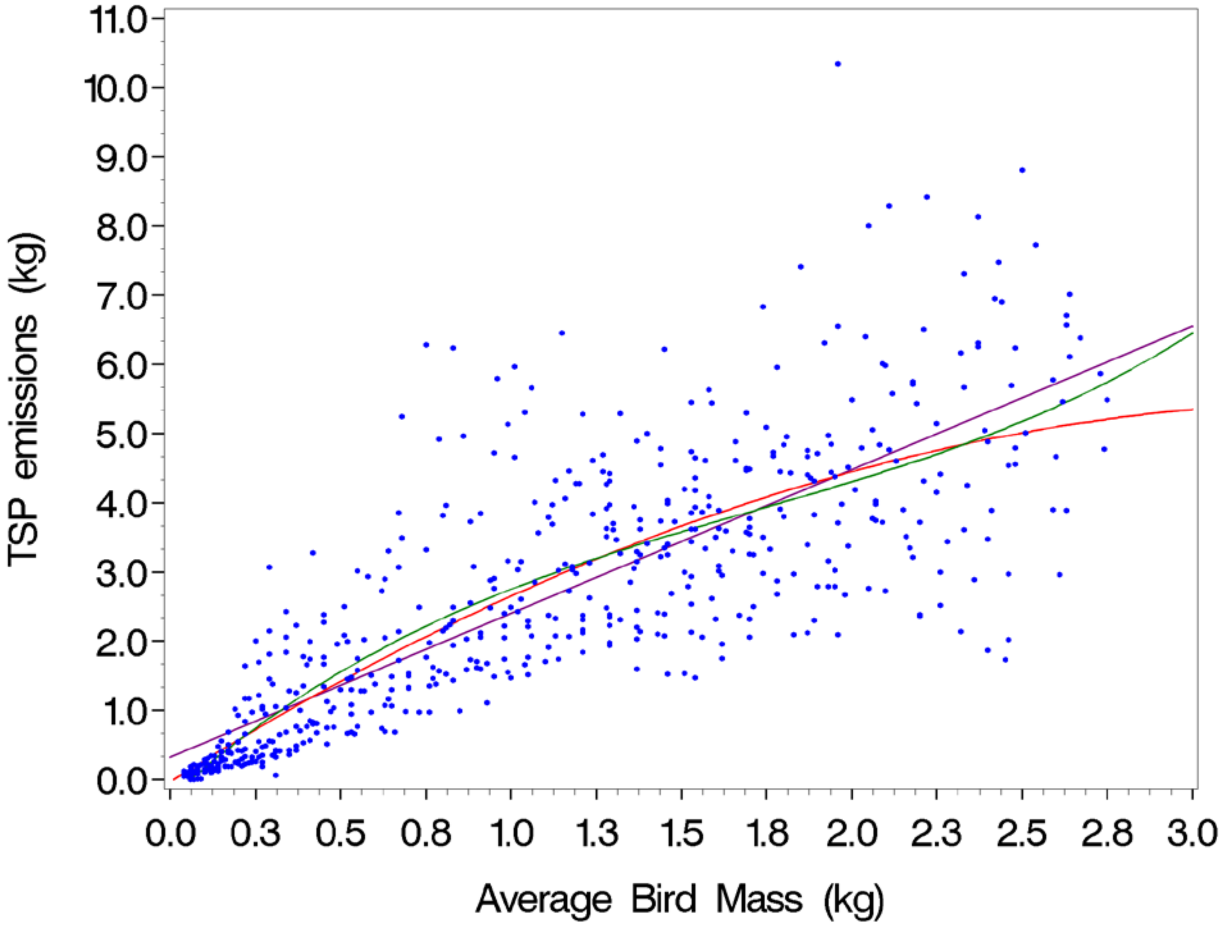


Figure 8-29. TSP Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on TSP emissions (see Section 7.3.1), the EPA discerned a relationship between TSP emissions and the degree of litter accumulation, based on the variance in TSP emissions values for lower bird weights (see Figure 8-30). When TSP emissions are plotted by average mass and color-coded to indicate the level of buildup, there is some indication that higher emissions correspond to built-up litter at any animal mass; however, there is substantial variability in the data. Further investigations showed that the increased variance could not be attributed to differences in sites (Figure 8-31), as all three sites show the same variability across the grow-out period.

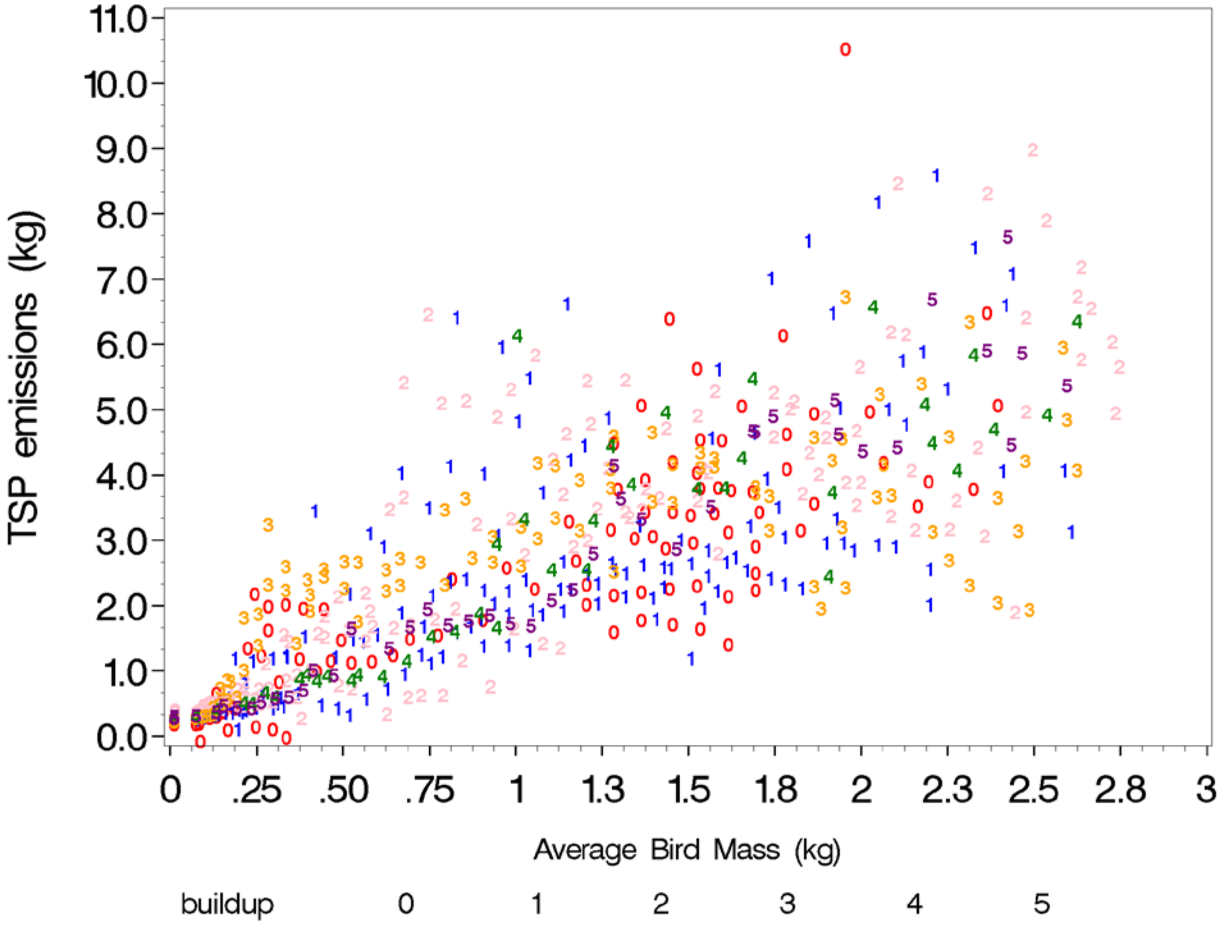


Figure 8-30. Overlay of *buildup* on TSP Emissions vs. Average Live Bird Mass

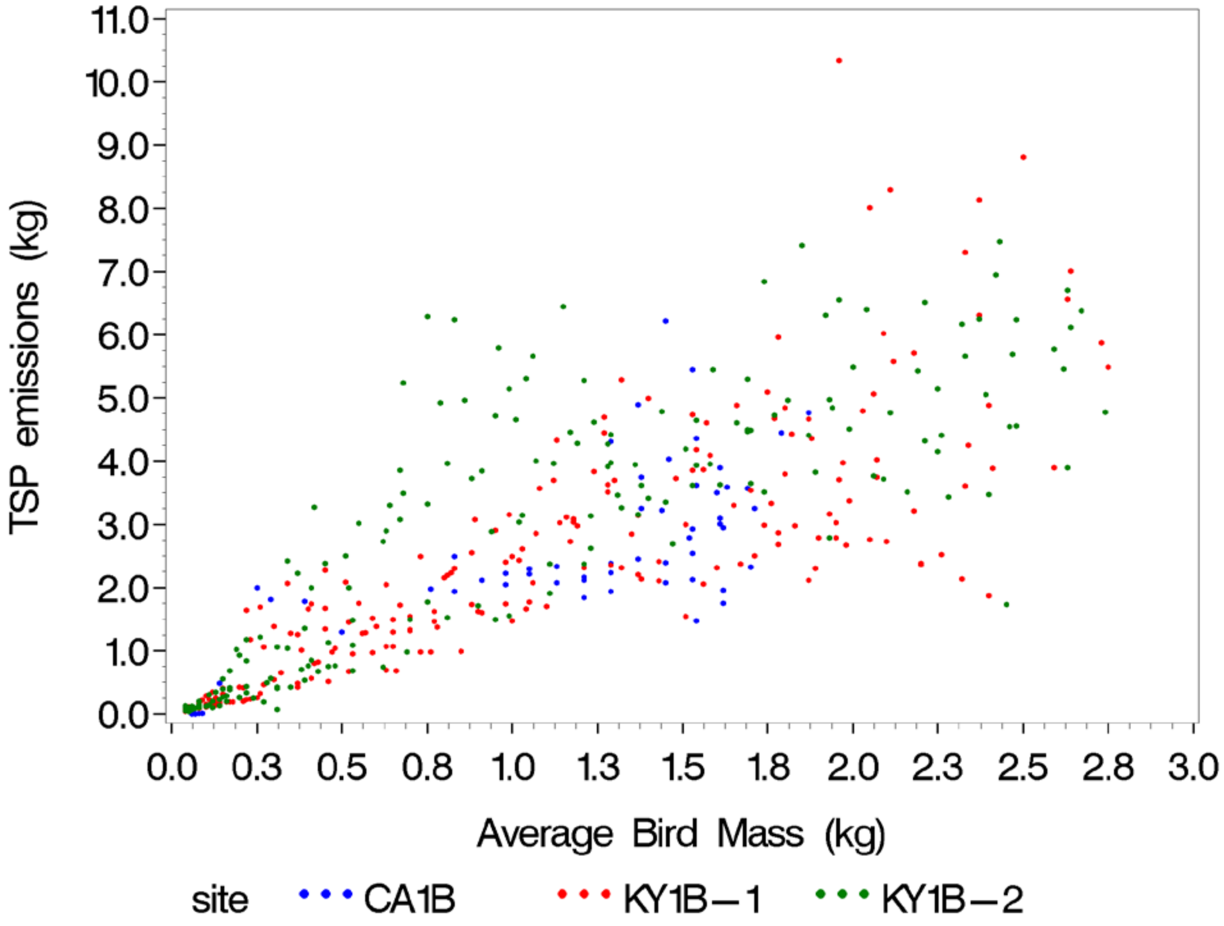


Figure 8-31. TSP Emissions vs. Average Bird Mass, Color-coded by Site

Plots of the build-up indicator parameters (i.e., *buildup*, *build*, *bld*) suggested average TSP emissions do not increase for flocks raised on built-up litter, because there is little difference in the minimum emissions levels between the litter conditions (Figure 8-32), and only a slight difference in average values. The EPA decided to include *build* as the functional form through which the variable *buildup* entered the mean trend function and test its significance using the p-value analysis to determine the final mean trend variables.

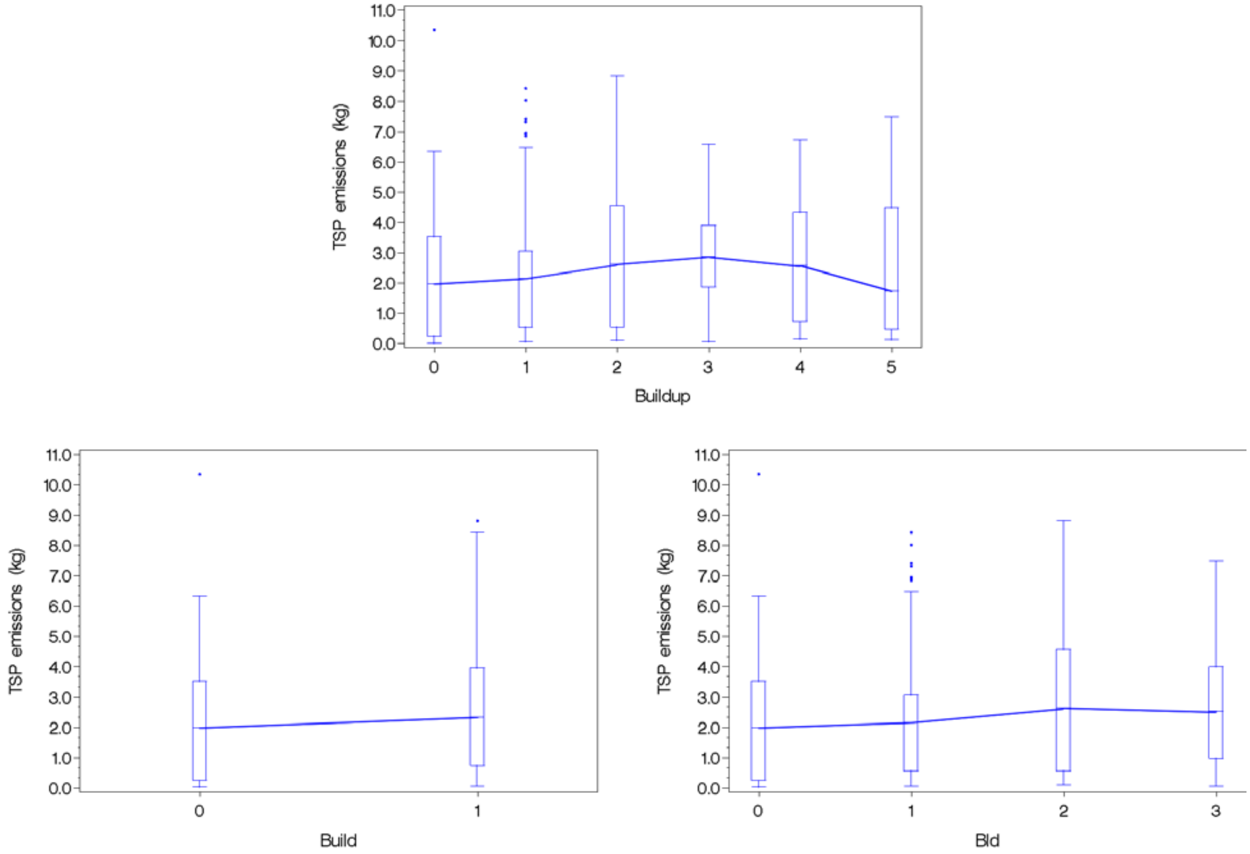


Figure 8-32. Box Plots of TSP Emissions vs. Categorical Variables for *buildup*

Figure 8-33, Figure 8-34, and Figure 8-35 show the scatter plots of TSP emissions versus the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, and the absence of a process-based reason to do otherwise, the EPA chose a linear functional form in developing the TSP EEMs (See Table 8-36).

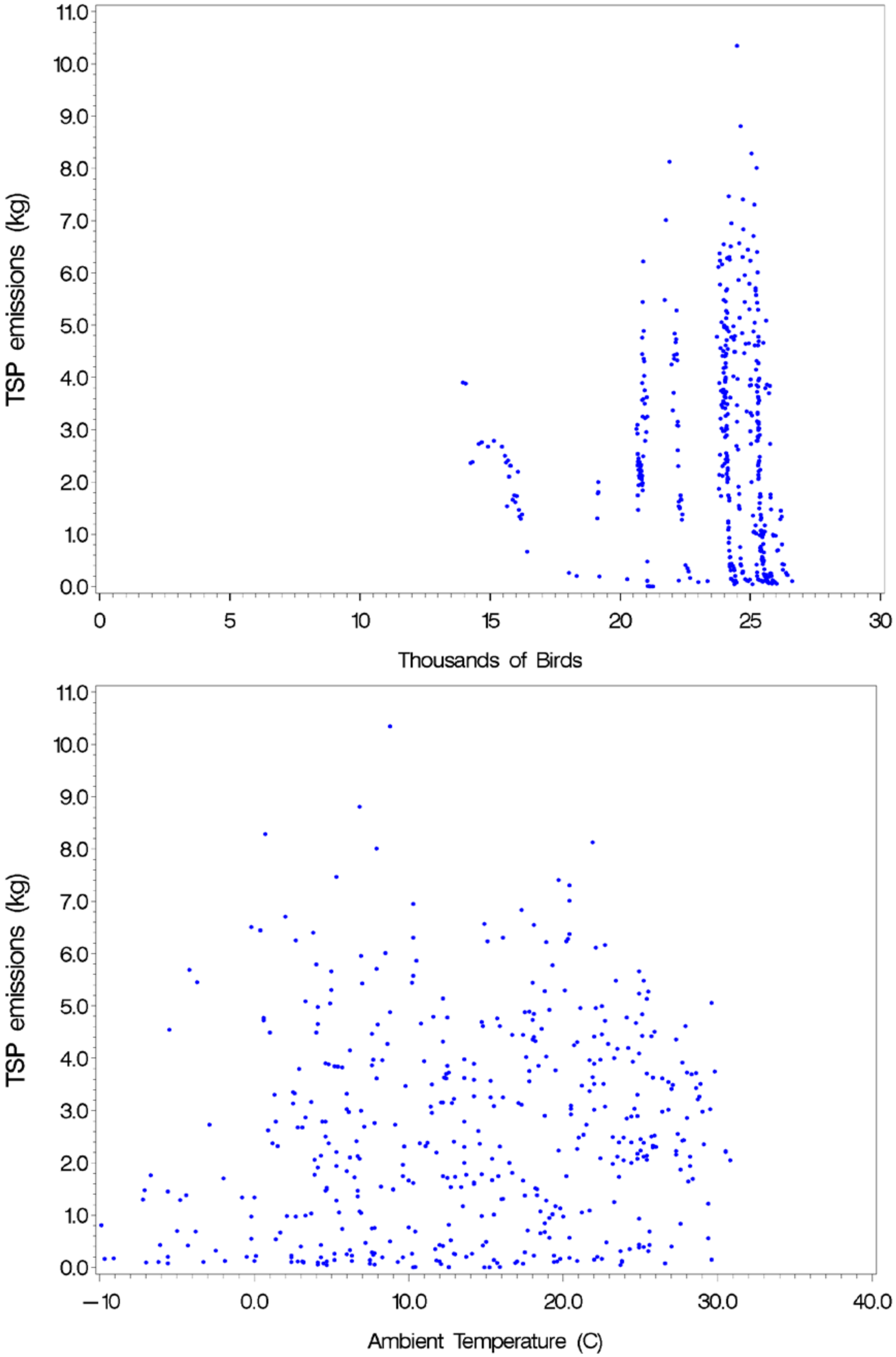
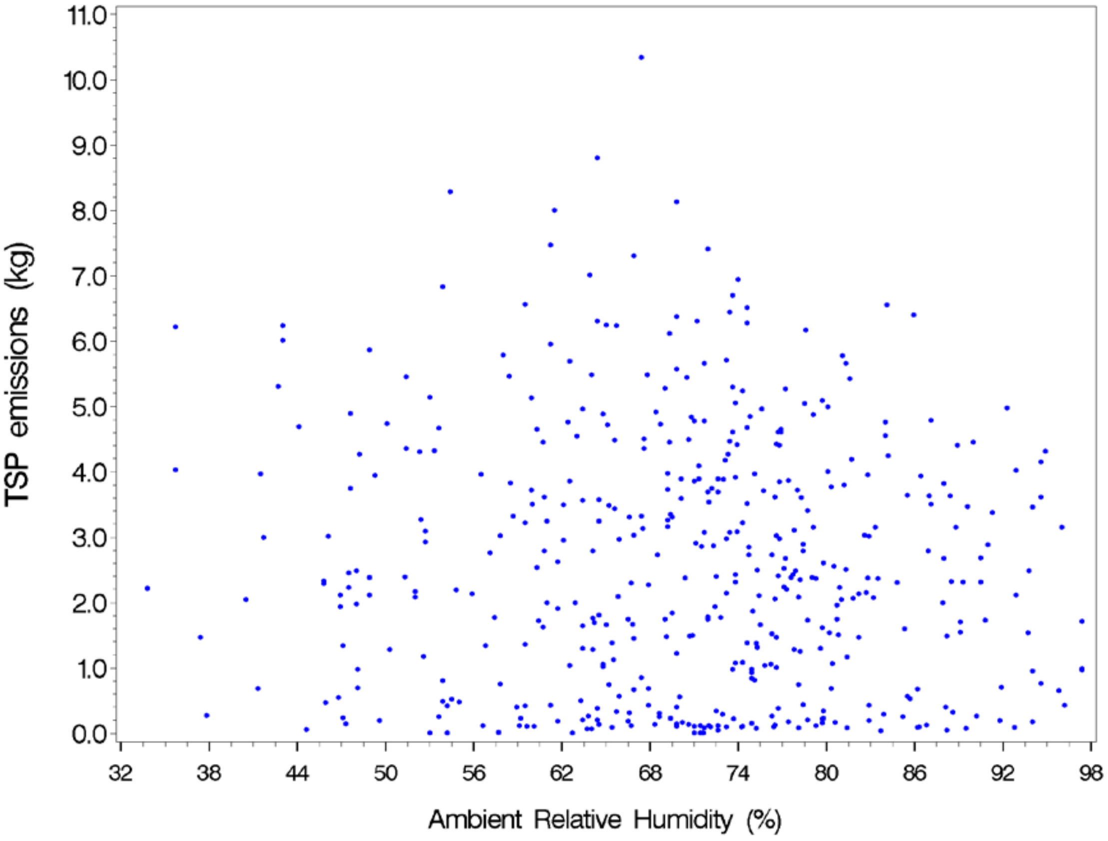


Figure 8-33. TSP Emissions vs. Predictor Variables *birds and *ta***



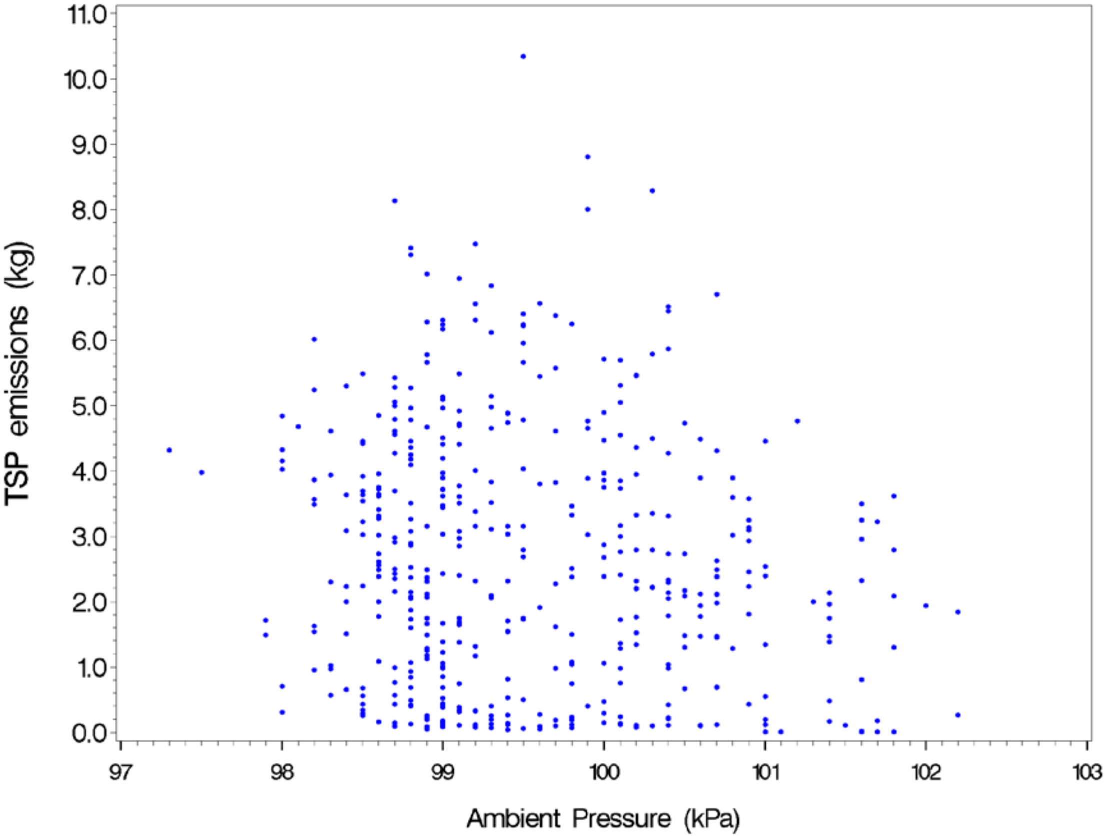


Figure 8-34. TSP Emissions vs. Predictor Variables *ha and *pa***

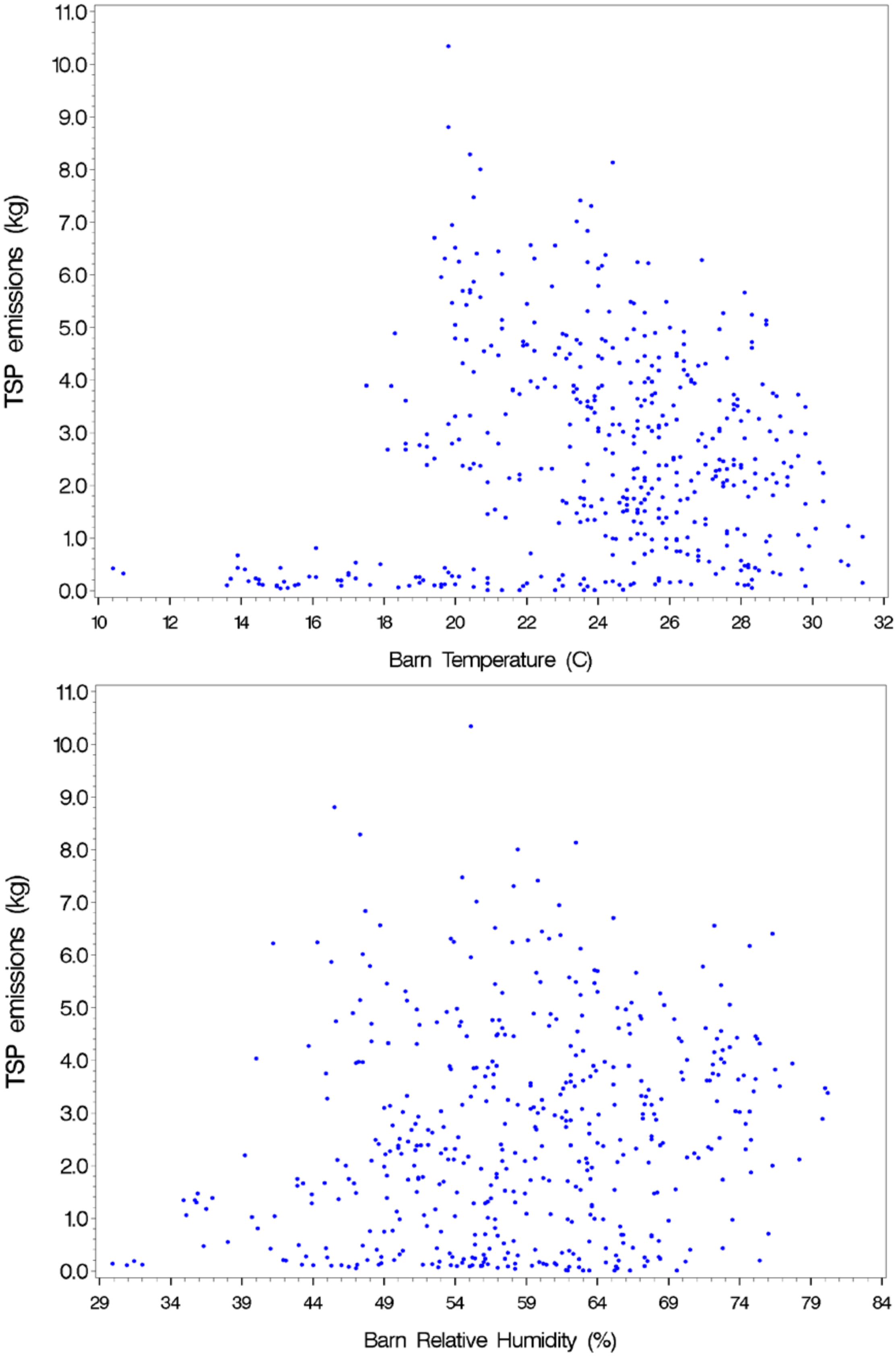


Figure 8-35. TSP Emissions vs. Predictor Variables *tc and *hc***

Table 8-36 summarizes the mean trend variables that describe the dependence of TSP emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem**, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable, *build*. For *avem**, the linear (*avem*) and quadratic ($avem^2$) terms were collectively considered the main effect for the EEM tested.

Table 8-36. Summary of Main Effect Mean Trend Variables for PM_{10}

Original Predictor Variable[a]	Main Effect Mean Trend Variable(s)
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.4.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-36. Initial testing of the R^2 of two-way and three-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of TSP EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-37.

Table 8-37. Candidate Mean Trend Variables for the I, IA and IAC TSP EEMs

EEM	Main Effects	Two-Way Interaction Terms
I, Quadratic (I EEM$_Q$)	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
IA, Quadratic (IA EEM$_Q$)	Same as I EEM$_Q$ plus: *ta, ha, pa*	Same as I EEM$_Q$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avempa, avem*^{2}*pa, taha, tapa, hapa*
IAC, Quadratic (IAC EEM$_Q$)	Same as IA EEM$_Q$ plus: *tc, hc*	Same as IA EEM$_Q$ plus: *buildtc, buildhc, birdstc, birdshc, avemtc, avem*^{2}*tc, avemhc, avem*^{2}*hc, tatc, tahc, hatc, hahc, patc, pahc, tchc*

8.4.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the TSP final EEMs are presented in Table 8-38.

Table 8-38. Centering and Scaling Reference Values for Continuous TSP Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	24	2.6
*avem**	1.0	0.77
*ta**	14	9.4
*ha**	71	13
*pa**	100	0.93
*tc**	24	4.0
*hc**	59	9.6

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or *avem*^{2}) and the creation of interaction terms (e.g., *avemta*).

8.4.4 Selecting Final Mean Trend Variables for TSP

Only a quadratic version of the I, IA, and IAC EEMs were tested. Table 8-39 contains the final mean trend variables for the selected form of each EEM after backward elimination of variables (see Section 7.5). Predictions based on the I EEM developed systematic bias for the intercept, γ_1, at all stages. The systematic bias was marginal, and did not indicate a serious issue with the EEM. Predictions based on the IA and IAC version of the EEM did not display systematic bias at any stage of the backward elimination process.

The selected form of the I EEM contained all the initial interaction terms. This EEM displayed the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2), and the best estimate of the intercept, γ_1. The selected form of the IA EEM displayed the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (low RMSE and highest R^2). The selected form of the IAC EEM displayed the best fit-statistics against the base dataset (smallest 95 percent confidence interval width) and the cross-validation dataset (low RMSE and highest R^2).

Table 8-40 shows the fit statistics for the best version of each EEM. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level, while an "x" indicates that it is significantly different from zero. Similarly, a check mark or an "x" in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Table 8-39. Final I, IA and IAC EEM Mean Trend Variables for TSP EEMs

EEM	Main Effects	Two-Way Interaction Terms
I	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*,birdsavem, birdsavem*^{2}
IA	*build, birds, avem, avem*^{2}*, ta, ha*	*buildbirds, buildavem, buildavem*^{2}*,birdsta, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha*
IAC	*build, birds, avem, avem*^{2}*, ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem*^{2}*, buildta, buildha, buildpa, buildhc, birdsavem, birdsavem*^{2}*, birdspa, birdstc, birdshc, avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avemhc, avem*^{2}*hc, taha, tapa, hapa, tatc, hahc, pahc*

Table 8-40. Final I, IA and IAC EEM Fit Statistics for TSP

	Fit Statistics							
EEM	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (g)	γ_1
I	1,228	1,235	96	5.2	1.0	0.71	0.19 ✓	0.87 x
IA	1,171	1,178	98	4.9	0.83	0.80	0.16 ✓	0.94 ✓
IAC	1,130	1,138	100	4.4	0.75	0.84	0.07 ✓	0.95 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the α = 0.05 significance level.

8.4.5 Summary of Final Results for the I, IA and IAC EEMs for TSP

The covariance parameters for the final forms of the EEMs are listed in Table 8-41. The coefficients for the EEM mean trend variables are listed in Table 8-42. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling factors for the predictor variables used in the final TSP EEMs are presented in Table 8-38.

Table 8-41. Covariance Parameter for Final TSP EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.6641	0.6704	0.6241
$\hat{\sigma}^2$	1.1696	1.0050	0.7724

Table 8-42. Regression Coefficient for Final TSP EEMs

p	x_p	$\hat{\beta}_p$		
		I	IA	IAC
1	*Intercept*	2.45	2.22	2.20
2	*build*	0.37	0.66	0.67
3	*birds*	0.09	0.02	0.10
4	*avem*	1.69	1.58	1.94
5	*avem*^{2}	-0.18	-0.03	0.08
6	*ta*	a	0.47	0.81
7	*ha*	a	-0.23	0.29
8	*pa*	a	a	0.05
9	*tc*	a	a	-0.26
10	*hc*	a	a	-0.97
11	*buildbirds*	0.22	0.48	0.38
12	*buildavem*	0.14	0.28	0.16
13	*buildavem*^{2}	-0.11	-0.31	-0.34
14	*buildta*	a	a	-0.23
15	*buildha*	a	a	-0.23
16	*buildpa*	a	a	-0.16
17	*buildhc*	a	a	0.47
18	*birdsavem*	0.26	a	0.40
19	*birdsavem*^{2}	-0.06	a	-0.11
20	*birdsta*	a	0.20	a
21	*birdspa*	a	a	0.00
22	*birdstc*	a	a	-0.05
23	*birdshc*	a	a	-0.04
24	*avemta*	a	0.08	0.05
25	*avem*^{2}*ta*	a	-0.23	-0.18
26	*avemha*	a	-0.24	0.03
27	*avem*^{2}*ha*	a	-0.08	0.11
28	*avemhc*	a	a	-0.44
29	*avem*^{2}*hc*	a	a	-0.13
30	*taha*	a	a	0.05
31	*tapa*	a	a	-0.16
32	*hapa*	a	a	0.08
33	*tatc*	a	a	-0.06
34	*hahc*	a	a	0.04
35	*pahc*	a	a	0.02

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.

[a] This variable is not included in the EEM.

8.5 EEMs for VOCs

8.5.1 Selecting Datasets

Table 8-43 shows the data completeness for VOC emissions at the California and Kentucky sites. As explained previously in Section 5, issues with the monitoring equipment prevented the collection of continuous data for VOCs at the CA1B houses. Consequently, the EEMs for VOCs were based on data from the Kentucky sites only.

A total of 360 days of VOC emissions measurements were available and were evenly distributed across the seasons. Of the 360 VOC observations available, five lacked the necessary inventory, ambient and confinement predictor variables for EEM development. After these missing data records were removed, the base dataset available for developing the VOC EEMs consisted of 355 observations. The EPA then randomly withheld 78 observations (approximately 22 percent of the 355 observations) to serve as the cross-validation data set.

Table 8-43. Data Completeness for VOC EEMs

Season	Description	CA1B		KY1B-1	KY1B-2	All Houses
		House 10	House 12	House 5	House 3	
All seasons	Number of grow-out days	642	647	288	267	1,844
	Days VOC data available	0	0	200	160	360
	Percent complete	0%	0%	69%	60%	20%
Winter	Number of grow-out days	150	153	87	74	464
	Days VOC data available	0	0	54	43	97
	Percent complete	0%	0%	62%	58%	21%
Spring	Number of grow-out days	157	158	83	55	453
	Days VOC data available	0	0	69	32	101
	Percent complete	0%	0%	83%	58%	22%
Summer	Number of grow-out days	156	157	55	74	442
	Days VOC data available	0	0	18	41	59
	Percent complete	0%	0%	33%	55%	13%
Fall	Number of grow-out days	179	179	63	64	485
	Days VOC data available	0	0	59	44	103
	Percent complete	0%	0%	94%	69%	21%

8.5.2 Choosing the Probability Distribution for VOCs

The EPA first evaluated the empirical distribution (i.e., histogram) of the observed daily emissions for VOCs in determining whether using the normal distribution could be justified. The histogram in Figure 8-36 shows that many of the observations for VOCs correspond to lower emissions values, with a single peak at values around 0.375 kg. The figure also shows that the number of observations decreases as emissions increase. Based on this histogram, the EPA determined that the empirical distribution was unimodal (single-peaked) and skew right.

The EPA separated the base dataset into bins according to values of average bird mass. Figure 8-37 shows histograms of VOC emissions within the following six evenly distributed bins of average bird mass (*avem**) values (in kg): 0.0 to 0.5, 0.5 to 1.0, 1.0 to 1.5, 1.5 to 2.0, 2.0 to 2.5 and 2.5 to 3.0. The figure shows that the histograms for bins 1, 2, 3, and 4 are skew right while those for bins 5 and 6 are symmetric. Further disaggregation according to the values of other variables shows a variety of empirical distributions for different sets of conditions, and the skew right pattern is by no means a consistent pattern. There are not enough observations under any specific set of conditions (e.g., bird mass and humidity ranges) to use the empirical distribution to determine the true distribution. Therefore, in the absence of strong evidence against doing so, the EPA used the normal distribution.

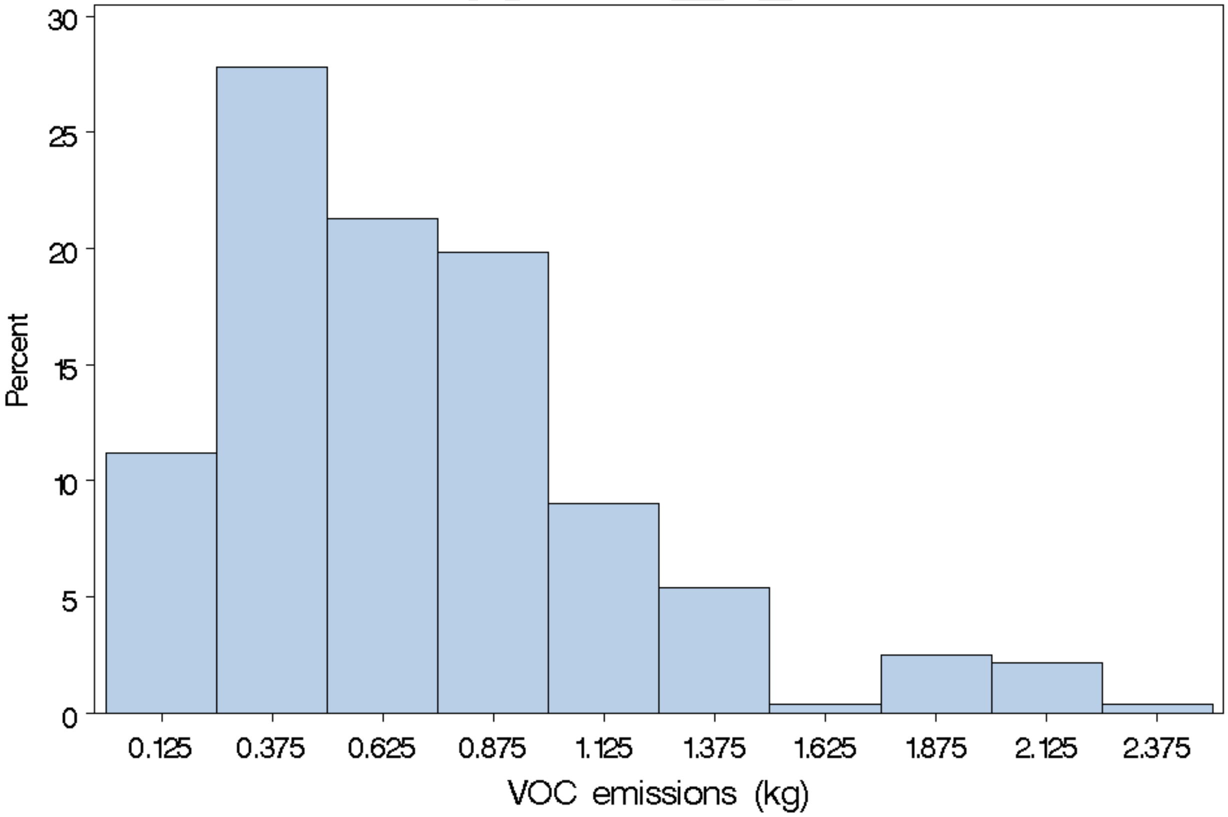


Figure 8-36. Histogram of VOC Emissions in the Base Dataset

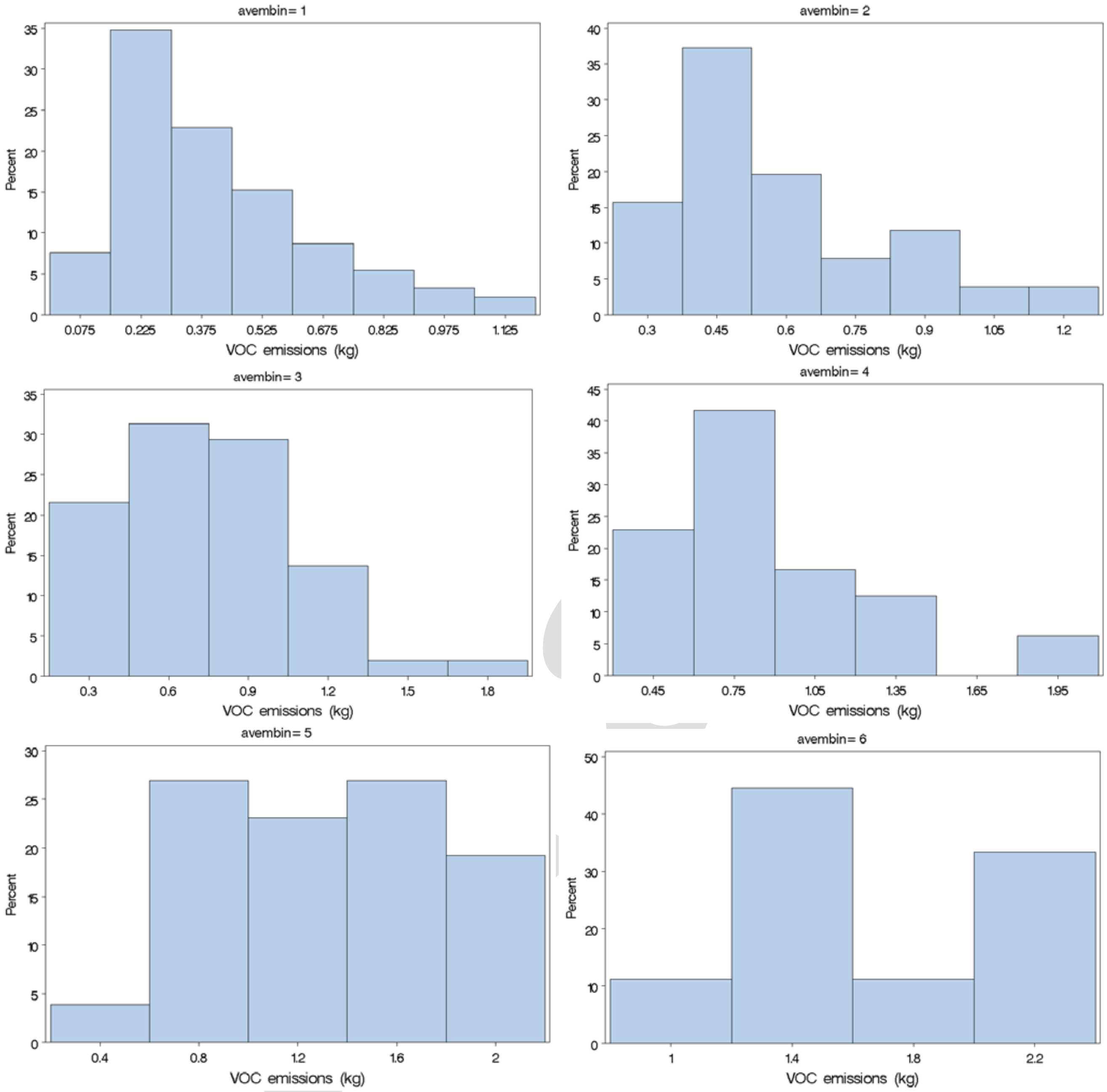


Figure 8-37. Histograms of VOC Emissions by *avem Bins**

8.5.3 Developing Candidate Mean Trend Variables for VOCs

8.5.3.1 *Choosing Predictor Variable Functional Forms*

Plots of VOC emissions versus average bird mass for all houses suggested a positive relationship, with a slight upward curvature. The gradual increasing trend suggested either a quadratic or a cubic form. Figure 8-38 includes linear, quadratic and cubic regressions of average mass overlaid on the VOC emissions as a point of reference for choosing a functional form. Because the appropriate form of the EEM was not apparent from the aggregated plot, the EPA reviewed plots disaggregated by house (Figure 8-39) and by flock (Appendix F) for further evidence of the functional form. Plots by house suggested a cubic form, especially in KY1B-1 House 5. Plots by flocks were less conclusive; suggesting that either a cubic or an exponential functional form would be suitable. Consequently, the EPA decided to test three versions of the I EEM (i.e., cubic, quadratic and exponential) to determine the best functional form for average mass.

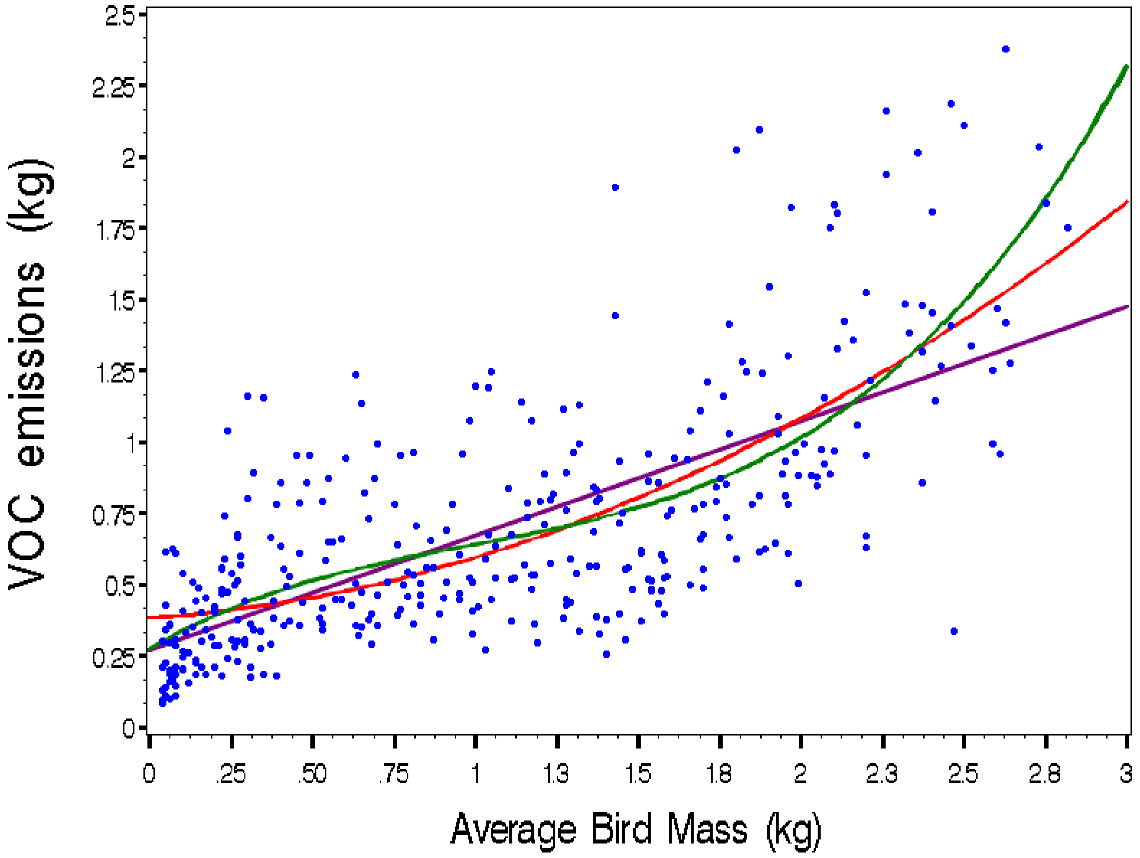


Figure 8-38. VOC Emissions vs. Average Bird Mass (Regression Overlays: purple = linear, red = quadratic, green = cubic)

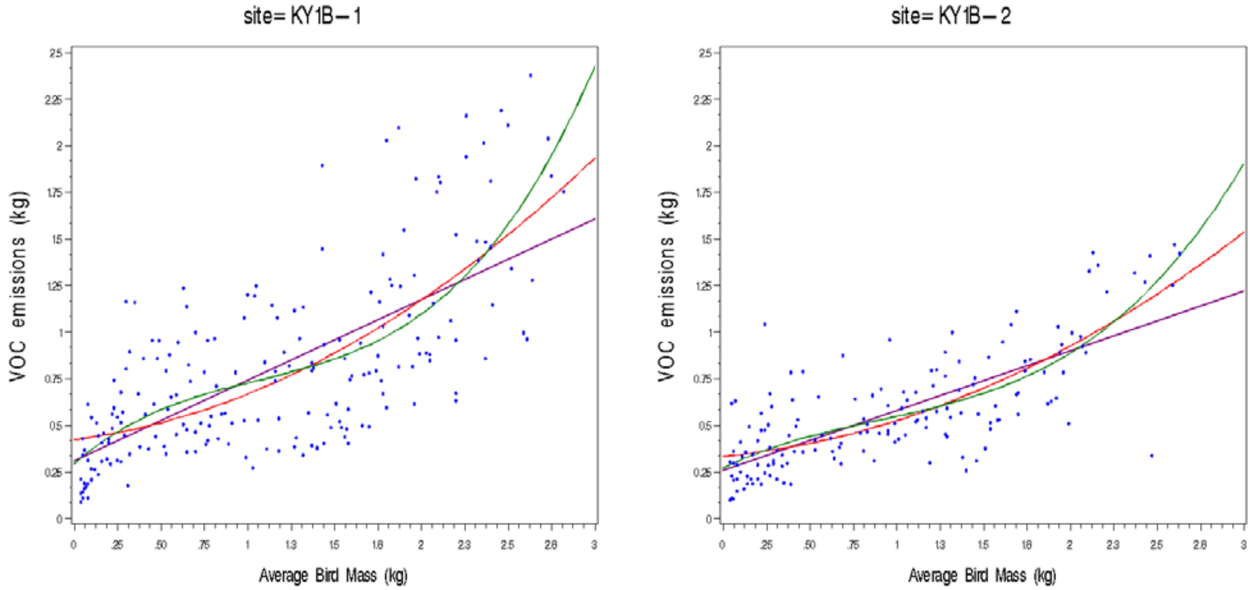


Figure 8-39. VOC Emissions vs. Average Bird Mass, by House (Regression Overlays: purple = linear, red = quadratic, green = cubic)

With regard to the effect of accumulated litter (*buildup*) on VOC emissions (see Section 7.3.1), the variance in VOC emissions values for lower weights, depicted in Figure 8-39, suggested a possible effect of litter condition on emissions. Plots of VOC emissions by average mass that are color-coded to indicate the level of *buildup* (Figure 8-40) suggested that higher VOC emissions correspond to built-up litter. However, the EPA was unable to draw a definitive conclusion from the scatter plot because only one full flock was raised on fresh bedding during the NAEMS.

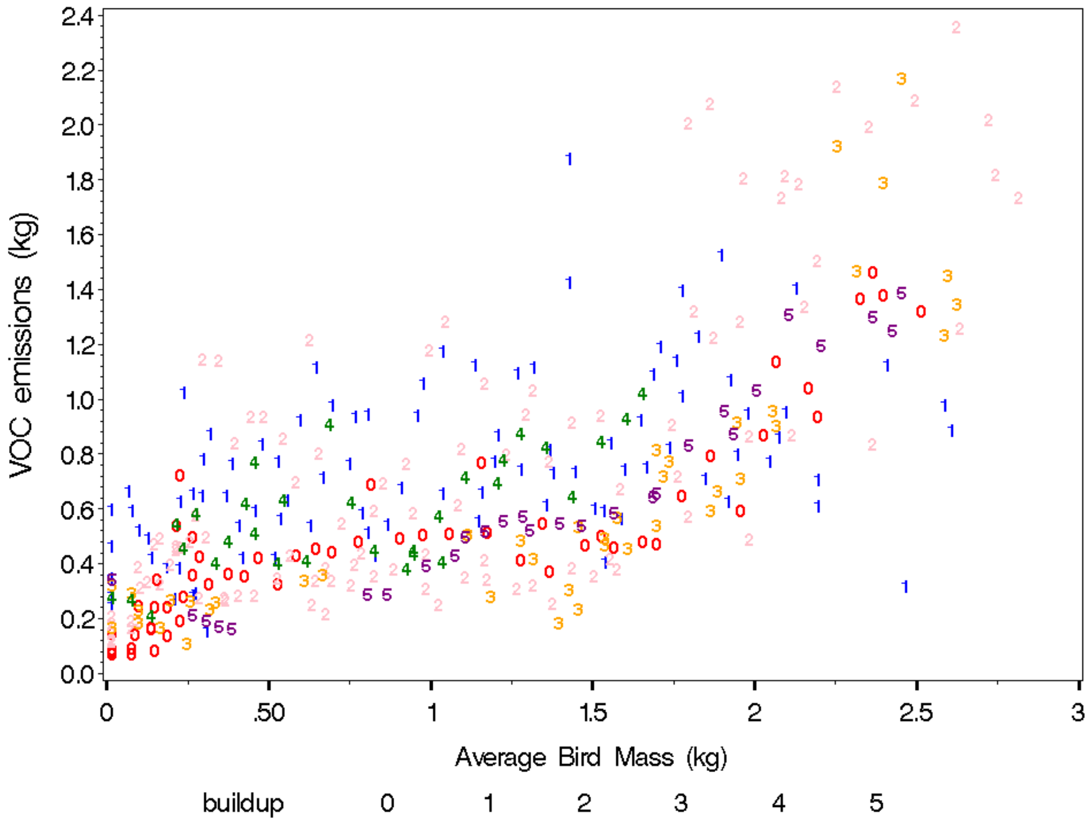


Figure 8-40. Overlay of *buildup* on VOC Emissions vs. Average Live Bird Mass

Plots of the build-up indicator parameters (i.e., *buildup*, *build*, *bld*) suggested that the average emissions increased for flocks raised on built-up litter. The trend is not as strong as with other pollutants, as there is only a small difference between the minimum emissions levels between the litter conditions (Figure 8-41), although the average emissions for the litter conditions does show a larger difference. To explore the issue, the EPA conducted preliminary tests to determine if a representation of build-up would significantly contribute to the mean trend variables for the VOC EEM. Consistent with the other pollutant EEMs developed, the EPA chose to include *build* in initial test EEMs, which showed *build* as a significant mean trend term. Consequently, the EPA decided to include *build* as the functional form through which the variable *buildup* enters the mean trend function and continue to test its significance using the p-value analysis to determine the final mean trend variables.

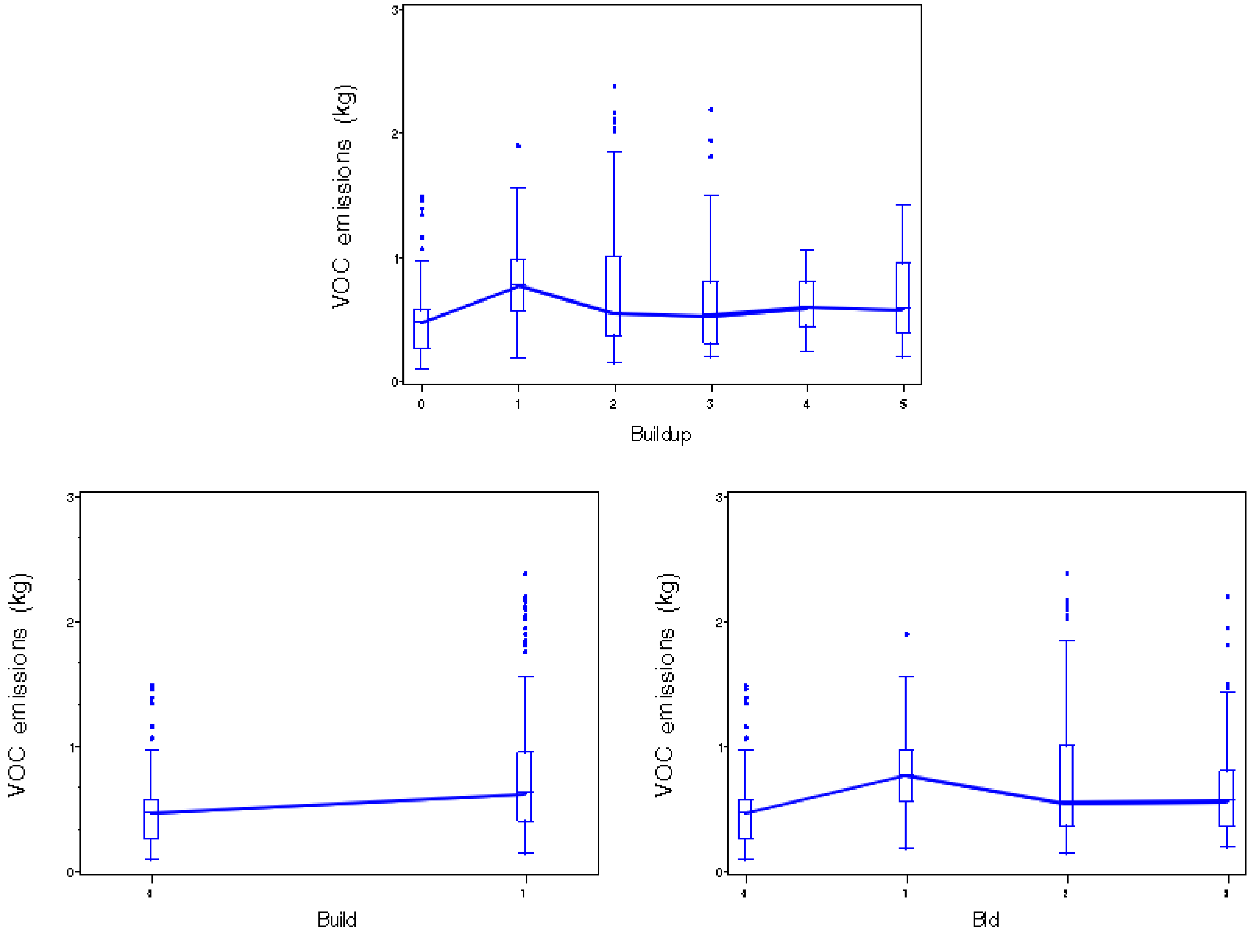


Figure 8-41. Box Plots of VOC Emissions vs. Categorical Variables for *buildup*

Figure 8-42, Figure 8-43 and Figure 8-44 show the scatter plots of VOC emissions by the remaining predictors (i.e., number of birds, ambient temperature, ambient relative humidity, ambient pressure, house temperature and house relative humidity). Appendix F contains scatter plots of the predictor variables by average animal mass bin. The plots do not indicate that the EPA should use a functional form other than linear. Based on this visual analysis, and the absence of a process-based reason to do otherwise, the EPA chose a linear functional form in developing the EEMs for VOCs.

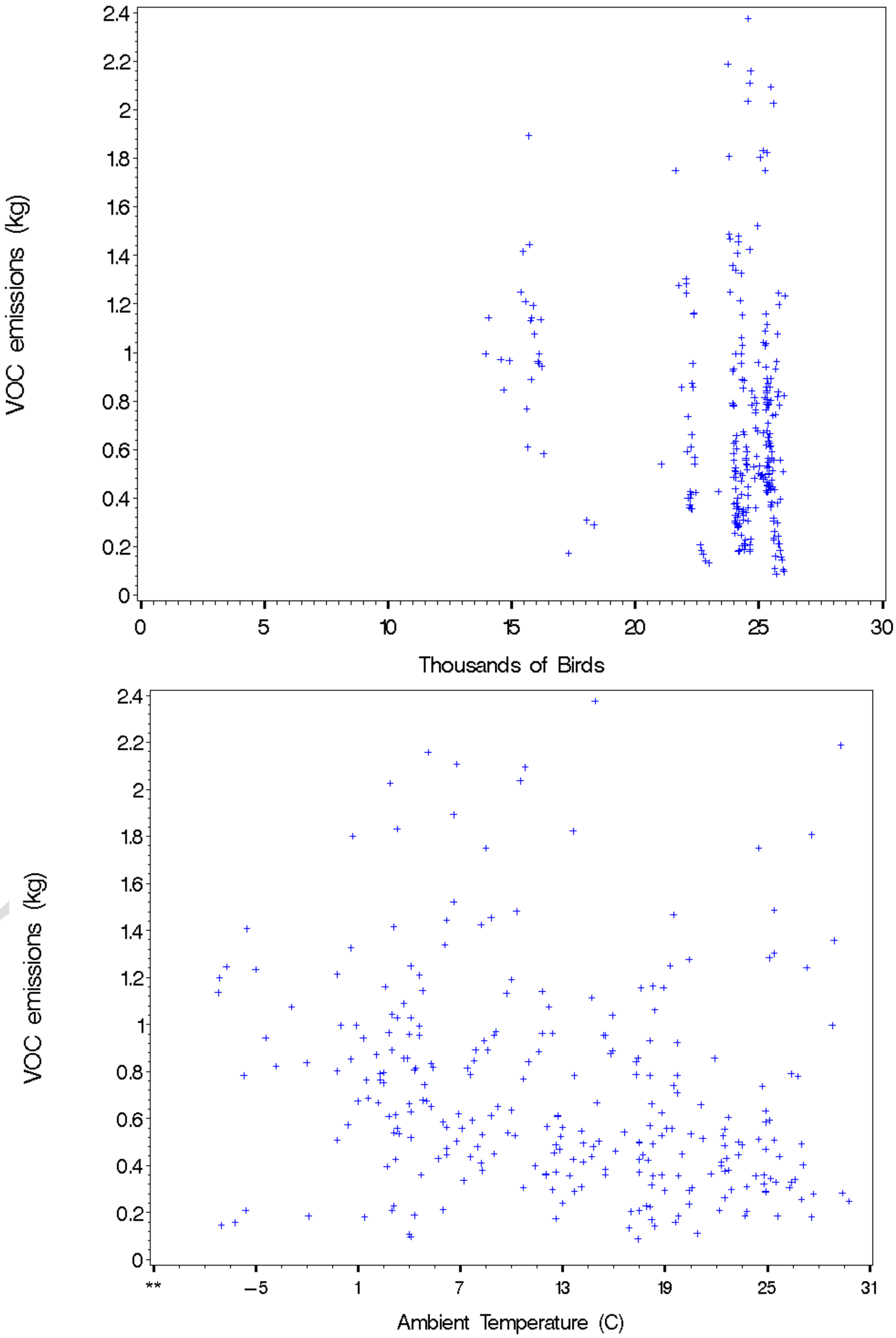


Figure 8-42. VOC Emissions vs. Predictor Variables *birds and *ta****

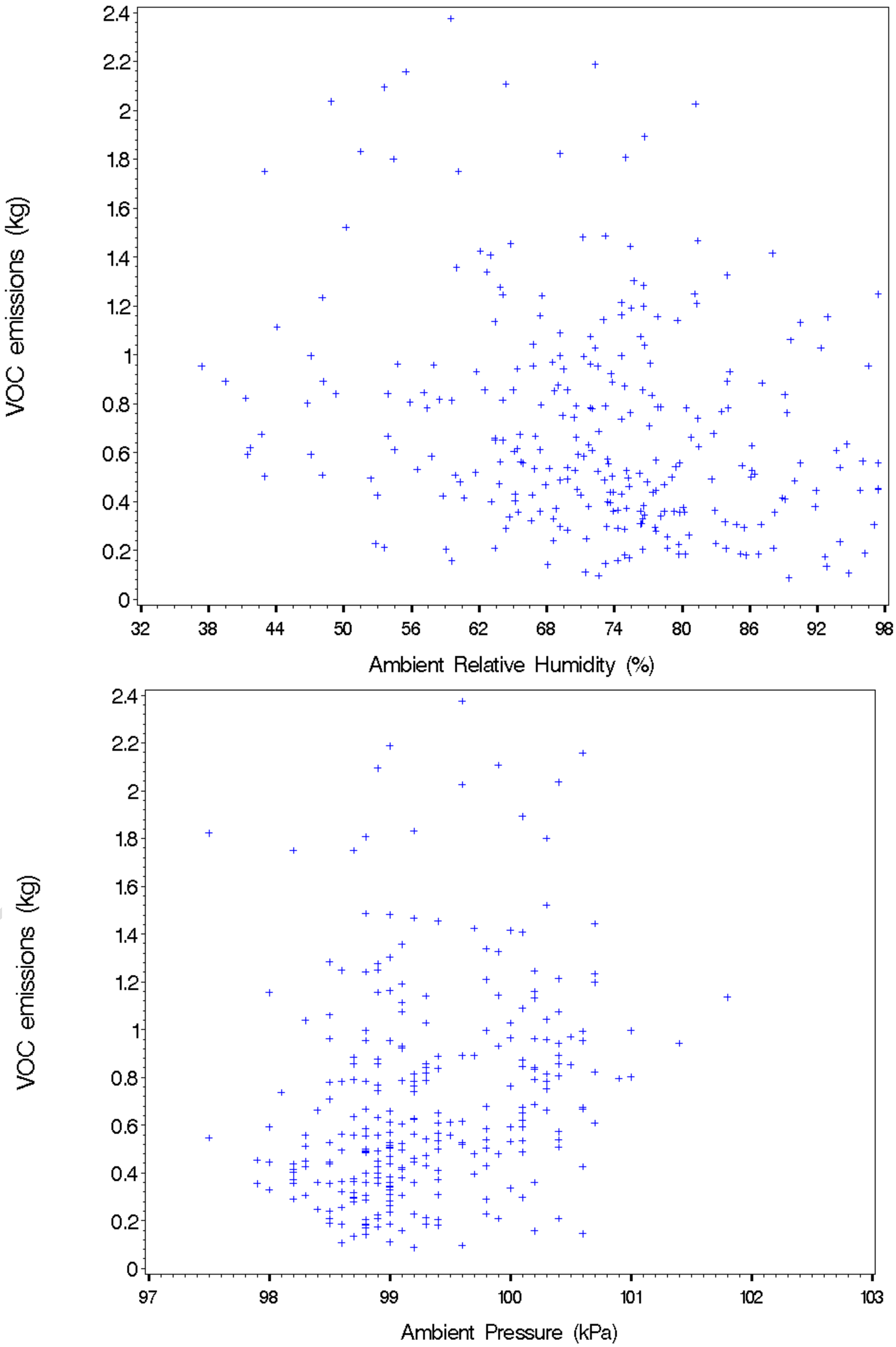


Figure 8-43. VOC Emissions vs. Predictor Variables *ha and *pa***

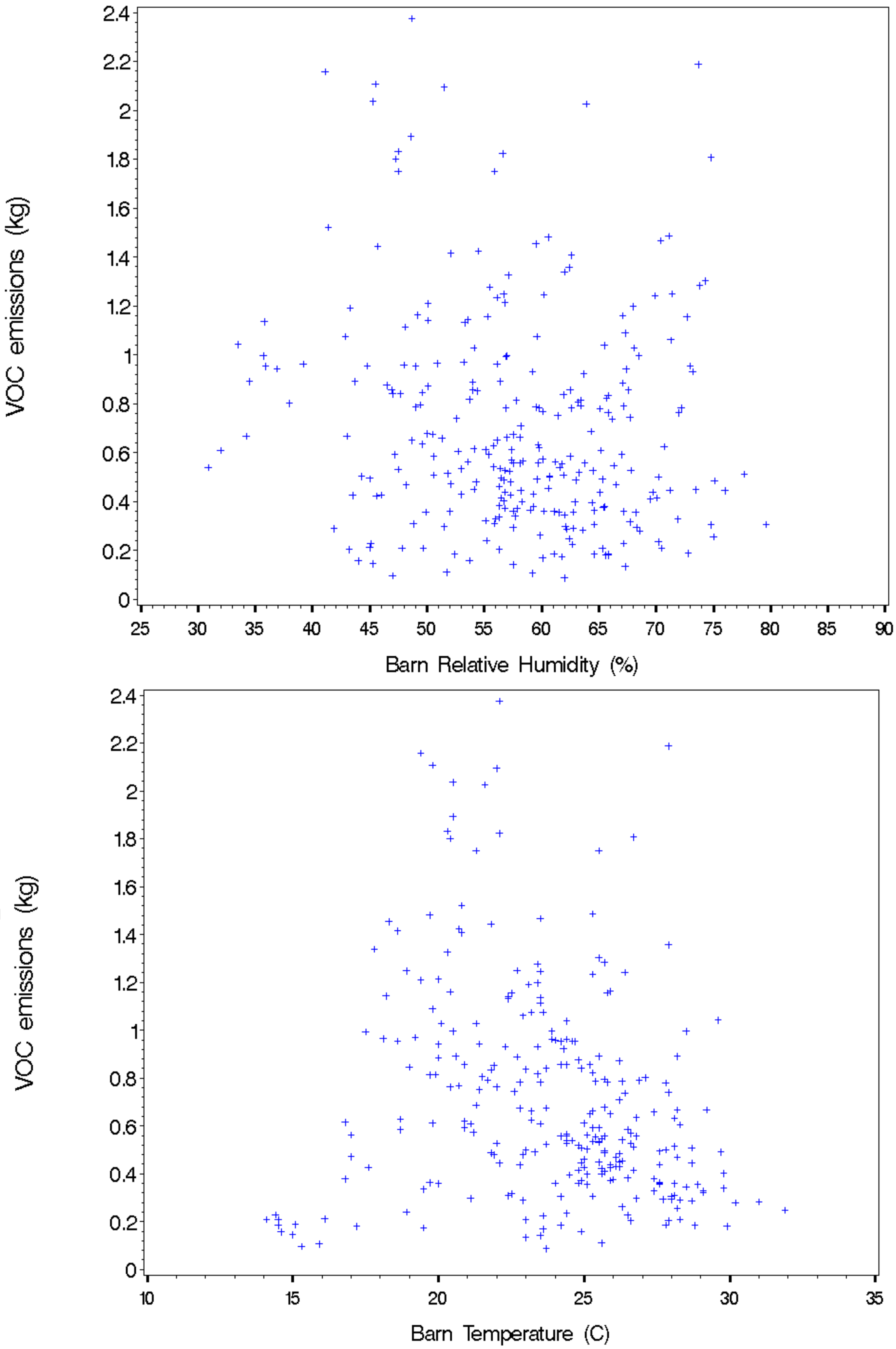


Figure 8-44. VOC Emissions vs. Predictor Variables *tc and *hc***

Table 8-44 summarizes the mean trend variables that describe the dependence of VOC emissions on the original predictor variables. The variables in column two were taken to be the main effect of the original predictors in column one of the table. For all predictors except *buildup* and *avem*, the mean trend variable was the same as the original variable. For *buildup*, the main effect was the indicator variable *build*. Forms of *avem** tested separately for EEM development included an exponential (*eavem*), quadratic (*avem* and $avem^2$), and cubic (*avem*, $avem^2$, and $avem^3$) form.

Table 8-44. Summary of Main Effect Mean Trend Variables for VOCs

Original Predictor Variable[a]	Main Effect Mean Trend Variables
buildup	*build*
*birds**	*birds*
*avem**	*avem*, $avem^2$ *avem*, $avem^2$, $avem^3$ *eavem*
*ta**	*ta*
*ha**	*ha*
*pa**	*pa*
*tc**	*tc*
*hc**	*hc*

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1).

8.5.3.2 *Creating Mean Trend Variables from Main Effects and Interactions*

The EPA created interaction terms and determined what level of interactions (e.g., two-way, three-way) to include in the set of candidate mean trend variables of Table 8-2. Initial testing of the R^2 of 2-way and 3-way terms conducted by the EPA suggested that consideration of two-way interactions was appropriate for development of VOC EEMs. The main effects and interaction terms for the versions of the three EEMs tested are presented in Table 8-45. Cubic versions of the IA and IAC EEMs are not shown in Table 8-45 because initial testing showed that none of the cubic terms for the EEMs were significant. A discussion of these initial tests for each of these EEMs is provided in Sections 8.5.4.2 and 8.5.4.3.

Table 8-45. Candidate Mean Trend Variables for the I, IA and IAC VOC EEMs

EEM	Main Effects	Two-Way Interaction terms
I, Cubic (I EEM$_C$)	*build, birds, avem, avem*^{2}*, avem*^{3}	*buildbirds, buildavem, buildavem*^{2}*, buildavem*^{3}*, birdsavem, birdsavem*^{2}*, birdsavem*^{3}
I, Quadratic (I EEM$_Q$)	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, buildavem*^{2}*, birdsavem, birdsavem*^{2}
I, Exponential (I EEM$_E$)	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA, Quadratic (IA EEM$_Q$)	Same as I EEM$_Q$ plus: *ta, ha, pa*	Same as I EEM$_Q$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa,avemta, avem*^{2}*ta, avemha, avem*^{2}*ha, avempa, avem*^{2}*pa, taha, tapa, hapa*
IA, Exponential (IA EEM$_E$)	Same as I EEM$_E$ plus: *build, birds, eavem, ta, ha, pa*	Same as I EEM$_E$ plus: *buildta, buildha, buildpa, birdsta, birdsha, birdspa, eavemta, eavemha, eavempa, taha, tapa, hapa*
IAC, Quadratic (IAC EEM$_Q$)	Same as IA EEM$_Q$ plus: *build, birds, avem, avem*^{2}*, ta, ha, pa, tc, hc*	Same as IA EEM$_Q$ plus: *buildtc, buildhc, birdstc, birdshc, avemtc, avem*^{2}*tc, avemhc, avem*^{2}*hc, tatc, tahc, hatc, hahc, patc, pahc, tchc*
IAC, Exponential (IAC EEM$_E$)	Same as IA EEM$_E$ plus: *build, birds, eavem, ta, ha, pa, tc, hc*	Same as IA EEM$_E$ plus: *buildtc, buildhc, birdstc, birdshc, eavemtc, eavemhctatc, tahc, hatc, hahc, patc, pahc, tchc*

8.5.3.3 *Centering and Scaling Predictors*

The EPA centered and scaled each continuous predictor variable prior to creating interaction terms by subtracting the mean of all observations in the base dataset from each value, then dividing by the standard deviation of the base dataset. The centering and scaling factors for the predictor variable for the final EEMs for VOCs are presented in Table 8-46.

Table 8-46. Centering and Scaling Reference Values for Continuous VOC Predictor Variables

Predictor Variable[a]	Centering Value	Scaling Value
*birds**	24	2.8
*avem**	1.1	0.76
*ta**	13	8.8
*ha**	72	12
*pa**	99	0.73
*tc**	27	3.5
*hc**	58	9.7

[a] An asterisk (*) is used to note that these predictor variables are the original values submitted to the EPA before the data were centered and scaled (see Section 7.3.1). Predictor variables are centered and scaled prior to the creation of higher-order terms (e.g., *eavem* or $avem^2$) and the creation of interaction terms (e.g., *avemta*).

8.5.4 Selecting Final Mean Trend Variables for VOCs

8.5.4.1 Inventory EEM

For the cubic version of the EEM, a full-reduced model F-test of the hypothesis that the coefficients $avem^3$, $birdsavem^3$, and $buildavem^3$ were simultaneously equal to zero produced a p-value of 0.43 which suggested that these terms should be removed from the EEM. This supported the conclusion that the functional form of *avem** is a lower-order polynomial rather than a cubic form. Therefore, the EPA only considered the quadratic and exponential forms (i.e., the cubic form of the EEM was not tested with the IA or IAC versions of the EEM).

Predictions based on the I EEM_Q form of the EEM developed systematic bias for γ_1 prior to completing the backwards elimination process. Predictions based on the I EEM_E completed the backward elimination process without any systematic bias.

The best version of the I EEM_Q occurred after the elimination of the $avem^2$ interaction terms (Table 8-47). This EEM displayed the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (lowest RMSE and highest R^2), without exhibiting systematic bias.

The selected form of the I EEM_E contains all the initial interaction terms. This version of the I EEM_E had the best fit-statistics against the test dataset and good fit statistics versus the cross-validation dataset, without systematic bias. The fit statistics for the selected I EEM_Q and I EEM_E are presented in Table 8-48. A check mark (✓) in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level, while an “x” indicates that it is significantly different from zero. Similarly, a check mark or an “x” in the column for γ_1 indicates whether or not the estimate is significantly different from one.

Overall, the I EEM$_Q$ and I EEM$_E$ generally have similar fit statistics, with the I EEM$_E$ having slightly better base dataset fit (smaller -2LL and BIC). The I EEM$_E$ version was slightly better with respect to the percent of the data that is within the 95 percent prediction interval (% in PI) as this value should be as close to 95 percent as possible. Therefore, the EPA selected the exponential version of the I EEM for VOC emissions.

Table 8-47. Final Candidate I EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction terms
I EEM$_Q$	*build, birds, avem, avem*^{2}	*buildbirds, buildavem, birdsavem,*
I EEM$_E$	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*

Table 8-48. Final Candidate I EEM Fit Statistics for VOCs

Candidate EEM	Fit Parameters							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
I EEM$_Q$	-19.0	-12.7	99	1.3	0.25	0.61	-0.01 ✓	0.93 ✓
I EEM$_E$	-29.2	-22.8	97	1.3	0.25	0.59	-0.01 ✓	0.92 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the α = 0.05 significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the α = 0.05 significance level.

8.5.4.2 *Inventory and Ambient EEM*

An initial test of the cubic version of the EEM showed a full-reduced model F-test of the hypothesis that the coefficients *avem*^{3}, *birdsavem*^{3}, *buildavem*^{3}, *avem*^{3}*ta*, *avem*^{3}*ha*, and *avem*^{3}*pa* were simultaneously equal to zero produced a p-value of 0.41, which suggested that these terms should be removed from the EEM. This further supported the conclusion that the functional form of *avem** is a lower-order polynomial rather than a cubic form. Therefore, the EPA only considered the quadratic and exponential forms.

The IA EEM$_Q$ developed systematic bias for γ_1 prior to completing the backwards elimination process, and the IA EEM$_E$ completed the backward elimination process without any systematic bias.

The selected form of the IA EEM_Q and IA EEM_E are presented in Table 8-49. The selected IA EEM_Q displayed the best fit-statistics against the test dataset (lowest RMSE and highest R^2), without exhibiting systematic bias. The selected version of the IA EEM_E had the best fit-statistics against the base dataset (lowest BIC and -2LL values) and the cross-validation dataset (lowest RMSE and highest R^2). The fit statistics for the selected IA EEM_Q and IA EEM_E are presented in Table 8-50.

Overall, the IA EEM_Q and IA EEM_E had similar fit statistics for the test dataset, with the IA EEM_Q having a slightly better R^2 value. The IA EEM_E had better base dataset fit (smaller -2LL and BIC), as well as a better representation of the percent of the data that is within the 95 percent prediction interval. Therefore, the EPA selected the exponential version of the IA EEM for VOC emissions.

Table 8-49. Final Candidate IA EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction terms
IA EEM_Q	*build, birds, avem, avem*^{2}*, ta, ha, pa*	*buildbirds, buildavem, buildavem*^{2}*, buildta, buildha, buildpa, birdsavem, birdsavem*^{2}*, birdsta, birdsha, birdspa, avemta, avem*^{2}*ta*
IA EEM_E	*build, birds, eavem, ta*	*buildbirds, buildeavem, birdsta, eavemta*

Table 8-50. Final Candidate IA EEM Fit Statistics for VOCs

Candidate EEM	Fit Parameters							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IA EEM_Q	1.5	7.8	100	1.3	0.22	0.70	-0.004 ✓	0.94 ✓
IA EEM_E	-39.5	-33.1	97	1.3	0.24	0.63	-0.01 ✓	0.90 ✓

Note: An "x" in the columns for γ_0 and γ_1 indicate systematic bias. A check mark in the column for γ_0 indicates that the 95 percent confidence interval for the intercept contains zero and the estimate is not significantly different from zero. A check mark in the column for γ_1 indicates the 95 percent confidence interval for the slope contains one and the estimate is not significantly different from one.

8.5.4.3 *Inventory, Ambient and Confinement EEM*

An initial test of the cubic version of the EEM showed a full-reduced model F-test of the hypothesis that the coefficients *avem*^{3}, *birdsavem*^{3}, *buildavem*^{3}, *avem*^{3}*ta*, *avem*^{3}*ha, avem*^{3}*pa, avem*^{3}*tc* and *avem*^{3}*hc* were simultaneously equal to zero produced a p-value of 0.18, which suggested that these terms should be removed from the EEM. This further supported the conclusion that the functional form of *avem** is a lower-order polynomial rather than a cubic form. Therefore, the EPA only considered the quadratic and exponential forms.

Neither the IAC EEM_Q nor IAC EEM_E tested by EPA developed systematic bias prior to completion of the backwards elimination process. The mean trend variables for the selected version of the IAC EEM_Q and IAC EEM_E are presented in Table 8-51.

The selected form of the IAC EEM_Q displayed the best fit-statistics against the test dataset (lowest RMSE and highest R^2). The selected IAC EEM_E had the best fit-statistics against the cross-validation dataset (lowest RMSE and highest R^2) coupled with a small confidence interval width and approximately 95 percent inclusion in the confidence interval. The fit statistics for both the selected IAC EEM_Q and IAC EEM_E are presented in Table 8-52.

Overall, the IAC EEM_Q and IAC EEM_E had similar fit statistics against the cross-validation data set, with IAC EEM_E having slightly better base dataset fit (smaller -2LL and BIC). The IAC EEM_E version was also slightly better with respect to the percent of the data that is within the 95 percent prediction interval. Therefore, the EPA selected the exponential version of the IAC EEM for VOC emissions.

Table 8-51. Final Candidate IAC EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction Terms
IAC EEM_Q	*build, birds, avem, avem^2, ta, ha, pa, tc, hc*	*buildbirds, buildavem, buildavem^2, buildtc, birdsavem, birdsavem^2, birdsta, birdsha, birdspa, birdstc, birdshc, avemta, avem^{2}ta, avemha, avem^{2}ha, tatc, tahc, patc, pahc, tchc*
IAC EEM_E	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildbirds, buildeavem, buildpa, birdsta, birdsha, birdstc, birdshc, eavemtc, tatc, tahc*

Table 8-52. Final Candidate IAC EEM Fit Statistics for VOCs

Candidate EEM	Fit Parameters							
	-2LL	BIC	% in PI	Width (kg)	RMSE (kg)	R^2	γ_0 (kg)	γ_1
IAC EEM_Q	20	27	99	1.2	0.21	0.72	-0.03 ✓	0.96 ✓
IAC EEM_E	-34.6	-28.2	96	1.2	0.23	0.65	-0.07 ✓	0.98 ✓

Note: A check mark in the column for γ_0 indicates that the estimate is not significantly different from zero at the $\alpha = 0.05$ significance level. A check mark in the column for γ_1 indicates that the estimate is not significantly different from one at the $\alpha = 0.05$ significance level.

8.5.5 Summary of Final Results for the I, IA and IAC EEMs for VOCs

A summary of the final mean trend variables for the VOC EEMs is provided in Table 8-53. The covariance parameters for the final forms of the EEMs are listed in Table 8-53. The coefficients for the EEM mean trend variables are listed in Table 8-53. The value of each main effect variable (x_p) must be centered and scaled when using these terms in Equation 7-1. The centering and scaling factors for the predictor variable for the VOC final EEMs are presented in Table 8-46.

Table 8-53. Final EEM Mean Trend Variables for VOCs

EEM	Main Effects	Two-Way Interaction terms
I	*build, birds, eavem*	*buildbirds, buildeavem, birdseavem*
IA	*build, birds, eavem, ta*	*buildbirds, buildeavem, birdsta, eavemta*
IAC	*build, birds, eavem, ta, ha, pa, tc, hc*	*buildbirds, biuildeavem, buildpa, birdsta, birdsha, birdstc, birdshc, eavemtc, tatc, tahc*

Table 8-54. Covariance Parameter for Final VOC EEMs

Covariance Parameter	Estimate		
	I	IA	IAC
$\hat{\rho}$	0.7746	0.7784	0.7770
$\hat{\sigma}^2$	0.1009	0.09747	0.08368

Table 8-55. Regression Coefficients for Final VOC EEMs

p	x_p	$\hat{\beta}_p$		
		I	**IA**	**IAC**
0	*Intercept*	0.031	0.19	-0.47
1	*build*	-0.69	-0.8	-0.65
2	*birds*	-0.82	-0.84	-0.72
3	*eavem*	0.59	0.53	1.12
4	*ta*	a	-0.23	-0.04
5	*ha*	a	a	0.02
6	*pa*	a	a	-0.1
7	*tc*	a	a	-0.18
8	*hc*	a	a	-0.1
9	*buildbirds*	0.626	0.9	0.88
10	*buildeavem*	0.38	0.4	0.21
11	*birdseavem*	0.13	a	a
12	*birdsta*	a	0.07	-0.07
13	*birdsha*	a	a	-0.04
14	*buildpa*	a	a	0.12
15	*eavemta*	a	0.12	a
16	*birdstc*	a	a	0.06
17	*birdshc*	a	a	0.11
18	*eavemtc*	a	a	0.2
19	*tatc*	a	a	0.04
20	*tahc*	a	a	0.04

Note: Each main effect variable was centered and scaled prior to creating higher-order terms, exponential terms and interactions.

[a] This variable is not included in the EEM.

9.0 DEVELOPMENT OF DECAKING AND FULL LITTER CLEAN-OUT PERIOD EEMS

This section summarizes the analyses used to develop the EEMs for the decaking and full litter clean-out periods of broiler confinement houses. Due to the limited number of data values and lack of supporting information specifying how each house was operated during the period between flocks when the litter removal activities were conducted, the pollutant-specific EEMs developed in this section are emission factors (EFs) rather than predictive equations. The emissions factors provide an estimate of the emissions released over the entire decaking or full litter clean-out period, which begins after the birds have been sent to market and ends when the new chicks are placed in the house. The period covered by the EFs includes when the litter removal activities were conducted and when the house was sitting empty before a new flock was placed in the house.

Section 9.1 discusses the data that are available regarding litter removal periods. Section 9.2 discusses the analyses the EPA performed to develop the EFs for decaking and full litter clean-out periods.

9.1 Available Data for Litter Removal Periods

Compared to grow-out periods, the decaking and full litter clean-out periods account for a relatively small portion of the overall broiler production cycle. While the typical grow-out period lasts approximately 50 days, a typical decaking period lasts 6 to 14 days and a typical full litter clean-out period lasts 12 to 14 days. Because the litter removal periods account for a small number of days over the course of a year, the number of data values collected under the NAEMS for these periods is significantly less than for grow-out periods. Table 9-1 compares the total number of days the NAEMS investigators were on site for litter removal periods to the total number of days on site for the grow-out periods.

Table 9-1. Comparison of Days on Site for Litter Removal and Grow-out Period Days

House	Total Monitoring Days on Site	
	Litter Removal	**Grow-Out**
CA1B House 10	125	648
CA1B House 12	122	651
KY1B-1 House 5	87	307
KY1B-2 House 3	97	282
Total	**431**	**1,888**

Over the course of the NAEMS, emissions and process parameter data were recorded for 24 decaking periods and 12 full litter clean-out periods (decaking is conducted more often than full litter clean-outs). The decaking periods monitored typically lasted between 3 and 22 days. There was an instance of a decaking period lasting 41 days at site KY1B-2, which contributed to the greater number of decaking observations for this site. However, this was due to a management change for the farm that halted broiler production rather than prolonged cleaning activity. The full litter clean-out periods observed during the NAEMS lasted between 6 to 25 days. Table 9-2 summarizes the total number of monitoring days available for each type of clean-out period. The average duration of decaking events at site CA1B were much shorter than decaking events at the Kentucky sites (Table 9-3), which accounts for the CA1B houses and the KY1B houses having a similar number of decaking days.

Table 9-2. Comparison of Days on Sites for Decaking and Full Litter Clean-out Days

House	Total Monitoring Days on Site	
	Decaking	**Full Litter Clean-Out**
CA1B House 10	62	63
CA1B House 12	58	64
KY1B-1 House 5	62	25
KY1B-2 House 3	88	9
Total	**270**	**161**

Table 9-3. Duration of Grow-out and Clean-out Periods

Monitoring Site		Clean-Out Periods					
		Decaking			**Full Litter Clean-Out**		
		Frequency	**Average Duration (days)**	**Range of Duration (days)**	**Frequency**	**Average Duration (days)**	**Range of Duration (days)**
CA1B	H10	~ 5 time per year [a]	7.75	6 – 11	Every third flock (~2 times per year)	12.6	6 – 21
	H12	~ 5 time per year [a]	7.25	3 – 11	Every third flock (~2 times per year)	12.8	6 – 23
KY1B-1	H5	~4 times per year	15.5	12 – 22	Once per year	25	NA[b]
KY1B-2	H3	~4 times per year	22	15 – 41	Once per year	9	NA[b]

[a] Occurred 8 times during the study.

[b] Not applicable. Only one full litter clean-out event was monitored during the study.

As noted in Section 4, the EPA's review of the NAEMS data identified a small number of negative daily emissions values for H_2S, PM_{10}, and VOCs. The number of measured negative values is low (less than 5 percent) compared to the total number of emissions records available for H_2S, PM_{10}, and VOC over the litter removal periods. After discussion with the NAEMS Science Advisor, it was determined that the negative values were the result of instrumentation drift, and are valid values. However, to avoid possible complications with EF development (e.g., the EEM predicting negative emissions) the negative values were withheld from the datasets used to develop the EFs for the decaking and full litter clean-out periods.

Table 9-4 summarizes the number of daily emission values that are greater than or equal to zero that are available for EF development by litter removal activity and pollutant. The limited amount of data for decaking and full litter clean-out periods is partially the result of the substantially shorter duration of the litter removal periods compared to the grow-out periods (2 to 20 days for clean-out activities compared to 45 to 54 days for broiler grow-out). Additionally, because the PM monitors had to be removed during litter removal activities to prevent damage to the instruments, fewer valid PM emissions were available during those periods. Consequently, the measurements available for PM_{10}, $PM_{2.5}$ and TSP emissions are only for periods after the litter removal activities were completed and the house was empty before the next flock of birds was placed. Finally, the intermittent PM sampling schedule at site CA1B did not include measurement of $PM_{2.5}$ or TSP emissions during decaking and full litter clean-out periods. The EFs developed for $PM_{2.5}$ or TSP were based only on data collected at the Kentucky sites.

Table 9-4. Number of Valid Non-Negative Daily Emissions Values for Litter Removal Periods

Litter Removal Activity	House	Count of Valid Non-negative Daily Emissions Values				
		NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
Decaking	CA1B House 10	51	55	6	0	0
	CA1B House 12	48	52	4	0	0
	KY1B-1 House 5	58	57	11	19	20
	KY1B-2 House 3	82	67	45	45	41
	Total	**239**	**231**	**66**	**64**	**61**
Full Litter Clean-Out	CA1B House 10	30	23	9	0	0
	CA1B House 12	30	23	5	0	0
	KY1B-1 House 5	21	8	5	1	5
	KY1B-2 House 3	8	8	3	3	3
	Total	**89**	**62**	**22**	**4**	**8**

9.2 EF Development for Decaking and Full Litter Clean-Out Periods

The EPA attempted applying ordinary least squares (OLS) regression analyses to develop predictive equations based EEMs for decaking and full litter clean-out periods. In OLS regression analyses, coefficients of the equation relating emissions to parameters (i.e., predictor variables) are estimated by determining numerical values for the parameters that minimize the sum of the squared deviations between the observed responses and the functional portion of the model. The EPA initially considered this approach because it is a widely accepted method for relating dependent variables (e.g., emissions) to independent variables (e.g., bird mass, house ventilation flow rate). However, the EPA rejected the use of OLS regression analyses for developing predictive equations based EEMs for litter removal periods because of the poor correlation of the resulting regression equations (i.e., R^2 values were less than 0.30).

The difficulty in applying the OLS regressions analyses to the litter removal period data was due to several characteristics of the available data. By design of the NAEMS, there are substantially fewer daily emissions values available for the decaking and full litter clean-out periods than for grow-out periods. Additionally, the emissions data that are available vary widely over the clean-out period as shown in Table 9-5. Applying the regression analyses to litter removal periods was further complicated because the data and supporting information do not specify how each house was operated during the period between flocks when the litter removal activities were conducted. For example, the available data do not indicate the date or time that the litter removal activities were initiated or completed, account for the manner in which the house doors and openings were managed, or identify the activities undertaken by farm personnel in the house during these periods. These factors could account for the variability in emissions and would likely improve the ability of a regression analysis to capture the emissions trends of the litter removal periods.

For the EEMs for litter removal periods, the EPA developed pollutant-specific emissions factors for the decaking and full litter clean-out periods. Typically, emissions factors relate pollutant emissions to an activity (e.g., kg of PM_{10}/kg of coal combusted). The EFs developed by the EPA relate pollutant emissions to the total weight of birds raised on the litter and the duration of the litter removal activity.

The emissions released during litter removal periods, which begin after the birds have been sent to market and end when the new flock is placed in the house, are directly related to the manure accumulated on the confinement floor, the amount of manure removed from the house by farm personnel, and the duration of the litter removal event.

Table 9-5. Range of Emissions for Broiler Litter Removal Periods

Pollutant (units)	Litter Removal Activity	Daily Average Emissions per House (g/d)	Range of Observed Emissions	Standard Deviation
NH_3	Decaking	8,254.62	[0.00, 50,900.00]	8,511.14
	Full litter clean-out	4,739.67	[0.00, 30,569.63]	6,732.66
H_2S	Decaking	12.72	[0.00, 98.60]	16.95
	Full litter clean-out	6.58	[0.05, 63.50]	11.51
PM_{10}	Decaking	20.41	[0.00, 171.52]	37.43
	Full litter clean-out	16.09	[0.00, 71.29]	19.68
$PM_{2.5}$	Decaking	13.83	[0.00, 153.18]	27.90
	Full litter clean-out	5.12	[0.00, 13.76]	6.03
TSP	Decaking	55.66	[0.00, 361.23]	90.87
	Full litter clean-out	39.90	[0.00, 161.71]	53.29
VOC	Decaking	186.29	[0.00, 1,632]	267.86
	Full litter clean-out	296.66	[0.00, 1,234]	367.40

The total amount of manure accumulated at the end of each flock was not a part of the NAEMS monitoring program. To represent the accumulated manure in the house prior to commencement of litter removal activities, the EPA used the weight of birds raised on the litter since the last cleaning event (i.e., one flock). The specific amount of manure removed by each decaking and full litter clean-out event was not provided to the EPA. Section 3 summarizes the available data regarding the volume of manure removed on two occasions at site CA1B (the manure removed from each house was not part of the monitoring program at the Kentucky sites). Consequently, the amount of manure removed was not included in the development of EFs for litter removal periods.

To develop the EFs, the EPA calculated the average daily emissions rate (g/d) for each litter removal event by dividing the sum of the daily emissions by the total number of days of the event (i.e., total number of days the house is empty). The emissions rate values for each event were divided by the total weight of birds raised on the litter (kg) to yield an emissions factor expressed in terms of g of pollutant emissions/kg bird-day. The EFs for each pollutant and type of litter removal period were calculated by averaging the event-specific emissions factors, as follows:

$$EF_{Weight-Day} = \frac{1}{n}\sum_{j=1}^{n}\left(\frac{[Total\ emissions]_j/[Number\ of\ days]_j}{[Total\ Weight]_j\ *}\right)$$

where j indicates a unique litter removal period and n is the number of litter removal events (24 decaking and 12 full litter clean-out periods).

The EPA evaluated three approaches for calculating the total weight of birds raised on the litter since the previous litter removal period:

*Cumulative Weight (CW) = Sum [(Daily bird inventory) * (Avg. daily weight (kg))]*

*Total Shipped Weight (SW) = (No. of birds shipped to market) * (Max. avg. weight (kg))*

*Max. Total Weight (MW) = (No. of birds placed) * (Max. avg. weight (kg))*

The cumulative weight was considered by the EPA because this value accounts for the actual weight of birds raised on the litter over the grow-out period. However, this approach requires the bird inventory and average weight values for each day of the grow-out period, which might not always be readily available for growers. The total shipped weight and maximum weight approaches require fewer data points to calculate an estimate of bird weight. The total shipped weight, based on the number of birds sent to market, was considered by the EPA because this value accounts for the mortality of the broilers over the course of the grow-out period. A high mortality rate would significantly affect emissions (i.e., fewer birds relates to less deposited manure). The total shipped weight was also considered because the broiler industry typically measures the production of a boiler house in terms of birds marketed. The maximum total weight, based on the number of birds placed in the house at the beginning of the grow-out period, was considered by the EPA because this value represents the highest possible measure of the weight of birds raised on the litter over the grow-out period. This approach to calculating maximum total weight would also account for a severe bird mortality event that occurred near the end of the grow-out period. In other words, the use of total shipped weight would underestimate the total bird weight raised on the litter in the event of a catastrophic loss prior to shipping. Table 9-6 summarizes the EFs developed for the decaking and full litter clean-out periods using the three weight calculation approaches. In general, the emissions factors suggest that decaking events have higher emissions than full litter clean-out events, with the exception of PM_{10} and VOC. This seems reasonable as the emissions factors take into account the days after the cleaning activity has taken place and the house is idle (i.e., no birds present). After decaking, the idle house will still have some residual biological materials that will continue to produce emissions. After a full litter clean-out, there is minimal residual manure to continue to produce emissions.

PM_{10} emission estimates for decking events are only slightly higher for one version of the emissions factors tested. This difference could simply be an artifact of the data, since the data only represent the period when the house was sitting idle after the cleaning activity. The higher VOC emission estimates for full litter clean-out could possibly be due to cleaning agents used providing an additional source. The NAEMS did not document the cleaning techniques of the broiler houses, so it is difficult to confirm this hypothesis.

To assess the predictive accuracy of the EFs, the EPA compared the measured emissions for litter removal periods to the emissions calculated using each type of EF. Due to the limited data available for litter removal periods, only two decaking events (one from site CA1B and one from a Kentucky site) and one full litter clean-out event (site CA1B) were withheld from the EEM development data set (a single full litter clean-out event was withheld because only two full litter clean-out periods were monitored at the Kentucky sites). Entire clean-out periods were withheld as the emissions factors developed were based on entire clean-out events rather than individual days. Additionally, the EPA's literature reviews and CFI described in Section 4 did not identify any studies that reported emissions from the litter removal periods.

Table 9-6. Emissions Factors for Broiler Litter Removal Periods

Pollutant	Type of Litter Removal Activity	EF (g pollutant/kg bird-day)		
		Cumulative Weight	Shipped Weight	Maximum Weight
NH_3	Decaking	0.006288	0.1380	0.1285
	Full litter clean-out	0.003108	0.0645	0.0629
H_2S	Decaking	0.000012	0.0003	0.0002
	Full litter clean-out	0.000005	0.0001	0.0001
PM_{10}	Decaking	0.000009	0.0002	0.0002
	Full litter clean-out	0.000011	0.0002	0.0002
$PM_{2.5}$	Decaking	0.000010	0.0002	0.0002
	Full litter clean-out	0.000003	0.0001	0.0001
TSP	Decaking	0.000038	0.0009	0.0008
	Full litter clean-out	0.000034	0.0007	0.0007
VOC	Decaking	0.000127	0.0026	0.0026
	Full litter clean-out	0.000182	0.0038	0.0037

For the assessment, the EPA calculated the three types of bird weight expressions, using the bird inventory data for the flocks, and the durations associated with the litter removal events data withheld for model validation. The measured emissions were compared to the emissions calculated by applying the weight and duration values to the EFs. Table 9-7 summarizes the absolute average difference in the measured and calculated emissions values. Based on this assessment, the EPA selected the EFs based on the cumulative bird weight for use in estimating pollutant emissions for litter removal periods.

Table 9-7. Difference in Measured Versus Estimated Emissions

Pollutant	Type of Litter Removal Activity	Absolute Difference in Emissions (g pollutant/kg bird-day)		
		Cumulative Weight	Shipped Weight	Maximum Weight
NH_3	Decaking	13,012.74	26,528.54	28,328.34
	Full litter clean-out	1,087.88	1,035.55	1,431.87
H_2S	Decaking	8.58	17.55	21.03
	Full litter clean-out	12.65	16.19	16.85
PM_{10}	Decaking	112.55	118.15	122.32
	Full litter clean-out	14.25	10.51	9.81
$PM_{2.5}$	Decaking	25.60	29.25	45.21
	Full litter clean-out	a	a	a
TSP	Decaking	214.90	228.66	288.86
	Full litter clean-out	a	a	a
VOC	Decaking	884.02	355.49	416.56
	Full litter clean-out	a	a	a

[a] No validation data available. CA1B did not have emission measurements of these pollutants for full litter clean-out events.

Using the EFs, the annual emissions for litter removal periods in a confinement house would be determined as the sum of the emissions calculated for each litter removal event that occurred during the year. For example, a farm would determine the cumulative bird weight of each flock raised on the litter in a confinement house between removal events based on daily inventory values and bird weights from site-specific growth curves. The farm also would record the duration of each decaking and full litter clean-out event that occurred in the house over the year. The event-specific emissions would be determined using the EFs and the cumulative bird weight and duration associated with each litter removal event. The farm's total annual emissions associated with litter removal periods would be the sum of house-specific emissions for each litter removal event that occurred over the year, as follows:

$$\text{Annual emissions}_{\text{Decaking}} = \Sigma((\text{EF}_{\text{Decaking}})*(\text{CW})*(\text{Duration of decaking}))$$

$$\text{Annual emissions}_{\text{Full litter clean-out}} = \Sigma((\text{EF}_{\text{Full litter clean-out}})*(\text{CW})*(\text{Duration of full litter clean-out}))$$

Total annual emissions$_{\text{Litter removal periods}}$ = Annual emissions$_{\text{Decaking}}$ + Annual emissions$_{\text{Full litter clean-out}}$

The daily emissions for a given litter removal event at a house would be calculated by multiplying the emissions factor by the cumulative weight only.

Table 9-8 provides an example calculation of the annual and daily emissions values for a confinement house. In this example, the total annual emissions (i.e., the sum of the event-specific emissions) is 656.39 kilograms. The daily emissions (kg/d) for the five flocks are 15.97, 16.59, 16.09, 16.11 and 8.08, respectively.

Table 9-8. Example Flock Characteristics

Flock No.	Cum. Bird Weight (1,000 kg)	Type of Litter Removal After Flock	Duration (days)	Emissions Factor (g pollutant/kg bird-day)	NH_3 Emissions	
					(kg/event)	(avg. kg/d)
1	2,540	Decaking	8	0.006288	127.77	15.97
2	2,638	Decaking	10	0.006288	165.88	16.59
3	2,559	Decaking	7	0.006288	112.64	16.09
4	2,562	Decaking	9	0.006288	144.99	16.11
5	2,601	Full litter clean-out	13	0.003108	105.10	8.08
Total annual emissions (kg) =					656.39	

10.0 REFERENCES

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Appendix A

QUALITY ASSURANCE PROJECT PLAN

for the National Air Emissions Monitoring Study

(Barns Component) QAPP Category #1

Revision 2.0

January 24, 2008

QUALITY ASSURANCE PROJECT PLAN

for the
National Air Emissions Monitoring Study
(Barns Component)

QAPP Category #1

Revision 2.0
January 24, 2008

Agriculture Air Research Council (AARC)
Purdue University Department of Agricultural and Biological Engineering

Prepared by
Purdue Agricultural Air Quality Laboratory (PAAQL)
West Lafayette, IN 47907

Approvals

____
Albert J. Heber, Science Advisor and Overall Project Manager, Purdue University

____
JiQin Ni, Assistant Project Manager, Purdue University

____
Teng Lim, Assistant Project Manager, Purdue University

____
Juan Carlos Ramirez, Project QA Manager, Purdue University

____
Bill Schrock, Project Manager, USEPA OAQPS

____
Joseph Elkins, QA Manager, USEPA OAQPS

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QAPP Distribution List

Official copies of this QAPP and any subsequent revisions will be provided electronically to the following organizations through the primary contact person listed:

Purdue University

Albert Heber	Department of Agricultural & Biological Engineering
Deb Dimmitt	Purdue University Sponsored Program Services

US Environmental Protection Agency

Joseph Elkins	USEPA OAQPS
Larry Elmore	USEPA OAQPS
Bruce Fergusson	USEPA OECA

Stakeholders in Livestock Industry

John Thorne	Agriculture Air Research Council (AARC)
Allan Stokes	National Pork Producers Council (NPPC)
Jim Tillison	National Milk Producers Federation (NMPF)
John Starkey	National Chicken Council (NCC)
Chad Gregory	United Egg Producers (UEP)
Producers	Confidential

Principal Investigators

Jacek Koziel	Iowa State University
Wayne Robarge	North Carolina State University
Lingjuan Wang	North Carolina State University
Curt Gooch	Cornell University
Frank Mitloehner	University of California-Davis
Ruihong Zhang	University of California-Davis
Ken Casey	Texas A&M University
Pius Ndegwa	Washington State University-Pullman
Larry Jacobson	University of Minnesota
JiQin Ni	Purdue University
Teng Lim	Purdue University

Copies of the EPA-Approved Quality Assurance Project Plan will be made available to any organization upon request.

Definitions of Abbreviations, Acronyms and Chemical Names

Abbreviations and Acronyms

AARC	Agricultural Air Research Council
ABE	Agricultural & Biological Engineering Department, Purdue University
AirDAC	Air Data Acquisition and Control software (SOP B2)
AMCA	Air Movement & Control Association International, Inc.
ANSI	American National Standards Institute
APECAB	Aerial Pollutant Emissions from Confined Animal Buildings
ASME	American Society of Mechanical Engineers
BACT	Best Available Control Technology
BESS	Bioenvironmental Systems and Simulations Lab at the University of Illinois
CAA	Clean Air Act
CAB	Confined animal buildings
CAFO	Confined animal feeding operation
CCB	Center-ceiling baffled inlet
CEM	Continuous emission monitoring
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COC	Chain of custody
CSRS	Cation self-regenerating suppressor
CTC	Cation trap column
CTM	Conditional Test Method
CV	Coefficient of variation
DA	Data Analyst
DAC	Data acquisition and control
DAQ	Data acquisition
dP	Differential pressure
DQA	Data quality assessment
DQI	Data quality indicator
DQO	Data quality objective
DSC	Datalogging and supervisory control
EP	Evaporative pad
EPCRA	Emergency Planning and Community Right-to-Know Act
FANS	Fan Assessment Numeration System
FRM	Federal Reference Method
FTIR	Fourier transform infrared
GC/MS	Gas chromatography/mass spectrometry
GSLG	Gas sampling location group
GSS	Gas sampling system
HVAC	Heating, ventilation and air conditioning
IC	Ion chromatography
IEC	International Electrotechnical Commission
IFAFS	Initiative for Future Agricultural and Food Systems

IMC	Independent Monitoring Contractor
ISO	International Organization for Standardization
JAWMA	Journal of the Air and Waste Management Association
LSAS	Location-shared analyzers and sensors
MC	Moisture content
MFC	Mass flow controller
MQO	Measurement quality objective
MSA	Methanesulfonic acid **OR** Mine Safety Appliances, Inc.
MSS	Major Stationary Source
MV	Mechanically ventilated
NAEMS	National Air Emissions Monitoring Study
NAS	National Academy of Sciences
NCC	National Chicken Council
NCSL	National Council of Standard Laboratories
NELAP	National Environmental Laboratory Accreditation Program
NMPF	National Milk Producers Federation
NPPC	National Pork Producers Council
NRCS	Natural Resources Conservation Service
NV	Naturally ventilated
OFIS	On-farm instrument shelter
PAAQL	Purdue Agricultural Air Quality Laboratory
PFA	Grade of Teflon
PI	Principal Investigator
PIR	Passive infrared
PM	Particulate matter
PM_{10}	Particulate matter less than 10 μm diameter
$PM_{2.5}$	Particulate matter less than 2.5 μm diameter
PP	Pull-plug manure pit
PPR	Pull-plug manure pit with recharge
PREF	Primary representative exhaust fan
PTE	Potential to Emit
QA	Quality assurance
QC	Quality control
QAPP	Quality Assurance Project Plan
RQ	Reportable quantity
RSD	Relative standard deviation
SA	Science Advisor
SLG	Sampling location group
SMP	Site Monitoring Plan
SOP	Standard Operating Procedure
RH	Relative humidity
TDS	Thermodesorption System
TEC	Thermo Electron Corporation
TEOM	Tapered element oscillating microbalance
TFC	Thin-film capacitor

TFS	Thermo Fisher Scientific
TPY	Tons per year
TSP	Total suspended particulate
UEP	United Egg Producers
UIUC	University of Illinois at Urbana-Champaign
UPS	Uninterruptible power supply
USDA	United State Department of Agriculture
USEPA	United States Environmental Protection Agency
VDC	Volts direct current
VFA	Volatile fatty acid
VOC	Volatile organic compound
VSCC	Very sharp cut cyclone
Z/S	Zero/span

Chemical Names

CO_2	Carbon dioxide
H_2S	Hydrogen sulfide
H_2SO_4	Sulfuric acid
Hg	Mercury
KBr	Potassium bromide
KCl	Potassium chloride
N_2	Nitrogen gas
NH_3	Ammonia
NO	Nitric oxide
NO_2	Nitrogen dioxide
S	Sulfur
SO_2	Sulfur dioxide

1. Project Management

1.1 Project/Task Organization

Figure 1.1.1 provides an overview of the personnel involved in the NAEMS, with lines of authority, and responsibilities and job titles for each individual. Dr. Albert Heber (Purdue University) is responsible for overall project management and for coordinating administrative logistics, including selecting University PIs and implementing sub-contracts, filing of project reports, and management of financial resources. As Science Advisor (SA), Dr. Heber is also responsible for directing the technical aspects of the project, including drafting the comprehensive study design, selecting test sites, creating, updating, distributing and implementing the quality assurance project plan, specifying instrumentation and equipment, designing, constructing and delivering the gas sampling systems, developing and distributing the data acquisition program, and analyzing the data. Dr. Heber's staff at the Purdue Agricultural Air Quality Laboratory (PAAQL) will be responsible for the initial acceptance of all test instruments, and for ensuring that all University PIs (and their staffs as appropriate) are adequately trained in the setup of the equipment and the methodology of the study. Dr. Richard Grant (Purdue University) will, as co-PI, be responsible for conducting all open-source and micrometeorological measurements, as described in the QAPP for the NAEMS Open-Source Component (submitted separately).

Members of Dr. Heber's PAAQL staff (one or two for each site) will also spend approximately one week assisting the University PIs with the setup of each individual site, including setting up the gas sampling system and other analytical instrumentation, setting up the on-farm instrument shelter (OFIS), establishing communications (including high-speed internet/data transmission), fixing sensor locations, and initiating installation and configuration of data-collection hardware and software. University PIs will then complete the setup at the individual sites, which is expected to take 1-2 mos. Dr. Heber or other PAAQL personnel will then return to the site for an initial audit of the completed and functioning setup. Once the project enters the data-collection phase (May 8, 2007 through approximately December 15, 2007, depending on the site), the university PIs and their designated staff member(s) (the site engineers in Fig. 1.1.1) will oversee the daily operation of all on-site equipment and instrumentation (e.g. gas analyzers, PM-monitoring equipment, environmental sensors). NAEMS-designated staff member(s) at each university are expected to visit their site, at minimum, once per week, and are expected to monitor the site remotely (via internet connection using the AirDAC program) at least once per day. Site PIs and their staff will also be responsible for all routine sample collection, including manure (and feed, bedding, milk, and eggs) sampling, assessing animal inventories, collecting and shipping VOC samples (described in Section 2.1.8), and conducting fan tests. In most cases, the samples (manure and other materials, VOCs) will be sent, as described in detail in Section 2.2, either to PAAQL, or to a designated commercial laboratory (Midwest Laboratories) for analysis.

Individuals who will serve as Principal Investigators for one or more sites are as follows:

- Dr. Jacek Koziel, Iowa State University
- Dr. Wayne Robarge, North Carolina State University
- Dr. Lingjuan Wang, North Carolina State University
- Dr. Larry Jacobson, University of Minnesota
- Mr. Curt Gooch, Cornell University
- Dr. Frank Mitloehner, University of California-Davis
- Dr. Ruihong Zhang, University of California-Davis
- Dr. Ken Casey, Texas A&M University
- Dr. Pius Ndegwa, Washington State University-Pullman
- Dr. Teng Lim, Purdue University
- Dr. Jiqin Ni, Purdue University

Purdue University will have specific fiduciary, communications and technical responsibilities. Purdue University will oversee the process to ensure the study funds and equipment are properly accounted for under the approved budget and federal check-off funding requirements and any applicable tax laws. Purdue University will report on the conduct of the study to EPA and the nonprofit entity. In addition, Purdue University will build a web site specific for this study and regularly post updates for the public to follow the progress of the study. Purdue University will oversee certain technical aspects of the study, will help interpret the progress of the study, and provide periodic reports to EPA and AARC.

Purdue University will directly administer: (a) all subcontracts with the principal investigators (PIs) doing the data collection; (b) purchasing and inventory control of all equipment throughout the study, (c) construction and distribution of mobile laboratories, (d) direct supervision of the teams of PIs in the course of the study, (e) direct supervision of data acquisition, data management, data processing, data and equipment QA/QC, etc., and (f) other activities as described below. Purdue University will interact with the business offices of the universities to administer their respective PI’s budgets. These budgets will vary depending on the location of the farm(s), the number of barns monitored, and local characteristics (e.g., distance PIs and technicians have to travel to visit the site(s), climate extremes, etc.). Individual PIs will likely employ their existing technicians and their own university business offices will handle their team’s payroll, travel reimbursements etc. as they would any other external contract or grant. Purdue University will monitor expenditures of each subcontracting university, approve transfer of funds to them according to approved budgets, review the financial statements of the business offices of the subcontracting universities, and report to EPA and AARC on a regular basis.

Purdue University will employ an in-house QA/QC Manager (Dr. Juan Carlos Ramirez), who will be responsible for conducting or directing audits of each site. Audits will be conducted during the first quarter of data collection for each site, and at the midpoint of the study. These audits are detailed in Section 3.1 of this QAPP. Data review for all sites will be conducted at Purdue by a team of data analysts. Drs. Teng Lim and JiQin Ni of Purdue will also be responsible, as PI on 2 sites and one site, respectively, for contributing to data review and processing of those sites. This arrangement will result in eight persons being the primary data analyst for 1-4 individual sites. The following is the current distribution of sites among data analysts, subject to change based on site requirements and personnel availability.

- Dr. Ruiqiang Liu – IN3B
- Dr. Jeong-Hyub Ha – IN5B
- Dr. Juan Carlos Ramirez – CA5B, WA5B
- Dr. Erin Cortus – CA1B, IA4B, OK4B, WI5B
- Dr. Kaiying Wang – NC2B, NC3B
- Dr. Bill Bogan – NY5B
- Dr. Teng Lim – CA2B
- Dr. Jiqin Ni – IN2B/IN2H
- Mr. Sam Hanni – NC4B

Data analysts will be responsible for daily on-line (remote) checking of their assigned sites, will receive warning emails whenever out-of-range data is encountered (SOP B2), and will conduct most data pre-processing (SOP B3) and all data processing (SOP B6) activities.

One contract analytical laboratory, Midwest Laboratories (Omaha, NE), will analyze all manure, feed, bedding, milk, and eggs samples generated in the NAEMS. Midwest Laboratories' QA/QC Director, Dr. Jerome King, will be responsible for overseeing the QA function of that portion of the project. Midwest Laboratories' QA/QC Program is based on the principles contained in ISO9000, ISO/IEC Guide 25, and ISO Guide 17025. The company is certified by the National Environmental Laboratory Accreditation Program (NELAP), and holds accreditation from USDA, the National Forage Testing Association, and several states (OK, NE, CO, IA, MN, and WI). Further details of Midwest Laboratories' Involvement, and their QA/QC program, are provided in the appropriate sections of this QAPP. PAAQL personnel led by Dr. Changhe Xiao, who will serve as NAEMS VOC Manager, will analyze all VOC samples collected in the study.

The Agricultural Air Research Council (AARC), a non-profit entity established by representatives of the dairy (NMPF), swine (NPPC), layer (UEP) and broiler (NCC) industries, will fund the study. The AARC Board of Directors will meet regularly, receive reports on the progress of the study, approve the budget, and review audits of expenditures. The AARC will be responsible for holding and disbursing to Purdue University the funds necessary to complete the study according to its approved schedule, protocol and budget. The AARC will also provide a communication mechanism to livestock and poultry producers, the media and other parties.

Specific USEPA personnel involved in NAEMS are as follows. OAQPS will designate one person as the overall Project Manager for EPA, while Joseph Elkins will serve as the QA Manager. Mr. Elkins will direct the external QA audits of the sites, which will be conducted by EPA and/or an EPA contractor (e.g., Battelle), as shown in Fig. 1.1.1.

Producers/farm managers involved in the study must be willing to: 1) attend a training session (Section 1.5), 2) make changes as needed to accommodate the project, and 3) maintain and share certain production records to facilitate data analysis and interpretation. A description of the type of data that each individual producer is expected to provide is given in SOP S1.

1.1.1 Personnel and Agencies Involved

Name	Affiliation	Phone	Email
Albert Heber	Purdue University	765-494-1214	heber@purdue.edu
JiQin Ni	Purdue University	765-494-1195	jiqin@purdue.edu
Teng Lim	Purdue University	765-494-1195	limt@purdue.edu
Bill Bogan	Purdue University	765-494-9005	bogan@purdue.edu
Erin Cortus	Purdue University	765-494-1195	ecortus@purdue.edu
Juan-Carlos Ramirez	Purdue University	765-496-1731	jramirez@purdue.edu
Claude Diehl	Purdue University	765-496-6937	diehl@purdue.edu
Sam Hanni	Purdue University	765-796-6937	shanni@purdue.edu
Changhe Xiao	Purdue University	765-494-1134	cxiao@purdue.edu
Ruiqiang Liu	Purdue University	765-494-1196	liu174@ecn.purdue.edu
Jeonghyub Ha	Purdue University	765-494-1196	ha3@purdue.edu
Kaiying Wang	Purdue University	765-494-1210	Wang237@purdue.edu
	Agricultural & Biological Engg, 225 S. Univ. St., W. Lafayette, IN 47907		
Richard Grant	Purdue University	765-494-8048	rgrant@purdue.edu
	Agronomy, Lilly Hall, 915 W. State St., West Lafayette, IN 47907		
Jacek Koziel	Iowa State University	515-294-4206	koziel@iastate.edu
	3103 NSRIC, Ames, IA 50011-3310		
Larry Jacobson	University of Minnesota	612-625-8288	jacob007@umn.edu
	210 Biosystems and Agricultural Engineering, St. Paul MN 55108-6005		
Wayne Robarge	North Carolina State University	919-515-1454	wayne_robarge@ncsu.edu
	Williams Hall 3406, Box 7619 NCSU, Raleigh, NC 27695		
Lingjuan Wang	North Carolina State University	919-515-6762	Lwang5@ncsu.edu
	D S Weaver Labs 186, Box 7625, NCSU, Raleigh, NC 27695		
Curt Gooch	Cornell University	607-255-2088	cag26@cornell.edu
	334 Riley-Robb, 18 Sky Acre Dr., Ithaca, NY 14850		
Frank Mitloehner	University of California-Davis	530-752-3936	fmmitloehner@ucdavis.edu
	2151 Meyer Hall, Davis, CA 95616		
Ruihong Zhang	University of California-Davis	530-754-9530	rhzhang@ucdavis.edu
	3046 Bainer Hall, Davis, CA 95616		
Ken Casey	Texas A&M University	806-677-5600	kdcasey@tamu.edu
	6500 Amarillo Blvd, West, Amarillo, TX 79106		
Pius Ndegwa	Washington State University	509-335-8167	ndegwa@wsu.edu
	L J Smith 202, Pullman, WA 99164-6120		
Joseph Elkins	USEPA OAQPS	919-541-2408	elkins.jospeh@epa.gov
Bruce Harris	USEPA OAQPS	919-541-7807	harris.bruce@epa.gov
Robin Dunkins	USEPA OAQPS	919-541-5335	dunkins.robin@epa.gov
Bill Schrock	USEPA OAQPS	919-541-5032	schrock.bill@epa.gov
Larry Elmore	USEPA OAQPS	919-541-5433	elmore.larry@epa.gov
	Mail Code C504-04, 4930 Page Rd., Durham, NC 27703		
Bruce Ferguson	USEPA OECA	202-564-1261	fergusson.bruce@epa.gov
	Ariel Rios Building, 1200 Pennsylvania Ave., N.W. Washington, D.C. 20460		
Confidential	Producers at each site	Confidential	Confidential

1.1.2 Personnel Responsibilities/Project Organization

Science Advisor	Heber
Quality Assurance Project Plan (QAPP)	Heber
QAPP Review/Approval	USEPA, Battelle, RTI, USDA
Select Monitoring Sites and University PIs	Heber
Field Support	Producers
Obtain Access Agreements	Heber, PIs
Prepare Producer Contracts	Heber
Internal QA/QC Audits of Field Tests	Purdue University
External Field Oversight	PIs
Media Inquiries	Heber
Field Data Analysis	Heber, PIs
NH_3 Data Reporting	Heber
H_2S Data Reporting	Heber
CO_2 Data Reporting	Heber
VOCs Data Reporting	Heber
$PM_{2.5}$, PM_{10}, and TSP Data Reporting	Heber
Data Compilation/Final Report	Heber
Final Report Review & Approval	Heber, EPA

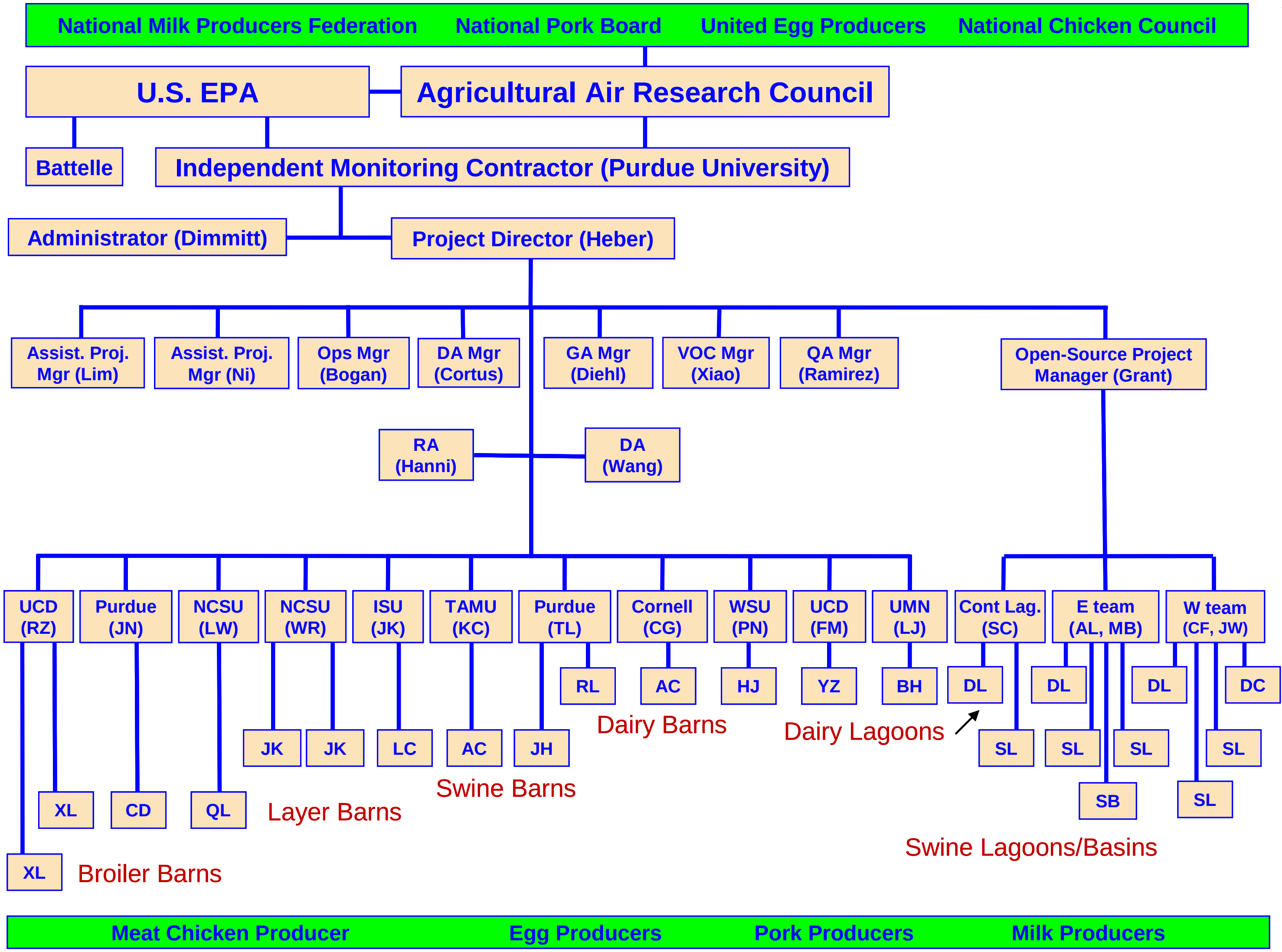


Figure 1.1.1. Responsibility & Authority Flow Chart for the NAEMS. Includes open-source measurements (see companion QAPP). GA = Gas Analyzer; RA = Research Assistant; DA = Data Analyst; DL = Dairy Lagoon; PL = Pork Lagoon; PB = Pork Basin; DC = Dairy Corral;

1.2 Problem Definition/Background

Air pollutants emitted from livestock buildings may represent a significant source of pollution to the wider environment. Aerial pollutants of particular interest in livestock buildings are ammonia (NH_3), hydrogen sulfide (H_2S), volatile organic compounds (VOCs), and particulate matter ($PM_{2.5}$, PM_{10} and TSP). It would be helpful to obtain more information about how much air pollution is emitted by livestock facilities, and how much emissions may be influenced by climate, animal species, and design and management of the facility, in a national study using consistent measurement protocols. The Environmental Protection Agency (EPA) expects Animal Feeding Operations (AFOs) to comply with air quality laws, but has found it difficult to determine if an AFO is in violation and if so, the extent of the violation. In 2000, EPA began applying federal air quality laws to AFOs (Schutz, et al., 2005).

Currently, air emissions from AFOs, such as PM, NH_3, H_2S, and VOCs, fall under the U.S. Clean Air Act of 1990 (CAA). In addition, there are notification requirements for NH_3 and H_2S under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act (EPCRA) (Schutz, et al., 2005).

1.2.1 Regulation under the CAA

A Major Stationary Source (MSS) is defined as any stationary source that emits, or has the potential to emit, 250 TPY of a regulated air pollutant. For livestock sources, that means 250 tons per year (TPY) of TSP or any particle size fraction thereof, 250 TPY of non-methane VOCs, or 250 TPY of H_2S. A MSS requires installation of Best Available Control Technology (BACT).

A facility must obtain a Title V permit if it emits more than 100 TPY of PM_{10} (but not TSP, which remains at 250 TPY) or VOCs. In most states, Minor New Source Review permits must be obtained and emissions fees must be paid if they emit more than 15 TPY of PM_{10}, 25 TPY of TSP, or 40 TPY of VOCs. These MNSR permits do not automatically require installation of controls, but controls can be required at the discretion of the state or local air pollution control agency (Secrest, 2004).

Potential to emit (PTE) refers to the maximum capacity of a stationary source to emit a pollutant under its physical and operational design (e.g., summer ventilation rate with full housing capacity times 12 would be the 12 month PTE rate). Any physical or operational limitation on the capacity of a source to emit (such as winter ventilation rate and its effect on total actual emissions) is treated as part of its "design" if the limitation or the effect it would have on the potential to emit is Federally enforceable (e.g., is contained in the source's CAA permit) (40 CFR 51.166). For example, if a livestock operation could emit over 250 TPY based solely on its high summer month rate times 12, and the source did not have a Federally enforceable MSS permit defining its PTE based on actual operational conditions (in this case, winter ventilation rate restrictions), then the source could be liable for violating the CAA. Whereas this practice has not been considered for livestock industries, the PTE definition was intended to apply to sources such as manufacturing facilities that, for example, could emit 250 TPY of VOCs except they only run two work shifts instead of three (Secrest, 2004).

For purposes of Title V (State Operating Permit Programs), a stationary source that emits, or has the potential to emit, 100 TPY of a regulated air pollutant must comply with 40 CFR Part 70 (Title V permit program). In practice, this means 100 TPY or more of PM_{10} (but not TSP), or 100 TPY of VOCs (Secrest, 2004).

Many state CAA implementation programs also include a requirement that a facility notify the state of its annual emissions if they exceed 40 TPY of VOCs, 25 TPY of TSP, or 15 TPY of PM_{10}. These "de minimis" sources may be subject to a letter notification process and must file emissions inventory reports and emissions fees as set forth in the State Implementation Plan (Secrest, 2004).

The primary authority for regulating sources under the CAA is the state or local air pollution control agency and specific requirements vary from state to state. The requirements are contained in the State Implementation Plan regulations. For example, California is divided into more than 20 county- and area-level air pollution control districts, and each defines "Major Source" at different levels of emissions, some of which are lower than the general Federal rule (e.g., 40 TPY of VOCs). Twenty states were notified by the EPA in 2004 that they did not meet ambient air quality standards for $PM_{2.5}$. States with non-attainment areas must submit plans by 2008 indicating how they plan to meet this standard, and meet the standard by 2010. Non-attainment areas are geographical regions that have failed to meet the air quality standards of specific pollutants based on state-operated networks of ambient monitors (Schutz, et al., 2005).

1.2.2 Regulation under CERCLA/EPCRA

The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) or the “Superfund” Act addresses the physical and financial responsibilities associated with the release of airborne hazardous materials (Schutz et al., 2005). The quantity of material released is used to determine if the facility must report the release. Thus, each reportable substance has a reportable release quantity. The reportable release quantity for NH_3 or H_2S, for example, is 100 lb in any 24-h period.

The Emergency Planning and Community Right-to-Know Act (EPCRA) of 1986 was passed to allow people to be aware of any hazardous materials that are stored in their community and to help citizens make better decisions about the risks associated with living or working nearby. EPCRA establishes a list of hazardous materials and a threshold planning and reportable release quantity for each hazardous chemical. Like CERCLA, the reportable release quantity is 100 lb/d for NH_3 or H_2S. In the case of AFOs, EPA is proposing that operations above a threshold size annually report the release of emissions from the operation unless mitigating practices can reduce the emission release (Schutz et al., 2005).

1.2.3 Emission Estimation Methodology

The EPA currently estimates air emissions based on the size and type of the AFO using emission factors, rather than on direct monitoring or process-based modeling. According to the NRC

(2003), these emission factors are based on inadequate data. New methodologies to estimate emissions from livestock or poultry operations are needed, but more up-to-date and comprehensive data is required to support the development of more reliable emission estimation the methodologies (EEMs).

A significant step towards obtaining the data needed to support new EEMs was taken through the Air Consent Agreement, under which livestock producers and commodity groups will sponsor the National Air Emissions Monitoring Study at a number of representative AFOs to obtain new emission data. The Environmental Protection Agency offered animal feeding operations (AFOs) in the swine, dairy, broiler chicken, and egg, industries a one-time opportunity to participate in a legal agreement that would provide protection from prosecution for past federal air law violations that may have occurred at those operations. In return, those industries would agree to participate in an extensive nationwide study that would generate data for determining emissions from major types of farms in geographic areas where they are located. NAEMS is the culmination of that agreement.

NAEMS was developed in response to a 2003 National Academy of Sciences (NAS) report that highlighted possible air pollution problems arising from animal feeding operations, and discussed the insufficiency of existing databases. NAEMS was designed by the Air Quality Group of the USDA’s Natural Resources Conservation Service (NRCS) to address the issues in the NAS report, and to determine whether AFOs were likely to have compliance issues regarding the CAA and/or CERCLA/EPCRA. Since the NAS assessment focused on the incompleteness of the existing emissions factors, it was determined from the beginning of this process that a multi-industry, comprehensive study (such as NAEMS) would be necessary to address the issue satisfactorily. Compared with previous studies of livestock air emissions, NAEMS was designed to have the following features:

1. A large number of pollutants measured simultaneously ($PM_{2.5}$, PM_{10}, TSP, NH_3, H_2S, VOCs)
2. A longer duration (24 months) at each site than previous studies, the longest of which was 15 months (Jacobson, et al., 2004)
3. Largest number of barn monitoring sites (14) that use the same protocol for good comparability. Jacobson et al. (2004) used six mobile labs in their study of PM_{10}, TSP, NH_3, H_2S and odor
4. Most careful selection of farms to enhance the representativeness of the sites for their respective industries
5. The highest level of quality assurance and quality control (Category 1 QAPP). As a result, this study will “set the bar” for future studies.

The technical approach to emissions measurements was addressed by a group of invited scientists and producers’ representatives, and officials from EPA and USDA, who spent 2.5 d in November, 2003 together at a meeting in Beltsville, MD, to decide on the measurement protocols for the study. It was decided at this meeting by consensus to utilize the “mobile lab approach” for barns (rather than portable monitoring units), and open-path micrometeorological techniques (rather than flux chambers) for open sources such as lagoons and manure basins.

Protocols were refined during ensuing conference calls among subcommittees during the next three months. The goals of the NAEMS are as follows:

1. Quantify aerial pollutant emissions from AFOs in the dairy, pork, egg, and broiler meat industries and provide reliable air emissions data from representative confined livestock farms in the continental U.S. for developing and validating EEMs for livestock production and to obtain nationally-representative emission rates.
2. Determine whether individual farms are likely to emit PM and VOCs in excess of applicable Clean Air Act (CAA) thresholds.
3. Determine whether individual farms are likely to emit ammonia (NH_3) and/or hydrogen sulfide (H_2S) in excess of applicable Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Emergency Planning and Community Right-to-Know Act (EPCRA) reporting requirements.
4. Promote a national consensus on methods and procedures for estimating emissions from livestock operations.
5. Produce a database with which additional studies of air emissions and effectiveness of control technologies can be compared and from which emission factors can be developed, including data from existing emissions studies that meet EPA's quality assurance criteria along with the new NAEMS-generated data.

In addition, it is expected that this project will result in a database with which additional studies of air emissions and effectiveness of control technologies can be compared, and from which emission factors can be developed. Data from existing emissions studies that meet USEPA's quality assurance criteria will be integrated into this database, along with the new NAEMS-generated data.

The primary users of this information will be the EPA and state regulatory agencies, in determining new emissions factors for use in modeling and in enforcement actions. Another will be the industries themselves, as they consider mitigation approaches to comply with the regulations. Using NAEMS data, the EPA will develop emissions-estimating methodologies. The NAEMS measurement protocol will be used by these groups (regulatory agencies if they require certain methods for measuring emissions, producers if they undertake such measurements themselves) and other scientists and consultants with an interest in agricultural air quality.

1.3 Project/Task Description

1.3.1 Monitoring Sites

The emissions measurements needed to complete this study and serve as the basis for the database described above will be conducted at a total of 14 different barn monitoring sites in the continental U.S. (Table 1.3.1). The sites were chosen based on their representativeness of one of four main industries, namely, swine, dairy, layers, and broilers. The regions from which sites for each industry were selected were defined in the National Air Emissions Monitoring Study Protocol (Appendix B of the Consent Agreement). Important factors that were considered in the evaluation of each site's industry representativeness included: a) management of buildings, manure, etc., b) farm design and layout, c) age and size of facilities, d) animal diet and genetics, and e) geographic distribution.

Table 1.3.1. Summary of sites selected for NAEMS. "Area sites" including corrals, basins and lagoons are described in the companion Open-Source QAPP.

Industry	**Barn sites**					**Area sites**			
	2-barns	**3-barns**	**4-barns**	**# Sites**	**# Barns**	**Corrals**	**Lagoons**	**Basins**	**Total**
Swine	0	4	1**	5	16	0	5	1	6
Dairy*	3	2	0	5	12	1	3	0	4
Layers	2	0	1	3	8	0	0	0	0
Broilers	1	0	0	1	2	0	0	0	0
Total	6	6	2	14	38	1	8	1	10

*In the case of dairy, "barn" can refer to a freestall barn or the milking center.
**Four independent rooms within one "quad" finisher barn

Other factors were considered in the site-selection process, including the degree to which each site is conducive to collecting reliable and accurate emissions data with a single mobile lab. Thus, site layout and topographical considerations were factors. It is preferable that the monitored room and/or buildings are adjacent to each other, so that they can be connected to a single mobile laboratory, and that the buildings be mechanically ventilated, with single-speed fans. The site must be operated by a supportive producer, who is willing to accommodate the measurements, willing to record extra information for the study, and able to provide accurate production and inventory records and feed-conversion data. The potential of each farm for testing emission-mitigation strategies after the conclusion of NAEMS was also factored into the decision-making process. Also important was the provision that each site be within a 2.5-h drive to a PI, with all-weather access, and have access available to phones, electric, internet, and nearby lodging. All sites selected were judged representative of the operations under study, and were visited by the SA and/or the selected PI for the site. The following sections describe in more specific detail the rationale that was used to choose sites in each of the four industries.

1.3.2. Site Selection for Swine

Swine production phases include sows (breeding, gestation, and farrowing), nursery pigs, and finishing pigs. The buildings are either naturally-ventilated (NV) or mechanically-ventilated (MV), but many buildings have a combination of the two ventilation types (depending, for example on the season). Manure treatment and/or storage generally consists of either basins (earthen, clay or synthetic lined earthen, concrete, glass lined steel) and deep underfloor pits that store manure collected from the barn, or clay/synthetic lined earthen anaerobic treatment lagoons that dilute (approx. 5:1), treat and store manure. Manure collection systems with external manure storage/treatment are generally scrape, flush or pull-plug.

Overall, the U.S. hog inventory is located in three general regions. The five top Midwest swine states (IA, MN, IL, MO, and IN) represent about 54% of the total inventory in the U.S. In the Southeast, NC, AR, VA, KY, and MS represent about 19% of the total, and in the West, OK, NE, KS, SD, and TX make up a combined 15% of the total.

Table 1.3.2 identifies the types of swine farms where measurements will be taken to provide the needed data to complete the objectives of this study. Barn monitoring sites were selected based on criteria such as facility age, size, design and management, swine diet and genetics. Also, every attempt was made to identify sites that would be suitable for both barn and area measurements. Descriptions of all of these parameters, including a discussion of the rationale for choosing each site, are found in the individual Site Monitoring Plans in Appendix A. Two farms in the Southeast, representing the sow and finishing phases of production with lagoon manure treatment, were selected, both in North Carolina. The NC sow site will also have its lagoon monitored; due to site layouts (the spatial relationship between the barns and lagoon, with respect to wind patterns), the lagoon and barns for the NC finishers will be measured at two different farms. Two farms in the Midwest, representing a finishing farm using a deep pit system (Indiana) and a deep pit sow farm (Iowa), were selected. Finally, one farm in the West (Oklahoma) was selected. This farm represents sow farms with lagoon treatment, and both components (barns and lagoon) will be measured.

On each of the farms, three barns will have measurements taken simultaneously. Sow farms will have emissions measured at one farrowing room and two gestation barns. On finishing farms, three barns will have emission measurements, except in the case of the Midwest finisher, in which four separate rooms of a "quad" barn will be treated individually.

Table 1.3.2. Swine industry barn sites.

SMP #	Production phase	Ventilation type	Number of units measured	Manure collection	Manure storage[2]	PI
Southeast						
NC4B[1]	Breeding/gestation	MV (tunnel)	2	PPR[3]	Lagoon	Robarge
	Farrowing	MV	1	PPR	Lagoon	
NC3B	Finisher	MV (tunnel)	3	PPR	Lagoon	Robarge
Midwest						
IA4B	Breeding/gestation	MV (tunnel)	2	Deep pit[4]		Koziel
	Farrowing	MV	1	PPR	Gestation pits	
IN3B	Finisher	MV (tunnel)	4	Deep pit[4]		Lim
West						
OK4B[1]	Breeding/gestation	MV (tunnel)	2	PPR	Lagoon	Casey
	Farrowing	MV	1	PPR	Lagoon	

[1] Barn sites that also have measured area sources, which are described in the open-source QAPP

[2] Characterizes type of farm, not necessarily a measurement location.

[3] PPR = pull plug with recharge

[4] Storage is inside the barn so separate measurement not needed for storage.

1.3.3. Site Selection for Laying Hens

Most U.S. layer housing types and manure management schemes fall under one of two categories: 1) high-rise houses in which manure is stored in the lower level and removed every 1 to 2 yrs; and 2) belt houses with quasi-continuous manure transfer to an external storage/ treatment facility. The locations for three sites with specific housing types were recommended for this study, with consideration of these housing categories, along with the potential impact of climatic differences and the geographical density of egg production (Table 1.3.3). Final site selections also depended on site-specific factors including: representativeness of facility age, size, design and management, and flock diet and genetics. A four-barn (two high-rise, two belt battery) site was chosen in Indiana, while a two-barn (high-rise only) site was selected in California. A two-barn site (high-rise only) was chosen in North Carolina. A detailed description of each site, including a summary of the rationale behind its selection for NAEMS, is given in the respective Site Monitoring Plans.

Table 1.3.3. Layer (egg) industry sites.

SMP #	Site Type	Ventilation type	Number of units measured	Manure Collection	Manure Storage	PI
East						
NC2B	High-rise	MV (tunnel)	2	CBC[1]	Inside	Wang
Midwest						
IN2B	High-rise Belt battery Manure shed	MV (sidewall) MV (sidewall) MV	2 2 1	CBC Belt Loader	First floor Shed -	Ni
West						
CA2B	High-rise	MV (sidewall)	3	DB[2]	Inside	Zhang

[1] CBC = curtain backed cages
[2] DB = dropping boards under cages

1.3.4. Site Selection for Broiler Chickens

Broilers are raised in confinement barns on dirt or concrete floors covered with litter. Broiler barns are typically mechanically ventilated (MV). The locations for two sites with specific housing types were recommended for this study with consideration of the potential impact of climatic differences and the geographical density of poultry meat production (Table 1.3.4). However, only one of these sites – a two-barn broiler ranch in California – will actually be included in the NAEMS. A second site is in Kentucky, and is being tested in another study that is not part of the NAEMS. EPA will decide at a later date whether the Kentucky site’s data can be integrated into the database that will be developed through the NAEMS.

Table 1.3.4. Broiler industry site (location in western U.S.)

SMP#	Site type	Ventilation type	Number of units measured	Manure collection	Manure storage	PI
West						
CA1B	Litter on floor	MV (tunnel)	2	Scraper	None	Zhang

1.3.5. Site Selection for Dairy

Milk production facilities include cattle (dry and lactating cows, and replacement heifers) and calves, and consist of freestall barns or open corrals and manure-storage facilities. The barns are most typically naturally–ventilated, except for some mechanically-ventilated freestall and tie stall barns. Only a small percentage of freestall barns are mechanically–ventilated, but the number is growing as tunnel ventilation is used to relieve heat stress in hot weather. Natural ventilation is exclusively used in freestall barns in more temperate regions, such as California. The naturally-ventilated barns range from partially-open barns with windows and flaps to fully-open free stalls. Open corrals are exclusively used in other parts of the country, such as New Mexico and the Texas panhandle. External manure storages generally consist of earthen basins that store undiluted manure collected from the barn after it goes through a solid separation process. Manure-collection systems generally are either scrape or flush. The measurements of emissions from manure storage systems and corrals will be conducted using micrometeorological techniques that are described in the companion QAPP on Open Source Emissions Measurements. The site selection criteria for the dairy industry are shown in Table 1.3.5.

Table 1.3.5. Dairy industry sites.

SMP #	Site Type	Ventilation type	Number of units measured	Manure Collection	Manure Storage[4]	Bedding Type[5]	PI
Northeast							
NY5B	Freestall	MV	2[3]	Scrape	Digester/ SS/Basin	SDS	Gooch
Midwest							
IN5B	Freestall	MV	2[3]	Scrape	Digester/ SS/Basin	SDS	Lim
WI5B	Freestall	MV	3	Flush	SP/Basin	Mattress/ shavings	Jacobson
West							
CA5B	Open freestall[2]	NV	2	Flush	SP/Basin	Soil/MS/ Almond shells	Mitloehner
WA5B[1]	Open freestall[2]	NV	2	Flush	SP/SS/Basin	MS	Ndegwa

[1] Barn sites that also have measured area sources, which are described in the open-source QAPP
[2] Cattle are free to walk from open freestall barn into dry lots between the barns.
[3] Monitored units include the milking center.
[4] SP = Settling pond
[5] MS = Manure solids; SDS = Separated digested solids

1.3.6. Study Boundary

The target population for the NAEMS, for which inferences will be made from the data collected in this study, consists of all AFOs in the continental U.S. within the dairy, pork, egg, and broiler meat industries. The overall distribution of the fourteen selected NAEMS barn monitoring sites is shown in Figure 1.3.1. The site's sizes range from 100,000 to 7,000,000 ft^2, and the barn's sizes range from 6,000 to 60,000 ft^2. At each site selected for monitoring in the NAEMS, from one to five buildings will be selected for air sampling. The descriptions of the sites, and the monitoring plans for each site, are described in Appendix B of the QAPP. The overall distribution of the NAEMS sites throughout the U.S. is as shown in Fig. 1.3.1. The descriptions of the sites, and the monitoring plans for each site, are described in Appendix A of this QAPP.

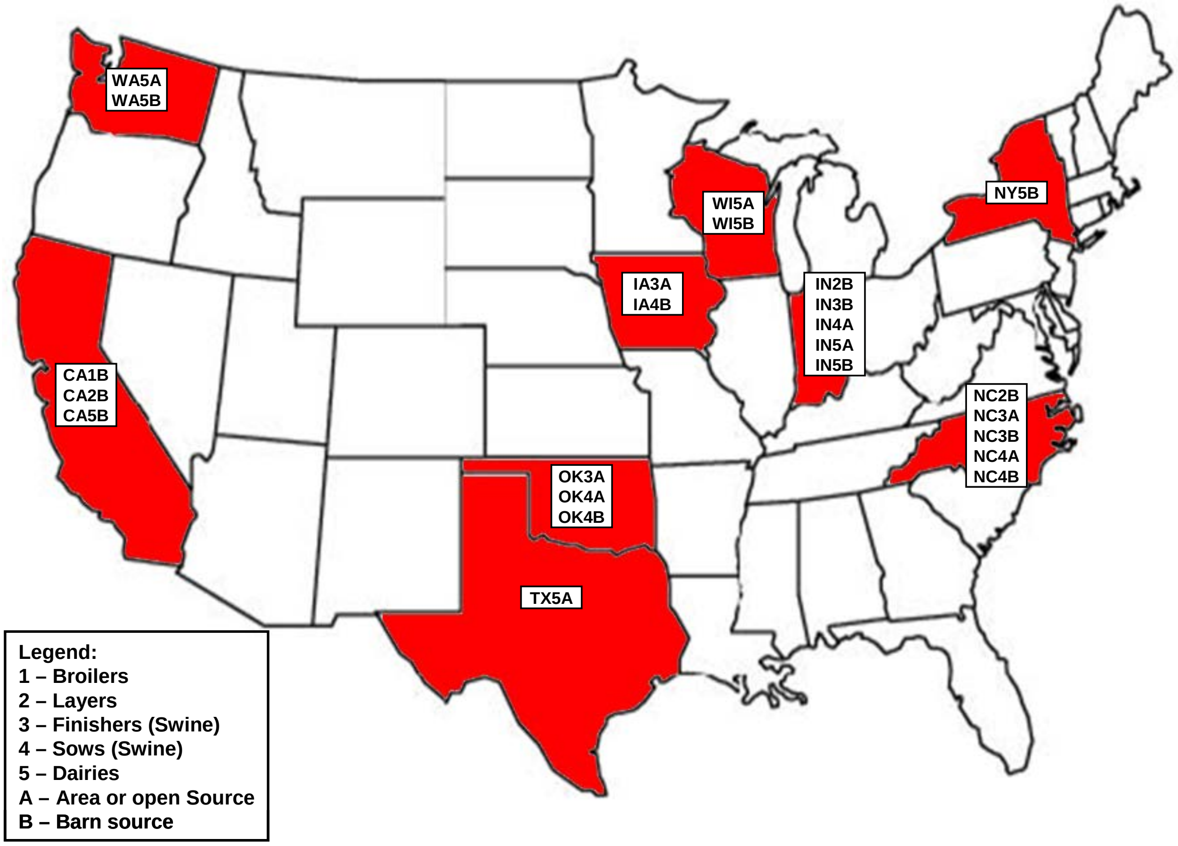


Figure 1.3.1. Locations of NAEMS sites (Barns and Open-Source).

The temporal boundary of this study is approximately three years after the first purchases of instruments and equipment. This time line includes 10 months for purchasing equipment and setting up the monitoring instrumentation at the farms (many of which will be set up well before 12 months), 24 months for collecting data from each site, and two months to decommission the last sites and prepare the final report. The 24-month duration of data collection assures that the project will meet the objectives of characterizing long-term emissions, and will adequately address the need for annual emission factors from animal facilities by regulatory agencies and others. Long-term measurements will also allow the recording of variations in emissions due to seasonal effects, animal growth cycles, and diurnal variations.

The spatial boundary for this study are the ventilation inlets and exhausts of the barns where the emissions will be measured. The emissions will be measured at representative exhaust points of the barn's ventilation systems. To obtain the building's net emission, the concentration of NH_3, H_2S, and VOCs will be measured at the barn inlet, and PM_{10}, $PM_{2.5}$ and TSP will be measured at a location close to the barn inlet where the instrument can be kept secure and accessible.

Some of the constraints to develop this study include:

- **Budget**: For example, more than one TEC TEOM (real-time PM monitor) per barn, and one gas sampling system and set of gas analyzers per site cannot be afforded.
- **Facility Size**: Large facilities tend to negatively affect data collection and data quality.
- **Ventilation Method**: Greater uncertainty and less data completeness occur with naturally-ventilated barns. Less uncertainty occurs with tunnel-ventilated barns.
- **Robustness**: Inability to measure each emission source at dairy sites (e.g. silage piles, digesters).
- **Participation**: Less than 100 percent participation in the Air Consent Agreement limited the available sites for selection, especially in some geographical regions.
- **Set-up Time:** Data collection is scheduled to begin four months after equipment can be purchased.
- **Location**: Distance between the principal investigators' offices and the sites.
- **Experience:** Expertise and experience of project directors, project managers, principal investigators, and their respective staff members.
- **Commitment**: Investigator's enthusiasm and dedication. They may have teaching loads and other research projects that may compete for their time and attention.
- **Producer Participation**: Effective producer collaboration and communication.
- **Vendors**: The willingness and ability of equipment and instrument manufacturers to prioritize the manufacture, delivery, pricing, and servicing of their products.

The inference limits for this study include the continental US. The validity of this inference was maximized by selecting representative sites in each region with major industries of interest, as described above.

1.3.7. On-Farm Measurements and Methods

An on-farm instrumentation shelter (OFIS) will house the equipment for measuring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn airflows, operational processes and environmental variables. Sampling will be conducted for 24 months, with averaged data logged every 15 s and 60 s (Section 2.1). Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the shelter will draw air sequentially from representative locations (including outdoor air) at the barns and deliver selected streams to a manifold from which on-line gas monitors draw their sub samples. Sampling line lengths will vary from site to site, but the maximum will generally be on the order of 350 m. Previous experience (Heber et al., 2006) has shown that the residence time for gas in a 300-ft long, ¼″ inside diameter sampling line, flowing at 4 L/min, is approximately 45 s. Thus, the maximum residence time in a 350-m sample line would be approximately 3 min. Sample flow rates will be selected at each NAEMS site such that the maximum residence time in the longest line at the site is 2 min. This will be conducted by referencing Table 1.3.6, which presents residence time as a function of sampling line length and flow rate. Each point is sampled for a minimum of 10 min, allowing the gas analyzers to reach and maintain equilibrium. The distance from the analyzer manifold of the GSS to the analyzers themselves will never exceed 3 m (10 ft), which is compatible with the sample-drawing capabilities of each of the analyzers. Sample flow will also always exceed the total draw of the gas analyzers by at least 25%. A schematic representation of the equipment housed in each OFIS is given in Figure 1.3.2.

Concentrations of constituents of interest will be measured using the following methods:

1. NH_3 will be continuously measured using a photoacoustic infrared detector (SOP G7).
2. H_2S will be continuously measured with a pulsed-fluorescence detector (SOP G5).
3. Carbon dioxide will be continuously measured using a photoacoustic infrared detector (SOP G7 or SOP G3, depending on the site).
4. PM_{10} will be continuously measured in real time using the tapered element oscillating microbalance (TEOM) (SOP P1) for representative exhaust locations in the barn, and the TFS FH62-C-14 Beta Monitor (SOP P4), for inlet air locations.
5. TSP will be measured for one week every 8 weeks, starting with the first week of the study, using a TSP inlet head on the TEOM or Beta Monitor.
6. $PM_{2.5}$ will be measured with a $PM_{2.5}$ inlet head on the TEOM inside the barns and the Beta Monitor outside the barns (inlet concentrations). $PM_{2.5}$ will be measured for two weeks in winter and two weeks in summer at each site.
7. Total non-methane VOCs, ethanol, methanol, and methane will be measured continuously with a multi-gas photoacoustic infrared detector (SOP G7) at certain sites (a minimum of one per species).
8. An initial characterization study of barn VOCs will be conducted on one day during the first quarter after site setup is complete, at one site for each of the four species (IN5B for dairy, IN3B for swine, IN2B for layers, and CA1B for broilers). While total VOCs are continuously monitored using photoacoustic IR along with building airflow rate, VOCs will be sampled with duplication at two barns (at the primary representative exhaust fan location, as defined in the site monitoring plan for that site). Three sampling methods will be evaluated: sorbent tubes (SOP V1) and Silcosteel canisters (SOP V2) for general VOCs, and all-glass bubblers (SOP V3) for amines. Each sorbent tube or canister sample will be evaluated using gas chromatography – mass spectrometry (GC-MS) (SOP V4 or V6, respectively); amines collected in bubblers will be analyzed by ion chromatography (IC) (SOP V5). The 20 analytes by mass for each species will be identified during this initial study. Following consultation with EPA to determine which of these analytes are present in sufficient quantity to warrant further monitoring, one or more sampling methods (sorbent tubes, canisters, and/or bubblers) will be chosen, and will be employed for the remainder of the study at sites with that species of animal.

Table 1.3.6. Residence time in sampling lines, as a function of sampling line length and sampling pump flow rate.

Tube length, ft	Flow rate (L/min)			
	4	5	7	8
0 (GSS only)	2.4	1.9	1.4	1.2
100	17	13	9.6	8.4
200	31	25	18	16
300	46	37	26	23
500	75	60	43	37
700	104	83	59	52
1000	147	118	84	74

Notes:
Tubing ID = 0.25 in (0.0064 m). Tubing internal volume = 0.97 L/100 ft
Sampling manifold is 20 in long, with a 3/8″ ID, for a volume of 0.036 L; Sampling pump has a volume of 0.06 L.

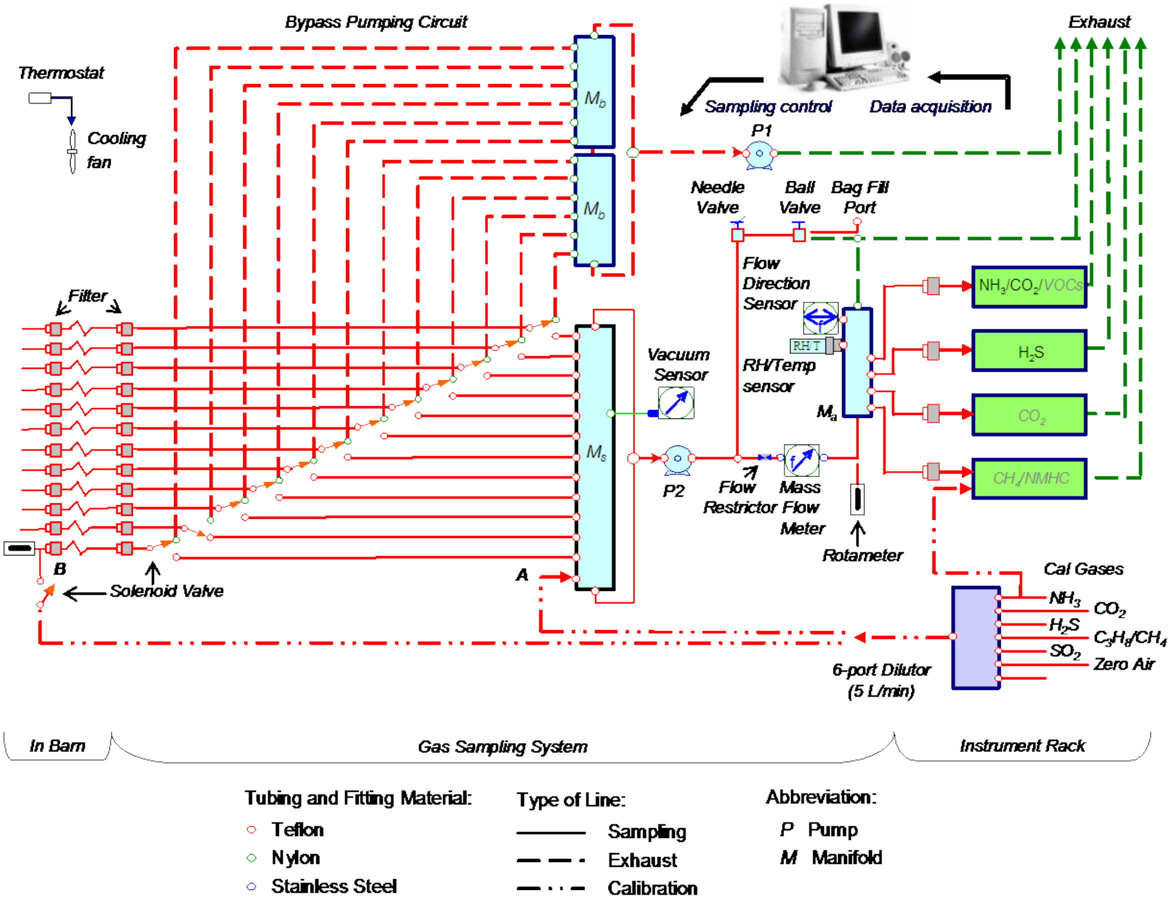


Figure 1.3.2. Schematic of GSS and instrument configuration. H_2S, CO_2, and NH_3/CO_2/VOC analyzers have internal pumps, and CO_2 analyzers have internal filters.

9. Two approaches will be used to evaluate acetaldehyde concentration during the initial characterization study. The first approach will be the standard GC/MS analysis of canister and/or sorbent tube samples. However, if the GC/MS method is observed (for example in analyte stability tests with the canisters) to be unsuitable for acetaldehyde, collection of bag samples followed by quantitative analysis with FTIR will also be attempted. If acetaldehyde is not observed by either method, it will not be analyzed during subsequent measurements.
10. By the end of the first overall quarter of data collection after all sites are set up, the SA will report results of the initial characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
11. Quarterly VOC samples using the selected VOC sampling method(s) will occur at all sites. Continuous monitoring for total non-methane VOC, and methanol and/or ethanol, as described above, will be conducted at a minimum of one site per species for the duration of the study.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers.

Specific processes that directly or indirectly influence barn emissions will be measured including animal activity, manure management/handling, feeding, and lighting. Environmental parameters including heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction, and solar radiation will be continuously monitored. Feed and water consumption, manure production and removal, mortalities, and animal production will also be monitored. As noted above, samples of feed, water, and manure will be collected and analyzed for total nitrogen. These data will enable the development and validation of process-based emission models in the future.

Monitored farms will be further characterized using farm management data. Farms will provide vital management information regarding ventilation controls/management and scheduling of barn activities such as manure management, animal load out, animal treatment, or feeding.

1.3.8. Issues Related to the Analytical Approach

There are several issues about the on-farm methods and instrumentation that relate to the development of the data quality objectives for the measurements.

1. Hourly and daily arithmetic averages will be calculated for each pollutant.
2. There are multiple sampling locations per gas analyzer and each location is sampled for one sampling period per sampling cycle. The duration of the sampling cycle depends on the sampling period, the number of sampling locations per barn and the number of barns monitored per site. The barn gas emission rate will be calculated every minute using the barn’s total ventilation rate and either the concentration measured during the same minute or linearly interpolated between two measured concentrations.

3. There will be only one sampling location per PM analyzer, which will monitor PM_{10}, $PM_{2.5}$ or TSP continuously with 1-min time resolution.
4. The pollutant concentrations will be measured at the inlet and at the exhaust of each barn or manure shed (gases only) for NH_3, H_2S, VOCs (NMHC), and PM.
5. For mechanically ventilated barns, the emission rate is the sum of the emission rates of each emission stream. The emission stream is defined as one or more fans for which one sampling location represents the exhaust concentration. The maximum number of emission streams is equal to the number of ventilation fans in the barn, which ranges from 3 to about 100 depending on barn capacity.
6. A practical maximum number of emission streams is 18 per site for gas sampling and one per barn for PM sampling.
7. Whereas fan operation is monitored continuously, the concentration of the emission stream is sampled once per sampling cycle.
8. In naturally ventilated barns, the concentration will be measured in each sidewall opening and at the ridge opening, for a total of at least three gas sampling location groups per barn.
9. The measurements will be obtained in a continuous mode during two years with exception of the VOC speciation sampling data.

The target population consists of all possible samples of each one of the six pollutants (Table 1.3.7). For gas samples, the total target population includes each one of the 10-min averaged emission rates times the number of emission streams being sampled:

Sampling units (SU) per day = $1440\frac{\min}{day} * \frac{1SU}{10\min} = 144SU/day$ per emission stream.

Number of potential SU per location (NPSU/L) = $144\frac{SU}{d} * 365\frac{d}{yr} * 2yrs = 105{,}120$ SU

Table 1.3.7. Number of sampling units for each compound.

Parameter	Units	Sampling units	NPSL	NASL/ barn	NPSU/L‡
Gas (NH_3, H_2S, VOC)	Min	10	3-100	1-6	105,120
PM	Min	10	3-100	1	105,120

NPSL: Number of potential sampling locations
NASL: Number of actual sampling locations
NPSU/L: Number of potential sampling units per location (during the 2-yr study). These values include the sampling of the barn inlet but does not consider the down time for calibration or maintenance of the instrument.

Temporal and spatial uncertainty is influenced by the size of the barn given these assumptions:

1. There is no temporal uncertainty if data is recorded every minute; uncertainty is therefore the lowest with continuous PM measurements, and the greatest with gas measurements and long sampling cycles.
2. Spatial uncertainty is the lowest when all the barn fans are monitored, and increases as the distance between monitored and unmonitored fans increases.
3. The distance between fans increases with barn length.
4. PM is measured in only one location per barn.

5. Gases are measured at 1 to 6 locations per barn with a greater number of locations as the size of the barn increases.

While the temporal uncertainty of PM measurements remains low with continuous monitors, the spatial uncertainty of PM measurements increases with barn size. For example, with the constraint of one PM monitor per barn, the PM monitor must be placed at only one end of a tunnel-ventilated barn with fans on both end walls. In the same barn, gas sampling can be conducted at both ends sequentially which increases temporal uncertainty and results in a smaller increase in spatial uncertainty as compared with PM.

1.3.9. Project Schedule

The anticipated schedule for the NAEMS is shown in Table 1.3.8. Site selection is complete, and a list of detailed site monitoring plans for all sites is included in Appendix A of this QAPP. Purchase of equipment will begin immediately upon approval of the QAPP, and is expected to be completed by early in month 7. Initial inspections and calibration of equipment will begin as soon after the initiation of purchasing as possible (i.e. as soon as equipment is received), and will be complete by early in month 8. Training of university PIs and their designated NAEMS staff member(s) at PAAQL will take place in month 5. The combination of these events (verification of equipment performance and training of PIs) will allow deployment and placement of the mobile labs to occur during months 5-12. All mobile laboratories will be in-place and set up by the end of month 12, at which point (earlier on a case-by-case basis) data collection will begin. Data collection will continue for 24 months at each site. At the conclusion of data-collection at the last site, two months will be devoted to a) decommissioning the last sites and b) preparing the final report. The final report for the project will be submitted by the end of month 38.

1.4 Quality Objectives for Air Emissions Data

The planning team formed to develop data quality objectives (DQO) included the Science Advisor, Dr. Albert Heber, the NAEMS Operations Manager, Dr. Bill Bogan, the NAEMS Quality Assurance and Control Manager, Dr. Juan Carlos Ramirez, and Assistant Project Managers Dr. JiQin Ni, and Dr. Teng Lim.

The overall data quality objective (DQO) of this research is to generate data of sufficient quality to allow accurate quantification of the aerial emissions of six contaminants – NH_3, H_2S, volatile organic compounds, and particulate matter emissions (TSP, PM_{10}, and $PM_{2.5}$) – from representative types of dairy, swine, egg and broiler buildings. More specifically, AFOs may be subject to the notification requirements of CERCLA for releases of hazardous substances from their facilities that exceed the reportable quantity (RQ) for that substance. Among these substances are NH_3 and H_2S, both with RQ thresholds of 100 pounds per day or 18.3 tons per year. These RQs are the emissions during any 24-h period (the maximum daily emissions).

The U.S. EPA will aggregate the data collected by this study with other available data to develop tools to estimate the air emissions from livestock production. These tools will allow identifying and quantifying exceedances of CAA, CERCLA and EPCRA thresholds. The type of the study is

Table 1.3.8. Project Schedule for NAEMS.

	YEAR 1												YEAR 2												YEAR 3										
Tasks & Benchmarks	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11
Purchase equipment	M1	■	■	■	■	■	■																												
Calibrate & test equipment	■	■	■	■	■	■	■	■																											
Train PIs					M3	■	■	■	■	■	■	M4																							
Outfit mobile labs (at PAAQL)	■	■	■	■	■	■																													
Deploy and set up mobile labs (on-site)			■	■	■	■	■	■	■	■	■	■																							
Develop CAPECAB software	■	■	■	■	■	■	■	■	■	■																									
Initial site VOC characterizations													■	■																					
Revise/finalize VOC monitoring plans													■	■	M6																				
Collect barn data						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Collect lagoon data									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
Internal (PAAQL) site audits										■	■	■	■	M5								■	■	■	■	M7									
Disassemble mobile labs																															■	■	■	■	■
Analyze data						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Establish and maintain NAEMS website	■	M2	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Reports (Interim)			■			■			■			■			■			■			■			■			■			■			■		
Report (Final)																																			

Milestones:

M1 – Begin purchasing of equipment

M2 – NAEMS website on-line

M3 – Convene training session for PIs (and any available site engineers) at PAAQL

M4 – Complete on-site setup of OFIS's at all sites and on-site training component for the Pis

M5 – Complete initial audits of all sites, during first quarter after each site's setup

M6 – Complete initial VOC characterizations, implement any necessary revisions to the QAPP for VOC analysis

M7 – Complete all internal mid-point site QA audits

M8 – Complete disassembly of mobile labs

M9 – Complete data analysis and submit final report estimation but the information will support decisions of the EPA related to compliance. For this type of intended use it is necessary to specify Performance Metrics and Acceptable Levels of Uncertainty (EPA QA/G-4, 2006, page 46).

1.4.1. Information Inputs

The primary measurements that will be collected from the NAEMS are air emission data, which include hourly, daily, monthly, and annual emission rates of NH_3, H_2S, total non-methane VOCs, total suspended particulate (TSP), PM having an aerodynamic diameter less than 10 µm and 2.5 µm (PM_{10} and $PM_{2.5}$, respectively) from each farm building.

The emission rates are calculated values based on measurements of pollutant concentration and barn ventilation rates, and these measurements depend on other primary (or independent) measurements. For example, ventilation rate depends on the differential static pressure between the indoor pressure and the ambient pressure, and the calibration and operating characteristics of each one of the fans in the barn. To standardize the moist ventilation rate (Q) to dry and STP conditions (20°C and 1 atm pressure), it is necessary to include the measurement of air temperature, pressure, and total moisture content. To calculate the air moisture content, it is necessary to measure the relative humidity.

In the same way, to calculate the pollutant concentration it is necessary to include other independent parameters. The pollutant emission rate will be expressed in mass units per unit of time. This conversion applies to all the pollutants. The gaseous pollutant concentration is obtained analytically in ppm or ppb and converted to mg per unit of volume. The PM concentrations are obtained already in the proper mass unit. For both gas and PM, their sampling volumes need to be converted to STP, which necessitates temperature and barometric pressure measurements to convert them to STP conditions.

Emission rates will also be expressed as mass per animal unit (or equivalent units). This will require the collection of farm information obtained from the producer. The producer will provide additional information that will facilitate the calculations of pollutant mass balances. This information will include, among others, nutrient volumes and composition, water consumption, animal inventories and mortalities. Manure will be sampled periodically, and analyzed to determine pH and concentrations of moisture, total Kjeldahl nitrogen, ammonia, nitrates, nitrite, and ash.

A complete list of the specific measurements and information that are required for this study are shown in Table 1.4.1. The measurement methods were selected by Dr. Albert Heber, the NAEMS SA, based on recommendations described in the NAEMS Protocol (Federal Register, 2005). As stated in the NAEMS Protocol, the SA may choose the measurement techniques that are most appropriate for the study; however, the final selection will be “dependent upon EPA approval of a comprehensive study design and budget.” More specific information about the measurement equipment that will be used in the NAEMS can be found in the NAEMS SOPs (listed in Appendix B).

1.4.2 Conceptual Model of the Environmental Problem

The problem that the NAEMS is addressing consists primarily of quantitating air emissions from livestock production facilities. The scope of the NAEMS is somewhat broad, covering four livestock species and fourteen (14) measurement sites; therefore describing the conceptual model is not straightforward. However, this exercise helps to illustrate the sources of variation in emissions and the factors that affect air emission measurements from livestock facilities. The production systems are a dynamic and active system of infrastructure, machinery, people and animals (Figure 1.4.1). The barns typically have the following systems:

1. Environmental monitoring, heating, ventilating and cooling systems
2. Equipment storage
3. Animal penning, handling and treating
4. Product collection, handling, treating, and storage
5. Feeding systems
6. Waste collection, handling, treating and storage

The inputs to a livestock production system include feed, water, new animals, and bedding. The feed and the bedding emit air pollutants to various degrees during storage and handling prior to their entry into the barn. The animals respire gases, and convert feed, water and air into manure, mortalities, and animal products, all of which emit air pollution (Fig. 1.4.1).

The livestock emission problem as it pertains to the NAEMS is conceptualized in Fig. 1.4.2. Livestock facilities emit a wide variety of air pollutants, some of which are odoriferous. Particulate matter is emitted across all three major regulated size fractions and most of the mass of particulate matter is greater than 10 µm in diameter. The PM emitted from barns contains viable particles. Barns emit NH_3 and H_2S in significant quantities. The total mass of volatile organic compounds consists of major VOCs such as ethanol, methanol, acetic acid and acetaldehyde. The greenhouse gases including methane, nitrous oxide, and carbon dioxide are also emitted in varying quantities depending on species and manure handling methods. A significant amount of water is emitted from barns making measurement and control of pollutants a greater challenge, especially when coupled with the emissions of particulate matter.

The sources of the air pollutant emissions in the barns include the animals themselves, feed, bedding and manure, depending on the time that each source is in the barn. Some barns allow animals to walk outside, e.g. freestall dairy barns with outdoor exercise lots. The feed and bedding at some livestock facilities is stored outside before delivery into the barns, e.g. dairies with outside forage piles and stockpiles of bedding (e.g. separated manure solids). The manure accumulation times in a barn varies from an hour in a scraped dairy freestall to over a year in a high rise layer barn.

Unlike many other industrial sources of air pollution, the diversity of sources among livestock facilities is very large because of the significant effects of diet, outside temperature, manure handling, animal growth and animal size. The spatial diversity of the emission sources on production sites also varies among species. Broiler sites have the least diversity because virtually all the air pollutants emit from the barn and all barns are similar in manure management (floor

Table 1.4.1. NAEMS Measurement Quality Objectives (MQOs).

Variable	Measurement Method	Reporting Units	Required Operating Range	MDL	Locations	Data Collection Periods							
						Data Reading (s)	Data Record (s)	Sampling Period, min.		Sampling Interval, min.		Interpolating Interval, min	
								Exhaust	Inlet	Exhaust*	Inlet	Exhaust	Inlet
NH_3	Infrared photo-acoustic	ppb	200,000	200	Inlet Exhaust	1	15/60	10	30	180	720	300	1440
H_2S	Pulsed fluorescence (SO_2)	ppb	10,000	50	Inlet Exhaust	1	15/60	10	30	180	720	300	1440
NMHC, CH_4, ethanol, methanol	Infrared photo-acoustic	ppb	5,000	20-200	Inlet Exhaust	1	15/60	10	30	180	720	300	1440
VOCs	GC/MS (mass spectrometer)	ppb	5,000	<10	Inlet Exhaust	24 h (canisters)	24 h (canisters)	24 h (canisters)	24 h (canisters)	3 mo	3 mo	3 mo	3 mo
VOCs (amines)	IC	ppb	5,000	<10	Inlet Exhaust	2h	2h	2h	2h	3 mo	3 mo	3 mo	3 mo
CO_2	Infrared photo-acoustic	ppm	300 to 10,000	100	Inlet Exhaust	1	15/60	10	30	180	720	300	1440
PM2.5	Tapered element oscillating microbalance (TEOM)	µg/m3	1,000	10	Inlet Exhaust	1	15/60	C	C	1 mo/2 yr	1 mo/2 yr	N/A	N/A
PM2.5 (audit)	Time integrated gravimetric	$\mu g/m^3$	1,000	5	Inlet Exhaust	48 h	48 h	2880	N/A	N/A	N/A	N/A	N/A
PM10	Tapered element oscillating microbalance (TEOM)	$\mu g/m^3$	10,000	10	Inlet Exhaust	1	15/60	C	C	7 wk / 8 wk	7 wk / 8 wk	N/A	N/A
TSP	Tapered element oscillating microbalance (TEOM)	µg/m3	30,000	10	Inlet Exhaust	1	15/60	C	C	1 wk / 8wk	1 wk / 8wk	N/A	N/A
Fan air speed	Vane anemometer	m/s	10	1	Fan	1	15/60	C	C	C	C	N/A	N/A
Fan run time	Vibration, current or rpm sensor, relays, whisker or sail switch, computer control signal	% of data record interval	100	2	Fan	1	15/60	C	C	C	C	N/A	N/A
Air velocity	Ultrasonic anemometer 3-D	m/s	40	0.01	Vents	0.1	30	C	C	C	C	N/A	N/A
Barn static pressure	Capacitive/diaphragm sensor	Pa	100	1	Indoor	1	15/60	C	C	C	C	N/A	N/A
Temperature	Thermistor or RTD	°C	0 to 50	0	Exhaust	1	15/60	C	C	C	C	N/A	N/A
Temperature	Thermocouple type T	°C	10 to 40	10	Indoor	1	15/60	C	C	C	C	N/A	N/A
Relative humidity	Thin-film capacitor (TFC)	°C	100	20	Exhaust	1	15/60	C	C	C	C	N/A	N/A
Process run time	Mechanical relay contacts Passive IR detection, etc.	% of data record interval	100	2	Manure Belts Scrapers Flushing Feeders Lights	1	15/60	C	C	C	C	N/A	N/A
Temperature	Thermistor/RTD, Passive shielded	°C	-35 to 45	-35	Ambient	1	15/60	C	C	C	C	N/A	N/A
Relative humidity	TFC, Passive shielded	°C	100	10	Ambient	1	15/60	C	C	C	C	N/A	N/A
Atmospheric pressure	Electronic barometer	atm	0.8 to 1.1	0.8	Ambient	1	15/60	C	C	C	C	N/A	N/A
Solar radiation	Radiometer	W/m^2	1500	10	Ambient	1	15/60	C	C	C	C	N/A	N/A
Wind speed	Cup anemometer	m/s	60	0.25	Ambient	1	15/60	C	C	C	C	N/A	N/A
Wind direction	Vane	degrees	360	5	Ambient	1	15/60	C	C	C	C	N/A	N/A

Table 1.4.1. NAEMS MQOs (*continued*)

Variable	Measurement Method	Reporting Units	Required Operating Range	MDL	Locations	Data Collection Periods: Data Reading (s)	Data Record (s)	Sampling Period, min.		Sampling Interval, min.		Interpolating Interval, min		Data Completeness % Valid	Data Category
								Exhaust	Ambient	Exhaust*	Ambient	Exhaust	Ambient		
Animal inventory	Producer	head	N/A	1	Barn	Daily	Daily	N/A	N/A	N/A	N/A	N/A	N/A	75	1
Animal mortality	Producer	head	N/A	1	Barn	Daily	Daily	N/A	N/A	N/A	N/A	N/A	N/A	75	1
Animal weight	Truck balance	kg	N/A	1	Truck	BE	BE	N/A	N/A	N/A	N/A	N/A	N/A	75	1
Manure volume	Producer estimate	gal	N/A	N/A	Barn	BE	BE	N/A	N/A	N/A	N/A	N/A	N/A	75	4
Manure pH	Electrochemical pH meter	pH units	0 to 14	0.01	Manure	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	75	4
Manure solids	Gravimetric	wt %	0 to 100	0.1	Manure	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	75	4
Manure NH_3 & N contents	Kjeldahl/titrimetric	wt %	0 to 5	0.01	Manure	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	75	4
Feed, bedding, milk, eggs, meat N contents	Kjeldahl/titrimetric	wt %	0 to 5	0.01	Manure	Varies	Varies	Varies	Varies	Varies	Varies	Varies	Varies	75	4
Feed input	Various. Truck weight	kg	100,000	10	Barn	Daily	Daily	N/A	N/A	N/A	N/A	N/A	N/A	75	4
Animal activity	Passive infrared detector	VDC	1	0.1	Barn	1	15/60	C	C	C	C	N/A	N/A	75	4
Sampling manifold pressure	Electronic	Pa	±20,000	±500	GSS	1	15/60	C	C	C	C	N/A	N/A	75	5
Sample flow rate	Mass flow meter	L/min	10	0.1	GSS	1	15/60	C	C	C	C	N/A	N/A	75	5
Laboratory temperature	Thermocouple	°C	-40 to 50	-40	Laboratory	1	15/60	C	C	C	C	N/A	N/A	75	5
Laboratory pressure	Electronic	Pa	±50	±1	Laboratory	1	15/60	C	C	C	C	N/A	N/A	75	5
Filter differential pressure, dP	Diaphragm	%	100%	5	Instrument	1	15/60	C	C	C	C	N/A	N/A	75	5
Temperature in raceway	Thermocouple	°C	-40 to 100	-40	Raceway	1	15/60	C	C	C	C	N/A	N/A	75	5

Notes:

* Depends on total number of locations. This is the maximum

Data Categories
- 1 Critical
- 2 Essential
- 3 Important
- 4 Auxiliary supporting data
- 5 QAQC variable

C: continuous

BE: Beginning and end of growth period.

MDL: Method detection limit

Data reading: Data is read every time period indicated

Data record: The data average during the time period indicated is recorded.

Sampling period: Period of time used to sample one location

Sampling interval: Period of time between sampling periods. It depends of the number of shared sampling locations. If there is only one location, sampling period and interval are the same.

Interpolating interval: Period of timeduring which there is no direct data measurement, and the data is obtained by interpolating the values between the initial and the final measurement and the data

DC: Data completeness, Number of valid data values collected a s a percentage of the scheduled measurements.

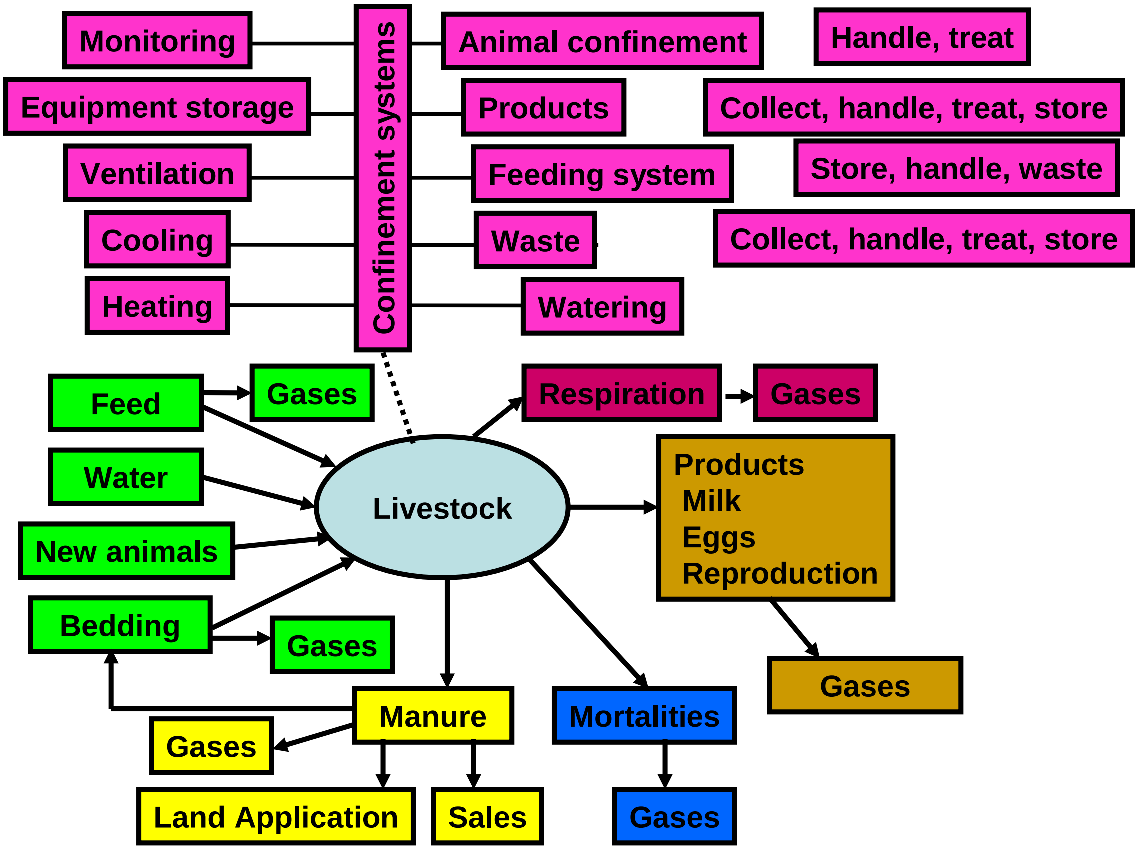


Figure 1.4.1. Various systems at confined livestock production facilities.

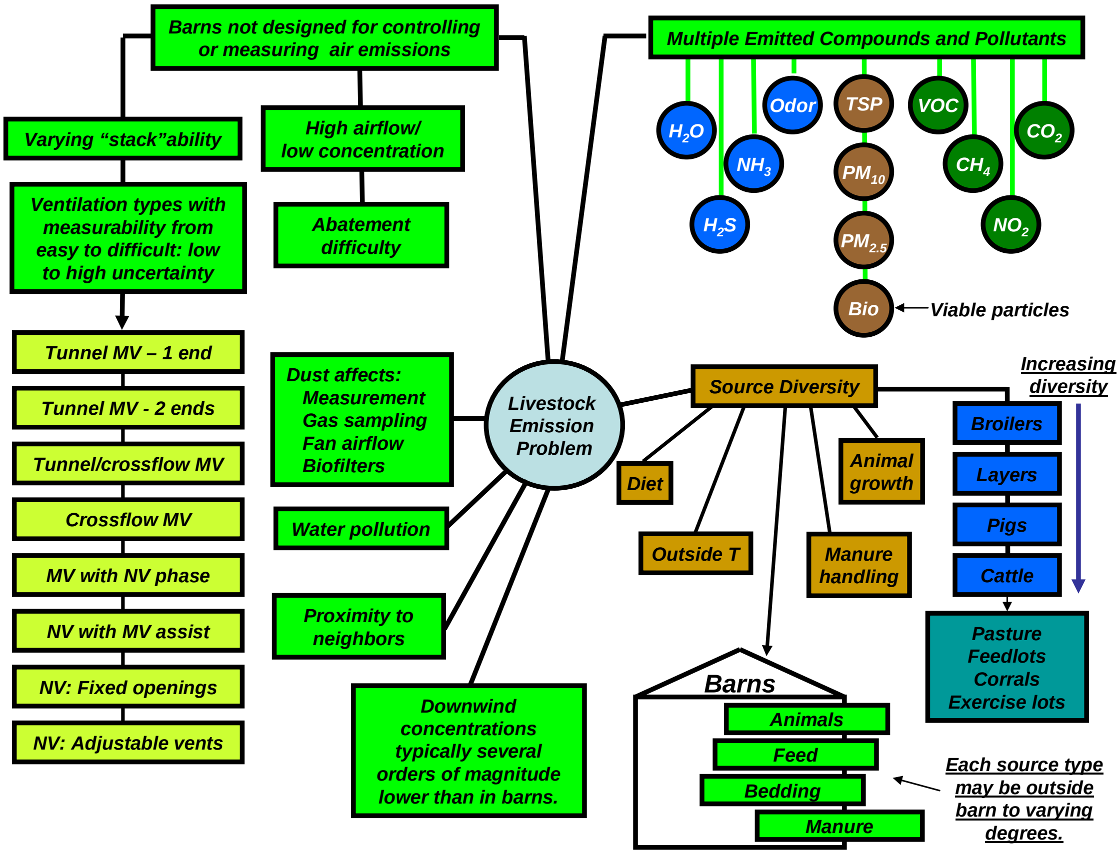


Figure 1.4.2. Measurement of farm air emissions.

litter) with no outside manure storage. Dairy facilities have the greatest farmstead diversity because of outside feed, bedding and manure storage and wide variance of site layouts ranging from tunnel ventilated freestall barns to open corrals.

Livestock barns are designed without consideration of the need for emission measurements, as compared with industrial stacks. Most barns have a multiplicity of horizontal wall-mounted exhaust fans that are characterized by low pressure and high airflow. The fans are typically protected by short weatherproof shrouds that fall way short of the EPA definition of a stack for stack testing purposes. Barns have a variety of configurations with some barns that are more conducive to emission measurements than other barns. Listed from most to least conducive, the following types of barns exist in the U.S.:

1. Tunnel ventilation year around with all the fans banked at one end of the barn (e.g. site NC3B).
2. Tunnel ventilation year around with fans banks located at each end of the barn (e.g. site IN5B)
3. Tunnel ventilation during hot weather and crossflow ventilation in cooler weather with one or more fans located along the length of the barn (e.g. site IA4B).
4. Crossflow mechanical ventilation, fans distributed on one or both sidewalls (e.g. site CA2B).
5. Mechanical ventilation with a natural ventilation phase at certain times.
6. Natural ventilation with a few fans to assist ventilation in cold weather.
7. Natural ventilation with fixed ventilation openings (e.g. site CA5B).
8. Natural ventilation with adjustable ventilation openings (e.g. site WA5B).

Mechanically ventilated barns are more likely to result in emission measurements that have less uncertainty than naturally ventilated barns because of the greater consistency of airflow, thus most of the barns in this study will be mechanically ventilated. Some of the measurement issues with mechanically ventilated barns are as follows:

1. Airflow is stepped up from low winter rates to high summer rates as outdoor temperature increases by staging the exhaust fans in the barn.
2. The number of fans in a barn ranges from 3 to 100 and they can be single speed, multiple speed or variable speed.
3. EPA Method 5 criteria cannot be met in the short shrouds that protect the fans.
4. Exhaust fans are typically distributed, banked or isolated in the barn. Sometimes the fans are located in the ridgeline of the roof.
5. The negative pressure caused by the exhaust fans can force air into the barn from attached structures such as manure sheds, milking parlors and other sheds
6. The fans are designed for low pressure operation (i.e. 5 to 30 Pa) and fan airflow is therefore affected significantly by wind, obstructions and dust buildup.

The dairy industry utilizes naturally ventilated barns exclusively in some parts of the country. The ventilation of naturally ventilated barns has the following characteristics:

1. Natural ventilation airflow induced by thermal buoyancy depends on the height of the barn, the density of the live mass in the barn and the temperature difference between inside and outside the barns. Dairy barns are low density and are kept cool, even in the winter.
2. Natural ventilation airflow induced by the wind depends on wind direction, and vent area and orientation.
3. Some barns have circulation fans inside the barn that can create strong internal airflow patterns.

Barn air pollutants come from animals, feed, bedding and manure, and ventilation air picks up and carries them out of the barn. These sources may also emit from the facility outside the barn, depending on the type of farm. Except for dairy farms where cows can sometimes walk outside into exercise lots and to and from the milking parlor, animals and birds are typically inside the barn 100% of the time. Swine and poultry feeds are typically stored outside in bins for one or more days but dairy forage is typically stored in large piles at the facility for several months. Except for alternative housing, bedding is not typically used in swine and layer barns and will not be used in the NAEMS sites. However, bedding is always used in dairy freestall barns and broiler barns (litter on floor). Dairies store bedding outside for an extended period before replacing the bedding in the barns on a daily basis. Similarly, dairies remove manure from the barns on a daily basis but typically have long-term outdoor manure storage. Swine and layer barns either remove manure often or have long term storage inside the building. Broiler manure is removed from the barn to an off-site location or to the land as fertilizer.

The study includes AFO operations from three different species – dairy, swine and poultry (broilers and egg-layers). In the “Response to Public Comments on the Animal Feeding Operation Air Agreement” (EPA, 8/2005), EPA stated that the AFO processes include a wide variety and that the mechanism to generate emissions from these operations is complex. Also, in the same document, EPA added that is impractical to expect that sufficient data could be collected in a timely manner to accurately characterize every different type of operation and practice in the AFO industry. The characteristics of the farms described in the consent agreement protocol were defined by a group of technical experts from the EPA and several universities, who concluded that “monitoring these types of operations will provide sufficient data to get a valid sample that is representative of the vast majority of participating AFOs” (EPA, 8/2005). Data will undergo quality assurance review, which will assess, among other things, representativeness, completeness, comparability, and accuracy.

1.4.3 Data Representativeness

Data representativeness is a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point or for a process condition or environmental condition (USEPA. 1998. *EPA Guidance for Quality Assurance Project Plans*. EPA QA/G-5). Recent studies have shown that seasonal variations in gas and dust concentrations and emissions from confined animal buildings (CAB) are significant. For instance, in the case of gas emissions, NH_3 emission per animal unit in July was about four times as high as in April, and H_2S emission had even larger variations. To obtain sufficiently representative measurement data, and to fully understand the effect of season on air emissions, measurement will cover all four seasons of each of two consecutive years. To fully achieve this goal, the measurements will be conducted continuously at the same site, and in the same buildings. Otherwise, the seasonal effect cannot be effectively studied due to variations of site, building structure, farming practice, etc. Data representativeness will thus be assured by the overall sampling design, which includes high-frequency sampling and a 24-month measurement period. Furthermore, measurements are conducted at two to four similar side-by-side barns at each site, which provides a degree of replication for each site. In addition, in the case of PM emissions, total suspended particles (TSP) will be sampled using an isokinetic multipoint system. This system uses three sampling heads across the exhaust fan inlet. The sample heads are positioned in the location and orientation that meets the head-designed sample air velocity within 10% (SOP P2).

Variable and multiple ventilation exhaust air streams and potential significant background concentrations at CAB present a challenge to the selection of locations for measuring pollutant concentrations that will adequately represent the mean concentration of the total building exhaust. Data representativeness within buildings will be assured by careful selection of two to four exhaust locations (instead of only one location), and by measuring concentrations at the ventilation inlet in addition to the exhaust outlets. The allocation of the exhaust measurement points for optimal representativeness must be conducted on a site-by-site basis because of wide variations in building layouts and configurations (see the individual site monitoring plans listed in Appendix A).

1.4.4 Data Completeness

Data completeness is a measure of the amount of valid data obtained from a measurement system, expressed as a percentage of the number of valid measurements that should have been collected (*i.e*., measurements that were planned to be collected) (USEPA. 1998. *EPA Guidance for Quality Assurance Project Plans*. EPA QA/G-5). Data completeness will be achieved by assuring that a minimum of 75% of the scheduled sampling results in valid data. More data will be collected if this criterion has not been met for one or more particular sites, by continuing data collection at the site(s) until 18 months (i.e. 75% of 24 months) of valid data has been collected. A greater percentage does not seem reasonable, given the potential for lightning strikes, equipment breakdowns, university schedules, and farm-related problems, and the limited budget for additional makeup monitoring.

Data completeness will be assured by:

1) utilizing a dedicated mobile laboratory at each individual site, thus eliminating time losses due to moving from site to site
2) using properly maintained and reliable instrumentation
3) maintaining a ready supply of spare parts
4) installing electrical backups such as uninterruptible power supplies

5) regular calibration checks
6) frequent remote access to the DAQ computer to download data
7) timely review of collected data to quickly identify problems
8) producer collaboration

On a site-by site basis, substitution rules for instances where one or more measurements are deemed invalid may be implemented. For sites where this is possible, this measure will also increase the completeness of the data. For example, if a sensor failure results in a period of invalid temperature measurements for a sampling point, it may be acceptable to substitute a temperature measurement from a nearby sampling point, if both sampling points are subject to the same conditions. Similarly, default values for relatively constant variables (i.e. atmospheric pressure) may be acceptable for replacing short periods of invalid data. Any use of substitution or default values will be reported in the quarterly report.

1.4.5 Data Comparability

Data comparability will be maintained by:

1) employing similar analytical methods and sampling protocol used in recent emission studies in confined livestock and poultry facilities
2) comparing measurements with previous mass balance and emissions rate estimates reported for similar swine, dairy, egg and broiler buildings
3) comparing NH_3 emissions with mass-balances of N calculated for each test building
4) using consistent, common equipment, instrumentation, common metric, quality assurance methods, and protocols

The last of these will be ensured through two mechanisms (Section 1.5): a) extensive training sessions that will be mandatory for all University PIs and all of their staff members who will be involved in the day-to-day operations at the sites, and b) the establishment of Standard Operating Procedure (SOP) documents for all important procedures.

1.4.6 Accuracy, Bias and Precision

Accuracy is a two-part quality indicator, and includes both bias (systematic error) and precision (random error). **Bias** or systematic error is a measure of the closeness of an individual measurement (or the average of a number of measurements) to the true value (EPA QA/G5). Accuracy of the measured value will be expressed in terms of the percentage decrease or increase from the known value and in terms of the absolute difference between the measured and known value (for example, when comparing a certified gas concentration with the value obtained from an analyzer). **Precision** is a measure of agreement among replicate measurements of the same property, under prescribed similar conditions (same source). Precision is defined as the standard deviation of replicate measurements of the known pollutant gas expressed as a percentage difference from the average value. Bias and precision will be maintained by regular calibration of instruments involving challenging the measurement system to perform replicate analyses of samples with certified concentrations (Section 2.6), or using NIST traceable instruments (for example, flow meters), or using collocated instruments (for example, for PM samplers or sonic anemometers).

1.4.7 Data Quality Objectives and Indicators

The data quality objectives (DQOs) for this study of barn emissions are as follows:

1. Measure gas emissions from MV barns with total relative uncertainty of ±27%
2. Measure PM emissions from MV barns with total relative uncertainty of ±32%
3. Measure gas emissions from NV barns with total relative uncertainty of ±50%
4. Measure PM emissions from NV barns with total relative uncertainty of ±53%.
5. Validate 75% of the scheduled air emission measurements for each pollutant.

Assuming negligible uncertainties due to spatial and temporal variations within the barn, DQOs 1-4 were calculated from estimated bias and precision values for concentrations and ventilation rates for MV and NV barns, and are presented in Tables 1.4.2 and 1.4.3. Information about the independent parameters (concentration and ventilation rate) on the left side of each table consists of nominal values, bias, precision, absolute and relative sensitivity, relative systematic uncertainty and relative random uncertainty.

The uncertainties for the emission rate on the right side of the tables include the relative systematic uncertainty (B_R) and relative random uncertainty (tS_R), and the total relative uncertainty ($\pm U_R$). According to the ASME PTC 19.1-1998 (based on the ANSI/NCSL Standard Z540-2-1997), systematic uncertainty (B_i) is bias, random uncertainty ($S_{x,i}$) is precision, and the total relative uncertainty ($\pm U_R$) represents the 95% confidence interval around the calculated emission rate and is the total DQO.

The absolute sensitivity (Tables 1.4.2 and 1.4.3) is the partial derivative of the emission rate ($E = C * Q$) with respect to the parameter considered (C or Q), and is equal to the nominal value of the other parameter. The relative sensitivity is the absolute sensitivity multiplied by the parameter nominal value, divided by the nominal emission rate. The relative systematic and relative random uncertainty of the emission rate are associated with the emission rate calculated using the nominal C and Q, the relative systematic and random uncertainties of C and Q, and the relative sensitivities of C and Q. The total relative uncertainty of the emission rate ($\pm U_R$) is the root-sum-square of the systematic and random standard deviations of the emission rate times the Student's t_c value for the 95% confidence level.

Data quality indicators (DQI) for the measurement of the individual pollutant concentrations, and of the ventilation rate in MV and NV barns are presented in Tables 1.4.4 to 1.4.11. Each table includes a summary of the method used to assess the DQI, and references the location in this QAPP where more information is available.

Table 1.4.2. Data Quality Objectives for air emissions from mechanically-ventilated barns.

Independent Parameter									Emission Rate (E) (µg/s)			
			Bias[b]	Precision[b]						Bias[b]	Precision[b]	**DQO**
Symbol	Units	Nominal Value[a]	Relative Systematic Uncertainty	RSD	Absolute Sensitivity	Relative Sensitivity	Relative Systematic Uncertainty Contribution[c]	Relative Random Uncertainty Contribution[c]	Nominal value	Relative Systematic Uncertainty[c]	Relative Random Uncertainty[c]	Total Relative Uncertainty[c]
P_i		V_i	B_i	S_{xi}	$\Theta_i = \delta E/\delta P_i$	$\Theta_i' = \Theta_i * V_i/E$	$(B_i*\Theta_i'/2)^2$	$(S_{xi}*\Theta_i')^2$	$E=C*Q$	$B_R = t(\Sigma(B_i*\Theta_i'/2)^2)^{0.5}$	$tS_R= t(\Sigma(S_{xi}*\Theta_i')^2)^{0.5}$	$\pm U_R = t((B_R/2)^2 + SR^2)^{0.5}$
Ammonia (NH_3)												
C	$\mu g/m^3$	141,000	5%	5%	1.5	1.0	0.0006	0.0025	211,500	15%	22%	27%
Q	m^3/s	1.5	15%	10%	141,000	1.0	0.0056	0.0025				
Hydrogen sulfide (H_2S)												
C	$\mu g/m^3$	14,130	5%	5%	1.5	1.0	0.0006	0.0025	21,195	15%	22%	27%
Q	m^3/s	1.5	15%	10%	14,130	1.0	0.0056	0.0025				
Non-Methane Hydrocarbons (NMHC)												
C	$\mu g/m^3$	9,200	5%	5%	1.5	1.0	0.0006	0.0025	13,800	15%	22%	27%
Q	m^3/s	1.5	15%	10%	9,200	1.0	0.0056	0.0025				
Particulate Matter ($PM_{2.5}$)												
C	$\mu g/m^3$	1,000	5%	10%	1.5	1.0	0.0006	0.0100	1,500	15%	28%	32%
Q	m^3/s	1.5	15%	10%	1,000	1.0	0.0056	0.0100				
Particulate Matter (PM_{10})												
C	$\mu g/m^3$	10,000	5%	10%	1.5	1.0	0.0006	0.0100	15,000	15%	28%	32%
Q	m^3/s	1.5	15%	10%	10,000	1.0	0.0056	0.0100				
Particulate Matter (TSP)												
C	$\mu g/m^3$	20,000	5%	10%	1.5	1.0	0.0006	0.0100	30,000	15%	28%	32%
Q	m^3/s	1.5	15%	10%	20,000	1.0	0.0056	0.0100				

[a] Maximum value of the expected concentration range (Table 1.4.1)
[b] As presented in Tables 2.6.1 (gases), 2.6.3 (PM), and 2.6.8 (barn airflow) of this QAPP
[c] As presented in the ASME PTC 19.1-1998 Test Uncertainty Supplement
C: Concentration; Q: Ventilation flow rate; t: Student’s t-value = 1.96

Table 1.4.3. Data Quality Objectives for air emissions from naturally-ventilated barns.

Independent Parameter									Emission Rate (E) (µg/s)			
			Bias[b]	Precision[b]						Bias[b]	Precision[b]	**DQO**
Symbol	Units	Nominal Value[a]	Relative Systematic Uncertainty	RSD	Absolute Sensitivity	Relative Sensitivity	Relative Systematic Uncertainty Contribution[c]	Relative Random Uncertainty Contribution[c]	Nominal value	Relative Systematic Uncertainty[c]	Relative Random Uncertainty[c]	Total Relative Uncertainty[c]
P_i		V_i	B_i	S_{xi}	$\Theta_i = \delta E/\delta P_i$	$\Theta_i' = \Theta_i * V_i/E$	$(B_i*\Theta_i'/2)^2$	$(S_{xi}*\Theta_i')^2$	$E=C*Q$	$B_R = t(\Sigma(B_i* \Theta_i'/2)^2)^{0.5}$	$tS_R= t(\Sigma(S_{xi}* \Theta_i')^2)^{0.5}$	$\pm U_R = t((B_R/2)^2 + SR^2)^{0.5}$
Ammonia (NH_3)												
C	µg/m³	141,000	5%	5%	1.5	1.0	0.0006	0.0025	211,500	30%	40%	50%
Q	m³/s	1.5	30%	10%	141,000	1.0	0.0225	0.0025				
Hydrogen sulfide (H_2S)												
C	µg/m³	14,130	5%	5%	1.5	1.0	0.0006	0.0025	21,195	30%	40%	50%
Q	m³/s	1.5	30%	10%	14,130	1.0	0.0225	0.0025				
Non-Methane Hydrocarbons (NMHC)												
C	µg/m³	9,200	5%	5%	1.5	1.0	0.0006	0.0025	13,800	30%	40%	50%
Q	m³/s	1.5	30%	10%	9,200	1.0	0.0225	0.0025				
Particulate Matter ($PM_{2.5}$)												
C	µg/m³	1,000	5%	10%	1.5	1.0	0.0006	0.0100	1,500	30%	44%	53%
Q	m³/s	1.5	30%	10%	1,000	1.0	0.0225	0.0100				
Particulate Matter (PM_{10})												
C	µg/m³	10,000	5%	10%	1.5	1.0	0.0006	0.0100	15,000	30%	44%	53%
Q	m³/s	1.5	30%	10%	10,000	1.0	0.0225	0.0100				
Particulate Matter (TSP)												
C	µg/m³	20,000	5%	10%	1.5	1.0	0.0006	0.0100	30,000	30%	44%	53%
Q	m³/s	1.5	30%	10%	20,000	1.0	0.0225	0.0100				

[a] Maximum value of the expected concentration range (Table 1.4.1)

[b] As presented in Tables 2.6.1 (gases), 2.6.3 (PM), and 2.6.8 (barn airflow) of this QAPP

[c] As presented in the ASME PTC 19.1-1998 Test Uncertainty Supplement

C: Concentration; Q: Ventilation flow rate. t= Student’s t-value = 1.96

Table 1.4.4. Data Quality Indicators for ammonia (NH_3).

Instrument: **INNOVA 1412**

DQI	Criteria, %	QC Method	Table
Precision	±5	RSD of multiple precision checks with reference gases over time	2.6.1
Bias	±5	Mean of multiple precision checks with span gas over time	2.6.1
Completeness	75	Percentage of the total scheduled NH_3 emission rate measurements	1.4.1

Table 1.4.5. Data Quality Indicators for hydrogen sulfide (H_2S).

Instrument: **TEC Model 450I**

DQI	Criteria, %	QC Method	Table
Precision	±5	RSD of multiple precision checks with reference gases over time	2.6.1
Bias	±5	Mean of multiple precision checks with span gas over time	2.6.1
Completeness	75	Percentage of the total scheduled H_2S emission rate measurements	1.4.1

Table 1.4.6. Data Quality Indicators for non-methane hydrocarbons (NMHC).

Instrument: **TEC Model 55I (NMHC)**
INNOVA 1412 (Total VOCs, methanol and/or ethanol)

DQI	Criteria, %	QC Method	Table
Precision	±5	RSD of multiple precision checks with reference gases over time	2.6.1
Bias	±5	Mean of multiple precision checks with span gas over time	2.6.1
Completeness	75	Percentage of the total scheduled NMHC/VOC emission rate measurements	1.4.1

Table 1.4.7. Data Quality Indicators for particulate matter ($PM_{2.5}$, PM_{10}, TSP).

Instrument: TEC TEOM Model 1400

DQI	Criteria, %	QC Method	Table
Precision ($PM_{2.5}$)	±10	Collocated Partisol, operated during 2 h period	2.6.3
Precision (PM_{10})	±10	Collocated TEOM, operated during 2 h period	2.6.3
Precision (TSP)	±10	Collocated TEOM, operated during 2 h period	2.6.3
Bias	±5	Flow audit using a NIST-traceable flow meter	2.6.3
Completeness	75	Percentage of the total scheduled emission rate measurements for each PM class	Section 2.1.2

Table 1.4.8. Data Quality Indicators for ventilation rate in MV barns.

Instrument: Setra Model 260 Differential Pressure Sensor

DQI	Criteria, %	QC Method	Table
Precision	±10	RSD of multiple differential pressure sensor precision checks with a NIST-traceable differential pressure sensor over time	Table 2.6.6
Bias	±15	Flow audit with collocated FANS analyzer	Section 2.1.5
Completeness	90	Percentage of total scheduled airflow measurements that are valid	Section 2.1.5

Table 1.4.9. Data Quality Indicators for ventilation rate in NV barns.

Instrument: 3D Ultrasonic anemometer (R. M. Young Model 81000)

DQI	Criteria, %	QC Method	Table
Precision	±20	Field intercomparison with identical anemometers during 30 min when measurements should be the same	Section 2.6 Table 2.6.8
Bias	±30	Zero air velocity audit using still air hood	Table 2.6.8
Completeness	75	Percentage of total scheduled airflow measurements that are valid	Section 2.6

1.5 Special Training/Certification

Personnel assigned to the NAEMS will meet the educational, work experience, responsibility, personal attributes, and training requirements for their respective positions. Records on personnel qualifications and training will be maintained in personnel files in a location designated by the SA, and will be accessible for review during audit activities. Adequate education and training are integral to any monitoring program that strives for reliable and comparable data. Training is aimed at increasing the effectiveness of employees and the project overall.

All producers participating in the NAEMS will attend a training session that will discuss the basic aspects of the project, the importance of the instrumentation (and precautions which the farm staff must take to ensure its proper operation), and effects of farm operation on the study. The importance of accurate producer-supplied information (see above) will be emphasized. Further details about this aspect of the NAEMS training are provided in SOP S1.

Training will be provided to all new field, laboratory, sample custody and data management personnel. A 50-question pre-test will be administered to all Site Engineers, and the scores of this test will be used to identify areas needing particular attention during the training sessions. Training will cover operation and maintenance of all instruments and analyzers used in the NAEMS, software operation, sample collection and handling, and general QA/QC measures. Training will be geared to ensure conformity with all of the SOPs, and address issues identified by the pre-test. Field measurement personnel (University PIs and their staff member(s) assigned to the NAEMS) will receive training (a total of 5 d for Site Engineers and 2 d for PIs) at Purdue University (PAAQL) through a combination of hands-on workshops and classroom-style presentations that will be led by members of the NAEMS research team with related expertise. PAAQL personnel and others will emphasize relationships between SOPs where appropriate. The PIs and Site Engineers will tour a NAEMS site close to Purdue, so that the classroom and lab training can be reinforced in a field setting. Attendance of PIs and Site Engineers will be documented throughout the training session, and this documentation will be kept on file at PAAQL. Additional training will be provided as the university PIs and/or their NAEMS-designated staff interact with PAAQL staff during the initial setup at each site; one or more PAAQL staff members will assist with setup of each site, for a minimum of about one week, including travel. Field and laboratory personnel (university NAEMS staff and new PAAQL employees assigned to NAEMS) will receive documented training (Table 1.5.1).

All NAEMS-related documents (QAPP, SOPs and SMPs) will be updated and maintained by PAAQL staff over the duration of this project. Section 1.6 of this QAPP describes the processes by which modifications will be made to these documents. Copies (electronic and hard copy) of the current (original or updated) versions of the QAPP, all relevant SOPs, and the SMP for the site will be available at each research site. The binders or files containing each site’s hard copies of the SOPs, SMP and QAPP will include a signature page, which the Site Engineer and other personnel working at the site will be required to initial and date to certify reading and understanding each document. This sheet will need to be signed each time a new version of a particular document is issued (Section 1.6).

1.6 Documents and Records

Each university partner will use Microsoft Excel to maintain electronic field notes including, but not limited to: site drawings, daily notes about the monitoring operation and the production buildings, results of field quality control measures, and any deviations from this QAPP. More specifications for field notes are provided in Section 2.9.2 of this QAPP. Every sample collected for off-site analysis will be documented in the field log book (including its exact location taken, medium (e.g. manure, bedding, canister sample for VOC analysis, etc), purpose, time of collection, and the name of the person collecting the sample. This information will also be entered on the chain-of-custody form (Appendix D), which will be sent with that group of samples. Copies of all chain of custody forms will be maintained on-site. Field logs will be kept in a central location in the field laboratory. Corrections on paper documents will be made by crossing out the error with a single line, and initialing and dating the correction. This correction technique is specified in all individual SOPs. A digital camera will be kept at each site for capturing pictures, which can then be incorporated into the electronic files for the site. Management of all electronic data files is discussed in detail in SOP B5. SOP B5 contains provisions for the management and retention of non-electronic (i.e. paper) copies of documents such as the Producer Event Form (SOP S1), drawings made based on site observations, etc.

The collaborating producer will keep records of mortalities, animal inventory, weight, and production (e.g. eggs, milk), and water and feed consumption. Animal inventory will be checked every six months (or whenever a new batch of animals is introduced) by study personnel, as described in SOP S2. The producer will also document special activities or procedures (e.g., generator tests, manure removals or agitation, changes in diet and animal health, temperature set points, ventilation interventions (e.g. changes in the fan staging scheme), fan maintenance and/or cleaning, building cleaning, power failures, etc) that may affect the study. Forms and procedures for producers to submit this information are included in SOP S1, which also provides further clarification to the producer about what events need to be reported. Every attempt will be made to ensure that producers check with research staff before initiating any such changes, and that producers do not disturb, move, modify, or impede any measuring devices or systems without first notifying the researchers. Procedural details of all of these issues are provided in SOP S1.

Any modification of this QAPP, including any one or more of its component SOPs or SMPs must be approved in writing by the NAEMS Science Advisor (Heber), EPA’s Project Manager, and EPA’s QA Manager..If only small portions of the QAPP need to be updated and not large sections or the entire document, the modification will be executed by issuing an amendment that replaces one or more individual sections, while specifying the exact change(s), and stating the reason(s) for the change. For example, this process would be used to amend or replace one or more individual SOPs or SMPs, without any modifications to the body of the QAPP itself. Copies of these approvals will be kept on file by the SA for the duration of the project. As soon as changes to a particular document are approved by the SA, the updated document will be electronically transferred (by e-mail and or remote access to site computers by PAAQL staff) to all sites for which the document is relevant. Site personnel will be notified of the specific change(s) in the document (for example, in the form of a Word document with changes tracked), and will replace electronic and/or hard copies of the document at the site with the new version (a .pdf file with changes accepted). They will also be required to sign and date the signature page in the site document binder or file as certification that they have read and understood the change(s) in the document. Any NAEMS-related personnel at any of the participating entities may suggest changes to any document.

Electronically-stored data will be backed up through several distinct mechanisms (SOP B5). A progressive backup of the on-site project folder, from the primary hard drive of the on-site computer to a secondary hard drive, will be conducted automatically daily, so that all files modified in a given day are backed up at the conclusion of that day. Additionally, the on-site project folder will be backed up to a CD or DVD, which will be kept off-site, every two weeks, or whenever there are changes in Category 2 and/or Category 3 data files, as follows:

Category 2 files

- Hardware configuration files (e.g. FieldPoint configuration files)
- Configurations of firewalls, virus protection, etc
- Email accounts, address books, message rules
- Favorite lists

Category 3 files

- Files provided by vendors (e.g. instrument manuals and quotations)
- Instrument communication software

Several different file types will also be emailed from the site PC (by the AirDAC program) to the responsible site PIs, and to the PAAQL Data Analyst assigned to the site (Section 2.9, SOPs B2 and B5). These individuals will archive the files to his/her departmental network server.

Manure analysis data files from Midwest Laboratories will be downloaded from the company’s secure web server, using a project-specific password. They will then be filed by the Data Analyst assigned to the individual site, and managed according to SOP B5. These data are checked for accuracy at the company, by an Area Supervisor, after entry and before release to PAAQL.

Once submitted to the IMC, all NAEMS-related data files will be archived on the administrative server for the Purdue University Agricultural and Biological Engineering (ABE) Department, the contents of which are automatically backed up daily. Data will be inspected (pre-processed) by PAAQL personnel, in accordance with SOP B3, within 2 d of data collection. It is during this pre-processing/inspection phase that data outliers indicating system problems will be identified. Full processing of the data will be conducted with the custom-designed CAPECAB program (SOP B6). The mathematical derivation of many of the individual functions of the CAPECAB program are discussed in SOP B4, which also specifies the procedure for correcting data that was obtained in the interval between a passed calibration check and a failed one.

An electronic copy of the most recent version of the QAPP (including the SMP for each particular site and all relevant SOPs) will be stored in the on-site project file. The QAPP, all SOPs, and all SMPs will also be stored electronically at PAAQL on the departmental server in read-only format (i.e. locked pdf files), in a location accessible to all project staff.

Records from this project will be retained for a period of not less than six (6) years following the end of the project. Midwest Laboratories will maintain all NAEMS data for seven (7) years.

2. Data Generation and Acquisition

The following sections describe the methods that will be used to generate and acquire data. The first section (2.1) describes the experimental design of the project and the sampling methods, and clarifies which SOPs contain the full procedure for each method. The other, subsequent sections describe analytical methods (again, with reference to SOPs for full detail), sample handling procedures, and data management.

2.1 Experimental Design, Selection of Sampling Locations, and Sampling Methods

The basis for the experimental design of this project is continuous measurements of gas and PM concentrations and building ventilation rates. Other types of sampling that are conducted periodically include air sampling for volatile organic compounds (VOCs), and manure sampling for determination of various manure chemical parameters. A list of all SOPs related to sampling is provided in Table 2.1.1.

Table 2.1.1. Sampling-related SOPs in the NAEMS.

Parameter	Sampling method	SOP(s)
Exhaust and inlet air	Custom-built gas sampling system (GSS)	G1
$PM_{2.5}$	Tapered element oscillating microbalance (TEOM)	P1
PM_{10}	Tapered element oscillating microbalance (TEOM)	P1
TSP	Tapered element oscillating microbalance (TEOM)	P1
Fan air speed	Vane anemometer	A3
Fan run time	Vibration or rpm sensor on fans, current switch on fan power supply, and/or fan stage relay monitoring	A7 & S4
Air velocity	3-D Ultrasonic anemometer	A6
Barn static pressure	Capacitive/diaphragm sensor	A5
Temperature	Thermistor or RTD	E2
Temperature	Thermocouple (type T)	E1
Relative humidity	Thin-film capacitor (TFC)	E2
Process run time	Mechanical relay contacts, vibration sensors	A7 & S4
Atmospheric pressure	Barometric pressure transducer (within TEOM)	P1
Solar radiation	Pyranometer	E3
Wind speed	Cup anemometer	E4
Wind direction	Vane	E4
VOCs	Canisters, sorbent tubes	V2 & V1
Amines	H_2SO_4 bubblers	V3
Manure	Various sampler configurations	M1
Animal Inventory	Producer-supplied data, manual counting, truck scales	S1 & S2
Animal Activity	Passive infrared sensor	S3

For each site, the cost and benefit of each sample location group (SLG) needs to be weighed against each other. The following assumptions and factors were taken into consideration in choosing sampling locations:

1. The best sampling strategy must be determined on a site-specific basis.
2. Uniform air mixing in the barn is assumed. The exhaust location is therefore a good representation of the animal exposure for every barn type except high-rise laying houses, where all the air is exhausted from the manure pit. Also, the pollutant concentration at one fan can represent that at other fans.
3. Monitoring another exhaust location is more important than a second inlet sample. Since inlets for incoming ventilation air are distributed throughout the building (ridges, eaves, leaks) and wind blows in all directions, a truly representative single inlet location at any given time is unlikely.
4. In the case of cool cells (evaporative pads), the inlet sample should be taken outside the cool cell, and not inside the cool cell.
5. In the case of side-by-side tunnel ventilated houses, one sample between the buildings at the curtain end should suffice for both houses because the fans are grouped together in one bank of fans.
6. The inlet sample for representing the eave and ridge inlet air can be represented by one sample for both buildings at an outside location in between the buildings.
7. One SLG can be split between (5) and (6), which allows one more SLG to be used for exhaust measurements.
8. In the case of banked fans, one location can represent the air leaving any and all of the fans. It is preferable to pick the fan that runs most of the time and let that SLG represent all the fans rather than allocating additional SLG’s to fans belonging to higher stages. There is less need to check the spatial variability with banked fans than there is in a laying house with 75 fans distributed along 1200 ft of sidewall.
9. Reject repeat measurement of exhaust SLG until inlet air is sampled. A tunnel-ventilated barn site illustrates how exhaust measurements could be maximized. All the fans are represented by one SLG at a continuous 36″ fan, so that the emission streams are E1, E2, and E3 for barns 1, 2, and 3 exhausts, respectively. Assigning one SLG for the tunnel inlet (called Ae, Figure 2.1.1) between the buildings and one SLG for the eave inlets (called Ai) between the buildings, the sampling schedule would be as follows: (E1, E2, E3), Ae, (E1, E2, E3), Ai, (E1, E2, E3), (E1, E2, E3), ..., and the (E1,E2,E3) cycle is kept rotating until 12 h later, when the Ae and Ai locations are sampled again. This option would mean that exhaust in each barn is measured every 30 min at the longest, when the sampling times are 10 and 30 min for the exhaust and inlet air, respectively. Inlet air is measured 8.3% of the time. Based on a 4-min equilibrium time, the total time of useful data will be 368 min, or 26%.
10. Item 9 presents another scenario, namely, that the sampling location could either be repeated or the sampling time for the exhaust SLG be increased effectively to 20 min or more. Here is an extreme case for the tunnel ventilated barns: (E1, E2, E3), Ae, (E1, E2, E3), Ai, (E1, E2, E3), …, and the (E1,E2,E3) cycle is kept rotating until 12 h later to sample the Ae and Ai locations again. This option would mean that exhaust in each barn is measured every 90 min at the longest, when the sampling times are 20 and 30 min for

the exhaust and inlet air locations, respectively. Inlet air is also measured 8.3% of the time. Based on the same 4-min equilibrium time, the total useful data minutes in this case will be 1160 min, or 81%, as compared with the 26% with the scenario under point 9.

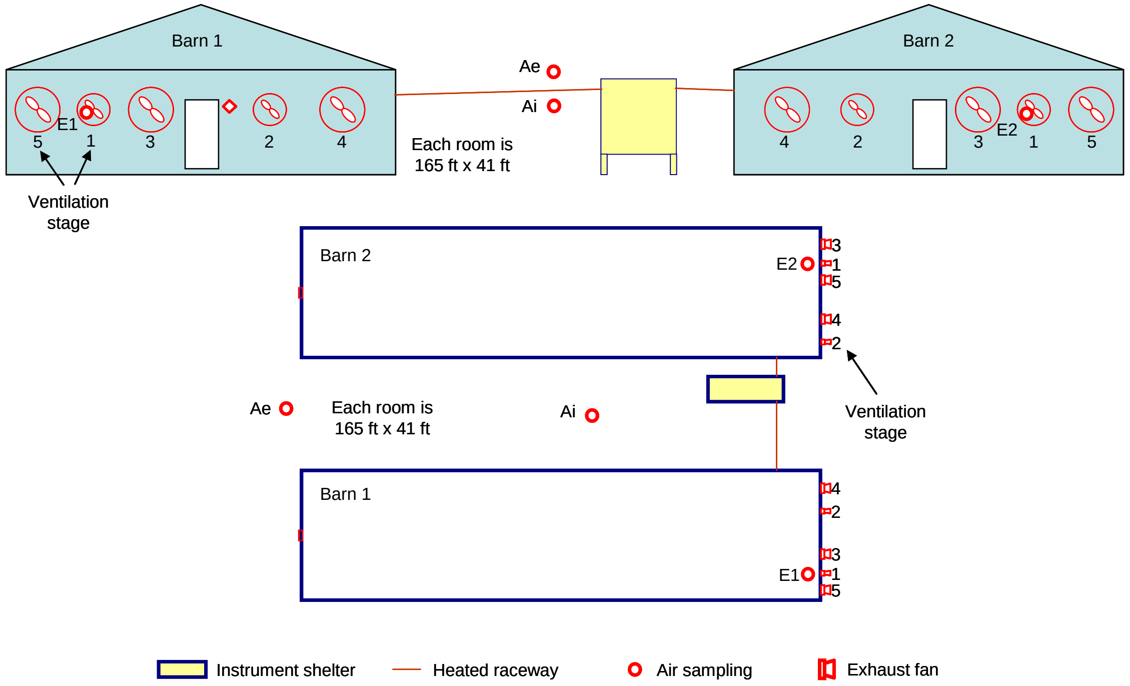


Figure 2.1.1. Sample location groups in two tunnel-ventilated swine barns. A third barn at this particular site is not shown.

11. The order of sampling locations could be randomly chosen between the two barns. However, exhaust samples at each location will be taken at equal intervals in each barn, e.g. 30 min intervals for 9ai above.
12. Use of ceiling inlets for the inlet location is less desirable than outside the barn because:
    a. The ceiling inlet is susceptible to reverse flow from the warm room. This may occur due to mismanagement of fans, mismanagement of inlets, or pressurization of the barn due to wind.
    b. Any inlet measurement inside the building requires explanation and justification. While the attic is typically not an emission source or sink, the assumption that attic concentrations are equal to inlet concentrations needs verification. Also, the assumption that there is no reverse flow of inside air to the attic sampling location needs proof.
13. Some barn ventilation systems are less conducive to emission measurements than others. Producers may have unorthodox and undesirable fan control strategies, and this was strongly considered during the site-selection process. However, in NAEMS and in past projects, several producers were willing to modify minor aspects of their ventilation systems specifically to enhance data quality for the study. In all cases, modifications were

within common industry practices, so that sites were representative of their industry as a whole. For example:

   a. The natural ventilation phase was eliminated from one tunnel-ventilated dairy freestall barn (NY5B in NAEMS).
   b. Stages 1 and 2 fans were switched at one site to bring the OFIS closer to the minimum fans (IA4B in NAEMS).
   c. Duty cycling of two minimum winter fans was switched to continuously running one fan, to ensure that there would be one fan that always had an exhaust stream. This was not necessary at any NAEMS sites.
   d. Variable-speed minimum fans have, in the past, been changed to single-speed fans; however, this was not done at any NAEMS sites.

14. Avoid starting the sampling cycle at the same times during each day. This can be accomplished by adding the two daily 30-min inlet samples to the sampling schedule, which will push the timing forward by 60 min each day.

The measurement locations, number of samples, and sampling frequency are given in the SMP for each site (Appendix A). If the monitoring site becomes inaccessible (for example, as the result of a weather-related or barn-operation emergency), the farm personnel should be contacted immediately for safety issues. If possible, simple immediate maintenance tasks can also be performed by the farm personnel with clear instructions given. A webcam connection, which will be included with each on-site computer, can be used for the purpose of guiding farm staff to perform operations in the trailer if, for any reason, access to the site by research personnel becomes impossible. Even if a site cannot be physically visited, it can still be monitored via the Internet, using PCAnywhere to access the AirDAC program running on the site computer.

2.1.1 Gas Sampling

Using the gas sampling system (GSS, SOP G1), gas samples will be obtained from between one and 22 exhaust air locations per barn, and a ventilation inlet or ambient air location group. In the NAEMS, it is more important that the latter sample represent as closely as possible the air that is entering the barns (the inlet air), although this might not truly be the ambient air for the site (i.e. the upwind air with no or baseline contaminants). This is true because the goal of the NAEMS is to quantify the pollution output of the barns, and this requires data for the inlet air. Gas sampling location groups (GSLGs) will consist of one or multiple sampling locations and tubes that bring air into a mixing manifold from one or more discrete sampling points. For example, a GSLG within a large naturally-ventilated dairy barn could consist of 6 sampling tubes that bring air into a mixing manifold from six discrete sampling points in one large opening of the barn (e.g. open sidewall). The fewer sampling points that are taken, the more important it becomes to assume uniform mixing in making extrapolations to the barn as a whole. The exact number and locations of the sampling points will vary from site to site, and are specified in the SMP documents for each site.

Certain farms require fewer gas sampling points because of site-specific fan locations and numbers. Since large buildings have multiple exhaust fans, it is not advisable to use the concentration found at one fan to represent that at many other fans, especially if the fans are separated by large distance, or if one is a pit fan and the others are wall ventilation fans. There is spatial variation between the exhaust locations: Pit exhaust fans probably will have higher gas concentrations, since they are closer to the gas source (i.e. manure) than wall exhaust fans, but will likely have lower PM concentration, since they are further from the source of PM (i.e. animals). Thus, there is a need for measuring several representative exhaust points. If the fans are grouped together, e.g. tunnel ventilation, a single point may then be representative of air exhausting from the entire group of fans. All of these considerations have been taken into account when developing the site-specific Site Monitoring Plans.

While sample air can be collected from multiple exhaust fan locations and composited (e.g. four pit exhaust fans, five end wall tunnel fans, etc. (Heber et al., 2001)) for measurement, it is preferable to have individual sampling points. For example, if one of the fans in a group which is being composite-sampled fails, the data for the whole group must be invalidated. When composite sampling is used, only one mean value is available for the entire group, and the differences between each point are unknown. Also, all fans that are included in a sample group must be operating at approximately the same speed for composite sampling to be appropriate.

Air from each location will be sampled and measured continuously for 10 min before switching to the next location. Thus, for a site with 12 sampling locations, a 120-min sampling cycle (without the inlet air sampling) will be applied, resulting in 11 to 12 sampling periods per day per location, depending on the number of inlet air sampling points. The first several minutes of gas-concentration data will be ignored to allow the measurements of the gas analyzers to stabilize. To ascertain that a specific equilibrium period will allow each analyzer to achieve at least a 95% response to a step change in the input concentration, the response time of the system will be initially tested by attaching a 50-L bag of calibration gas at the end of the longest sampling tube in the GSS. If the equilibration time of a particular gas analyzer (e.g. the MSA Model 3600 CO_2, analyzer (SOP G3)) is shorter, then less data from that analyzer will be ignored. The gas sampling system (GSS) is equipped with a bypass sampling pump that composites the flow from all GSLGs which are not currently being supplied to the gas analyzers, and purges them simultaneously, with a total flow of about 10 L/min. The bypass pump operation shortens the equilibration time and avoids idle barn air in the sampling system.

The sampling time for the inlet location will be 30 min, and this location will be sampled twice per day. The longer sampling period allows enough time for all gas analyzers to reach equilibrium, because the concentration difference (e.g. step change) from the previous sample may be significant. The lower sampling frequency is feasible because inlet analyte concentrations are more stable when compared with those of barn exhaust or animal areas.

Based on the size of facilities being monitored in this study and the number of GSLGs, the shortest sampling cycle will be one hour, and the longest sampling cycle will be just over three hours (190 min). The average cycle duration for the 14 sites will be just under two hours (approx. 105 min). This is assumed to be sufficient to capture the variations in emissions, especially when there are multiple exhaust locations in each building. With this configuration, the pollutant concentrations in exhaust air from each individual exhaust location will be measured at least 8, and as many as 24 times daily, with an average for all sites of approximately

12 times daily. This will result in a total of approximately 24 to 60 measurements daily per building (assuming that each building will have 1-5 GSLs or GSLGs).

The duration of sampling at a given location can be calculated as the total number of samples times the number of readings per sample. For a monitoring site that has ten sampling cycles per day, the minimum sampling duration will be 20 (measurements per building) x 3 min (after 7-min equilibration time per sampling cycle) = 60 min or 4.2% of the day. Although this seems like a small percentage of the time, the long-term measurement and sampling at different times of day (Step 14 of Sec 2.1) help to ensure representative sampling. The 20 three-minute samples from each location are distributed throughout the day, thus capturing the diurnal variations of emissions.

2.1.2 Particulate Matter (PM) Sampling

2.1.2.1 PM$_{10}$

PM$_{10}$ (10-µm particles and smaller) will be monitored using the Thermo Electron (formerly Rupprecht & Patashnick (R&P)) TEOM (Tapered Element Oscillating Microbalance) 1400, which is a continuous PM monitoring device. With the appropriate inlet, the TEOM is designated by USEPA as an equivalent method for PM$_{10}$ (EPA Designation No. EQPM-1090-079) (USEPA 1999a). See SOP P1 for more details on the description, operation, calibration and maintenance of the TEOM.

PM$_{10}$ concentrations will be measured continuously with the TEOM, generally at one minimum winter ventilation fan in each building, and generally side by side with an exhaust air gas-sampling point. The sampling location will be inside the building near the inlet of the fan, however, far enough away to avoid concerns about anisokinetic sampling. The one exception to this rule is in the belt-battery portion of the IN2B layer site, where, because of space limitations in the barn, the TEOMs located upstream of the manure drying tunnels will be downstream of the barn exhaust fans feeding into the drying tunnel. The air velocity around the sampling head should be 2 m/s (400 fpm) or less. This corresponds to the minimum air velocity in a tunnel-ventilated building in the summer.

2.1.2.2 PM$_{2.5}$

Concentrations of PM$_{2.5}$ will be measured using the Thermo Electron TEOM 1400 continuous sampler, and audited at sites IN2B, IN3B and IN5B with the TFS Partisol Model 2000 single-channel sampler; both of these will be equipped with PM$_{2.5}$ sampling inlets. The Model 2000 sampler is designated as a FRM (RFPS-0498-117) for collection of PM$_{2.5}$ when used with the WINS (Well Impactor Ninety-Six) impactor and the VSCC (very sharp cut cyclone). The sampler draws air through the PM$_{10}$ inlet, PM$_{2.5}$ WINS impactor, and a 47-mm Teflon sample filter, which traps the PM$_{2.5}$ fraction. The sample filter is conditioned and weighed before and after sampling. The resulting difference in mass is the collected PM$_{2.5}$ mass (µg). Electronic systems in the sampler are designed to monitor and maintain the volumetric flow rate, and to record the elapsed sampling time, enabling the R&P Model 2000 to calculate the total sample volume (m³). This allows the mean PM$_{2.5}$ concentration (µg/m³) for the sampling period to be calculated. Further details on the PM$_{2.5}$ equipment and methodology are given in SOP P1 (TEOM) and

SOP P3 (Partisol). The TEOM 1400 will be fitted with $PM_{2.5}$ inlets for a sampling period of two weeks in the summer (June-August) and two weeks in the winter (December-February) during the first year of data collection, with a goal of obtaining data for both hot and cold conditions. Site personnel will consult the 15-day weather forecast for their site(s) before finalizing the scheduling, to avoid nonrepresentative weather conditions. They will also avoid nonrepresentative operational conditions inside the barns.

2.1.2.3 Total Suspended Particulate (TSP)

The TSP concentration of the exhaust air stream will be determined using the TEOM sampler, equipped with an R&P TSP inlet. The TSP inlet will be installed onto the TEOM inlet system for one week in every eight weeks for continuous TSP concentration measurement while temporarily interrupting the PM_{10} measurements. The sampler works exactly as the TEOM PM_{10} sampler, except the PM_{10} inlet is replaced with the TSP inlet. There is no size separation, because the inlet is designed to allow very large PM to pass through. However, precipitation and PM with very large fall velocities are prevented from entering the sampling system. Filters are replaced more frequently than that of PM_{10} and $PM_{2.5}$ measurement, depending on the PM loading and site maintenance schedule. Further details of the TSP measurement and equipment are provided in SOP P1. TSP results will be checked by comparing them with the gravimetric samplers (SOP P2) at one dairy site (IN5B), one swine site (IN3B), and one layer site (IN2B). It will be assumed that the particulate profiles for layers and broilers will be sufficient that it will be unnecessary to conduct the check at the CA broiler site.

2.1.3 Temperature and Relative Humidity Measurements

Up to sixteen copper-constantan (Type T) thermocouples per building (depending on the size and complexity of the building) will be used to sense temperatures at the following locations: 1) heated raceways, 2) animal pens/cages, 3) summer and winter air inlets, and 4) exhaust fans. The thermocouples will be used with a 16-bit thermocouple module (FP-TC-120, National Instruments, Austin, TX). The sensors will be two-point calibrated prior to and following the 24-month monitoring period using heated (50 ºC) and ice-water baths, and will be periodically checked in-place with a NIST-traceable portable temperature sensor. Further details of the thermocouple-based temperature measurements are presented in SOP E1.

An electronic RH/temperature transmitter (NOVUS Model RHT-WM, Omni Instruments, Arroyo Grande, CA) will also be used to monitor temperature and RH at representative exhaust locations and other locations in each building (as detailed in the SMP for each site), as described in SOP E2. The same transmitter, equipped with a passive solar radiation shield, will be used to measure temperature and RH at a representative outdoor location (SOP W1). The Omni RHT-WM has accuracies of ±1.5% RH and ±0.5 ºC at 25ºC.

2.1.4 Pressure Measurements

Building static pressure will be monitored continuously at locations near the exhaust fans. Pressure measurements will be made with differential pressure (dP) transmitters (Model 260, Setra Systems, Boxborough, MA) with a range of -100 Pa to +100 Pa, and an accuracy of ±1% full scale. These sensors will be 9-point calibrated with NIST-traceable standards by the manufacturer. The pressure sensor will be shunted to calibrate zero and compared with reference pressure transducer to calibrate it at various span pressures. Pressure snubbers will be used to minimize effects of air movement from wind or ventilation fans on the measurement. Further details of the pressure measurement methodology are presented in SOP A5.

Atmospheric pressure will be monitored with a barometric pressure transducer in the TEOM, as described in the TEOM SOP (SOP P1).

2.1.5 Ventilation Fan Monitoring

Sites with MV barns will have the status and airflow of the PREF fans (at a minimum) continuously monitored using a bi-directional impeller anemometer (Model 27106, R.M. Young Company, Traverse City, MI). The advantages of the impeller anemometer, which is much smaller in diameter than the fan, are that the significant effects of wind and building static pressure are accounted for with the technique and real-time measurements are made. These anemometers will be calibrated during the in-field tests with the FANS analyzer (SOP A3) and, if feasible, during BESS tests. The operation of individual fans will also be measured using vibration sensors (SOP A7) rpm sensors (SOP A11), or current switches. Each fan monitoring sensor will be connected to the data acquisition system (SOP B1). Open impeller anemometers and rpm sensors also provide performance information about the exhaust fans that can be used in airflow rate estimations. The operating status (operating time, %) of fan stages will be monitored via auxiliary contacts of fan motor control relays (SOP A4). A mean of sixty 1.0-Hz readings will be recorded every minute.

In the case that a site has large barns (with over 20 ventilation fans each), and employs dedicated farm personnel for checking and maintaining the fans on a daily basis, the monitoring of each individual fan is unnecessary. Instead, fan monitoring equipment will be assigned to representative fans based on the following criteria: 1) airflow from every PREF and one representative fan of every other fan model employed at a site will be monitored with an open impeller anemometer; 2) all variable speed fans will be monitored using an rpm sensor or an open impeller anemometer; 3) up to two fans for every ventilation stage will be monitored using either an rpm sensor or vibration sensor; and 4) up to two additional fans for every ventilation stage will be monitored using current switches activated by fan motor current. Criteria 4 may be replaced with or used in conjunction with fan stage relay monitoring.

The airflow of a fan can be estimated by taking the published fan performance curves for the particular fan model and interpolating at the measured exhaust fan dP. However, a systematic error is generally inherent with this method, because the performance of fans deteriorates due to dust buildup, belt wear and shutter degradation. Based on unpublished tests (Heber, 2002), actual airflows are expected to be 5 to 50% less than would be expected based on the published fan curve data. Therefore, a FANS analyzer (Becker 1999; Gates et al., 2002), a calibrated anemometer system with multiple traversing impellers, will be used to spot-measure actual fan capacities in the field. The FANS analyzer will first be calibrated (preferably but not necessarily with each fan model removed temporarily from the buildings, or with another identical fan with an identical configuration) using the University of Illinois BESS Lab. Use of the FANS analyzer in the field is detailed in SOP A2. The BESS lab can measure fan capacity with an accuracy of ±2% using a standard method (AMCA, 1985), which is described in SOP A1. The spot measurements with the FANS will be conducted at least once per eight months, and will each consist of at least two to three replications at each fan that is tested. The FANS (or field-collected) data will be used to adjust the estimated fan airflow rate generated using the published fan performance curve.

Airflow rates of representative fans will be determined using the FANS analyzer (SOP A2), or a portable anemometer and the traversing method (SOP A8) if the FANS cannot be used due to limited access or tight spaces. The number of fans to be tested at each farm should be as many as practical and needed for accuracy. It seems feasible that a minimum of 25 fans per barn (or 25% in barns with more than 100 fans) should be measured (specific numbers for each site will be delineated in the SMPs), but this depends on the age and condition of the fans, and the number of static pressures tested with each fan. Other requirements are as follows:

1. The airflows of all the fans whose exhausts are sampled to determine gas or PM concentration will be tested.
2. A minimum of 2 fans per stage should be tested. These should be randomly selected from among all fans operated in the stage.
3. Once 2 or more fans per stage have been selected, the remainder of the fans to be tested (25 or 25%, whichever is greater) should be randomly chosen from other stages with extra weight given to lower-stages.
4. If a barn has more than one fan model, a minimum of 25% of the fans of each model should be tested.
5. Variable-speed fans should be tested at a minimum of three speed settings that must include the minimum and maximum speed settings used by the producer.

A minimum of two runs will be conducted per fan; if the airflows from these two runs do not agree to within 5% or less, additional runs will be conducted until the difference is less than 5% for two consecutive runs. However, all runs conducted will be considered valid data for that fan unless there is evidence that the test was flawed. If the RSD of the airflows of the entire group of same-model, same-speed, and same-stage (if a stage effect exists) fans is greater than 5% and $n > 10$, then additional fans will be evaluated, unless all fans in the barn have already been tested.

The accuracy of airflow measurements will be improved if the fans can be tested at more than one static pressure. If it is possible to manipulate the static pressure in the barn, then it should be conducted at a minimum of two static pressures so that the fan performance can be known through the operation of the fan.

The total building airflow rate will be calculated (SOP A4) by summing the individual airflow rates of all operating fans. The accuracy in measuring daily mean building airflow with this method (with data from either the FANS analyzer or traversing) is estimated at ±10%.

Wind speed and direction will be monitored continuously with a wind direction vane and a cup anemometer (SOP E4). Wind information will be used to correlate with and confirm wind-induced static pressure influences on fan airflow.

Airflow through barns that are not mechanically ventilated (i.e. open dairy barns at sites CA5B and WA5B) will be determined using 3-Dimensional Sonic Anemometry, as described in SOP A6. The 3-D sonics will be placed in the ventilation openings, as shown in Figure 2.1.5.1, which shows how multiple anemometers will be spaced in each wall and in the ridge to better determine a true average flow through each of these locations.

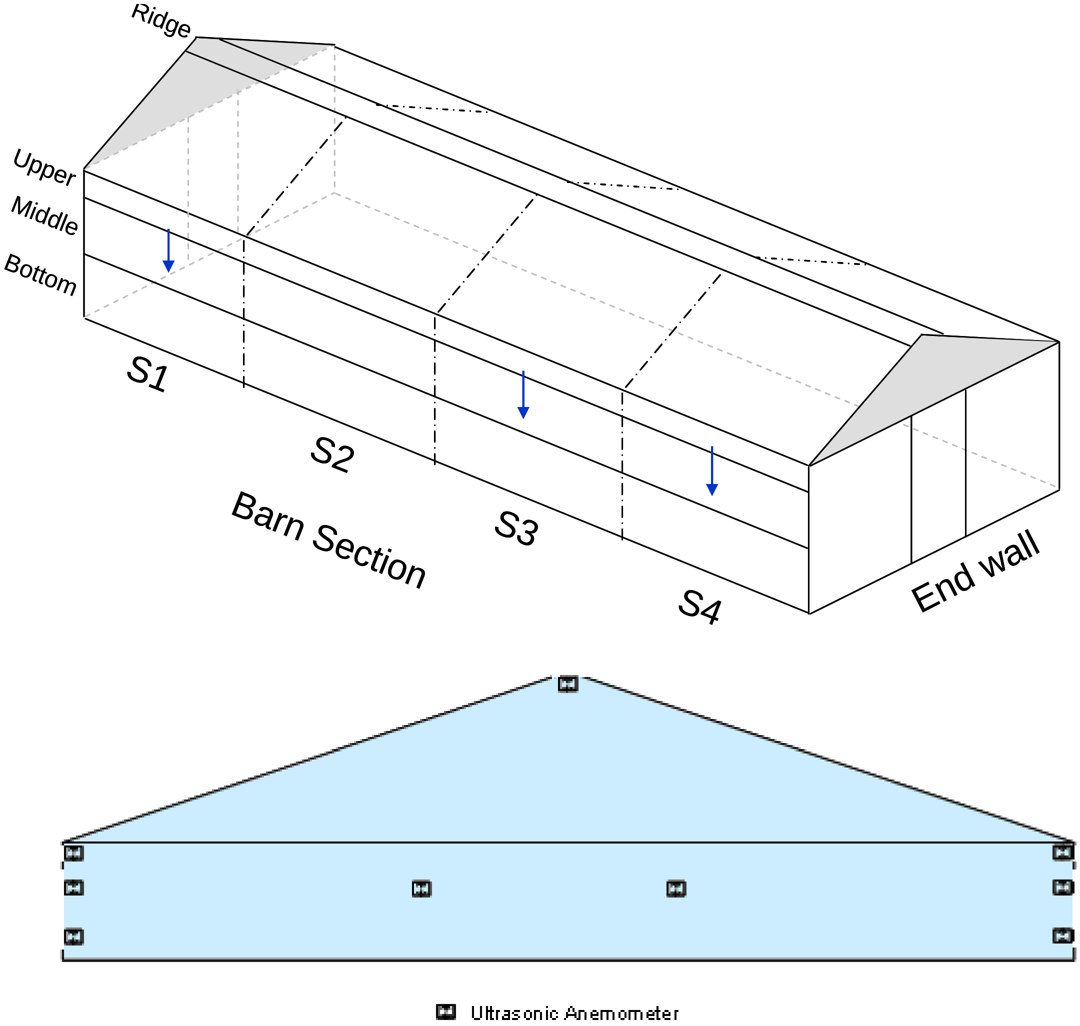


Figure 2.1.2. Locations of sonic anemometers in a naturally-ventilated freestall barn. In this case, the top (eave) sidewall anemometers can be shifted down into the middle sections (arrows) during periods when the sidewall curtains are fully open.

2.1.6 Animal Inventory and Productivity

Producers will be required to provide their animal inventory (i.e. head count) at the beginning of the study, assuming that occurs in the middle of a growth period. Otherwise, the initial inventory will be submitted as soon as the barn is filled at the beginning of the next growth period. Inventories will be regularly updated whenever livestock are removed from or added to a barn, or whenever mortalities occur (in the latter case, producers typically maintain their own daily mortality logs, which will be supplied to the study personnel). Producers will supply data on feed consumption. To the greatest extent possible, this will be barn-specific; if not, whole-farm data will be converted to barn-specific data based on the number of head in the entire facility *versus* the individual barn. Layer and dairy producers will also supply data on the number of eggs or the amount of milk produced, so that these may be used, together with the compositional data of these materials, as inputs (along with manure and bedding data) for an N balance of the facility (SOP S5). This will serve as a theoretical check on the amount of N that is determined through sampling to be emitted as NH_3. Details of the collection of this information from producers is provided in SOP S1. Periodic checks of both counts and weights of livestock will be conducted by study personnel, and are described in SOP S2. Specifically, every six months, study personnel will verify the head counts at each swine and dairy site by counting animals in the study barn. Weights of swine and cows will not be checked, but will rely on producer-supplied information. At layer sites, birds will be counted and weighed in 0.1% of the total cages in each barn. Bird handling for this procedure can be conducted by study personnel, or farm staff under observation by study personnel. The same percentage of birds at the broiler site will also be counted and weighed; again, the study personnel can either conduct the counts and weighings themselves, or observe the farm staff doing them. Poultry counts and weights will be verified every six months.

2.1.7 Animal Activity

Activity of animals, and barn workers, will be monitored using Passive Infrared (PIR) detectors. These detectors operate according to the pyroelectric principle; a crystalline sensor inside the PIR detector generates a surface electric charge when exposed to heat (infrared radiation). A filter window is incorporated to establish an incoming IR range that is most sensitive to animal- and human-body thermal radiation. The pyroelectric sensor has two sensing elements. A body, the radiation source, passing in front of the sensor will activate the first element and then the other. The radiation source must pass across the detector in a horizontal direction if the detector is vertically installed. The detector output is proportional to the temperature difference between the object and the background, and to the velocity of the object. The Visonic Model SRN-2000 PIR detector has a maximum range of 18 m, depending on the detector configuration and mounting. Details on the methodology and equipment used for activity measurements are given in SOP S3.

2.1.8 Other Periodic Sampling

2.1.8.1 Air Sampling for Volatile Organic Compounds (VOCs)

Air sampling for VOCs will be conducted at the primary representative exhaust fans (PREFs) for each building. The PREFs are identified in the respective SMPs. Two different “broad spectrum” methods will be used for VOC sampling, to increase the number of analytes measured that contribute to the total VOC mass, since each method can only detect limited types of analytes. In the first method, Carbopack X/C sorbent tubes will be used, as described in SOP V1. This methodology is adapted from USEPA Compendium Method TO-17, “Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes” (USEPA 1999c). The stated detection limit for this method is between 0.5 and 25 parts per billion (ppbv) concentration in the tested air stream. In the second method, samples will be collected using pre-conditioned canisters, in accordance with SOP V2. Canisters will be cleaned and certified according to SOP V7, which is derived from TO-15 and TO-14.

Volatile amines will be collected (SOP V3) using midget bubblers filled with dilute H_2SO_4, in a method adapted from the American Public Health Association’s “Tentative Method of Analysis for Primary and Secondary Amines in the Atmosphere (Ninhydrin Method)”, and the Occupational Safety and Health Administration’s Instruction CPL 2-2.20, and USEPA Conditional Test Method CTM-027 (“Procedure for Collection and Analysis of Ammonia in Stationary Sources”) (USEPA 1997).

The specific choice of VOC collection technique(s) that will be applied at each site depends on the results of the initial site VOC characterization. All subsequent VOC sampling will be conducted at the primary representative exhaust fan (PREF) for the building in question. Sampling will be conducted every three months or every quarter. Duplicate samples will be collected at each PREF location during each sampling event, so that the precision of the sampling and analytical method combination can be assessed.

2.1.8.2 Manure Sampling

Manure samples will be collected from various storage or treatment facilities, including building deep pits, storage basins, lagoons, and storage piles. The exact sampling locations are specified in the SMP for each site. Different sampling equipment and techniques are employed, based on manure characteristics (liquid or dry samples) and/or limitations of facilities (SOP M1). It is important to take a sufficient number of samples to be representative of the manure storage or treatment unit. To develop an accurate model for nutrient (N) balance, it is also important that the manure sample represents the average holding time encountered by the manure in the monitored housing unit, and any manure treatments that occur within the housing unit that may affect the form of N and/or its release to the air. For example, with respect to holding time prior to land application, if only manure that has been stored the maximum time is sampled, its N content will be lower than average, and NH_3 emissions will be overestimated. Conversely, if the manure sample is fresher than the average storage time, N content will be overestimated, and emissions underestimated. To achieve this, it is necessary that the manure be well-mixed prior to or during sampling.

The number of samples and sampling frequency are specified in the Site Monitoring Plans for the individual locations (Appendix A). Furthermore, each individual sample is generally composited from a number of subsamples, which depends upon site-specific factors, and is specified in the SMPs. Subsamples are taken, and either mixed in a bucket or pail, or spread out on a plastic tarp and mixed, until a homogeneous state is achieved, at which point a sample is collected. Further details of these procedures, and information on the types of containers that should be used and volumes to collect, are given in SOP M1.

2.2 Sample Handling and Custody

Filters used for $PM_{2.5}$ sampling when the FRM method (SOP P3) is used as a periodic check on the performance of the TEOMs or Beta Monitors, and other sampling devices (such as canisters, sorbent tubes, and bubblers) will be inspected for contamination and defects and cleaned before use. Details on these processes, including the detailed certification program for canisters (SOP V7) and the conditioning process for sorbent tubes (SOP V1), are provided in the respective SOPs. After sampling, they will be visually inspected prior to delivery to the laboratory. Considerable care will be taken when handling sampling equipment, according to the precautions that are described in the individual SOPs. For example, care must be taken when recovering filters from PM sampling devices, to ensure that the collected PM cakes are not lost or disturbed. Manure samples must be placed on a sufficient amount of ice before shipping that they remain cold throughout transit. In general, samples collected should be sent to the laboratory for analysis as soon as possible, and certain time constrains should be applied according to each SOP, such as the necessity of having the samples analyzed within a certain time frame. Samples that do not require special preservation, such as TSP and $PM_{2.5}$ filters, can be kept in the OFIS for up to a month before they are sent in as a group for analysis. Details of sample preparation and shipping are described in the relevant SOPs.

Samples will be labeled and logged on standard field data sheets as they are collected, or will be logged into the field log book or electronic field notes. Details of labeling the individual samples, numbering systems, and use of specific types of tags or labels are included in the SOPs. The samples will then be gathered, stored and transferred to the laboratory for evaluation. All field data will be recorded and checked for completeness and accuracy before leaving the site. Chain of custody will be documented with signatures of those who relinquish and receive the samples. Chain of Custody (COC) sheets (Appendix D) will be filled out electronically, and will be sent along with the samples. Electronic completion of the forms will enable them to be emailed to the lab, so that the lab will have the tracking information, and be able to plan for the arrival of the samples. Upon receiving the samples, laboratory personnel will sign on the chain of custody form and check the conditions and completeness of the samples. The laboratory personnel designated to receive VOC samples at PAAQL will be Dr. Changhe Xiao, who will serve (Figure 1.1.1) as the NAEMS VOC Manager. Specific personnel will be designated by Midwest Laboratories, which has a designated Sample Receiving Supervisor, as the recipient(s) for manure, bedding, feed, milk, and egg samples that are sent there for analysis. Midwest Laboratories stores the samples in a chain-of-custody cooler, and then uses an in-house Accountability Record, which each person handling the sample must sign, and record the date and time that the samples were checked out and returned. Completed COC forms for samples arriving at Midwest Laboratories will be forwarded to PAAQL after analyses of the samples are complete, although Midwest will retain the samples themselves. Any abnormal conditions, such as warm manure samples, broken sample containers, turned-over filters, uncapped sorbent tubes, sampling canisters with improper pressure, etc. will be recorded on the COC, and in the laboratory data sheets. Responsible personnel will be informed, and corrective actions (e.g. scheduling for repeat sampling) will be taken immediately and recorded. In the case of VOC samples, it is anticipated that this will entail PAAQL personnel contacting the PI for the particular site. In the case of samples received by Midwest Laboratories, they will contact the PAAQL Data Manager/Data Analyst assigned to the site, and he/she will contact the site PI. All of the related data sheets, including field sampling, chain of custody, and laboratory data sheets will be kept in a designated binder in the laboratory. Copies of COC forms for all groups of samples sent from a particular site will also be maintained in a designated binder in the OFIS at that site.

2.3 Analytical Methods

2.3.1 List of Analytical Methods

Table 2.3.1 summarizes analytical methods that will be employed in the NAEMS. Greater detail on each method is provided after the table.

Table 2.3.1. Analytical methods used in the NAEMS. See cited SOPs for further details.

Variable	Measurement Method	PAAQL SOP
NH_3	Infrared photoacoustic	G7
H_2S	Pulsed fluorescence (as SO_2)	G5
VOCs	GC/MS (mass spectrometer)	V4 (Sorbent tubes) V6 (Canisters)
Amines	Ion chromatography	V5
CO_2	Infrared photoacoustic	G3, G7
Gas cylinder composition	FTIR	G12
Manure pH	Electrometric (KCl electrode)	M2
Manure solids content	Total solids – Drying @ 103-105°C Volatile solids – Heating @ 550°C	M3
Manure nitrogen	Micro-Kjeldahl + Titrimetric	M4
Manure NH_3	Micro-Kjeldahl + Titrimetric	M5
Nitrogen content of feed, milk and eggs	Micro-Kjeldahl + Titrimetric	S6

2.3.1.1 Ammonia

Two different types of analyzers (chemiluminescence, photoacoustic infrared) are available to measure NH_3 concentrations in the NAEMS. Although the same instruments will be used at each site, the measurement range will depend on the expected atmospheric NH_3 concentrations at the site. The expected concentration depends on the species (layer and broiler are typically higher than dairy or swine), manure removal frequency, and season (NH_3 levels are typically higher in winter, when ventilation rates are lower).

In the first method, NH_3 will be measured with a chemiluminescence NH_3 analyzer (Model 17C, Thermal Environmental Instruments (TEI), Franklin, MA), which combines an NH_3 converter and a nitrogen oxides analyzer (SOP G4). The NH_3 analyzer's full scale will be set at 20 to 200 ppm, depending on the expected maximum levels in the building (e.g. 150 ppm for layer houses, 24 ppm for swine finishing, etc) (Table 2.6.2 provides information on the maximum expected concentrations at each site). If initial NO and NO_2 measurements are negligible, the analyzer will be operated in the N_t (total N) mode (SOP G4), which will decrease its response time (thus allowing for collection of more usable data) and reduce the cost of scrubber replacements.

NH_3 concentrations in air will be measured using photoacoustic infrared (IR) detection with the INNOVA Model 1412 Multi-gas Monitor (Innova AirTech Instruments, Ballerup, Denmark), which is capable of measuring several gases (including NH_3) simultaneously. With this method, a gas sample is introduced into an acoustic cell, where it is exposed to pulsing infrared light of specific wavelength. Gas selectivity in the Model 1412 is achieved through the use of optical filters; by installing up to five of these filters in a central filter wheel, concentrations of up to 5 component gases (and water vapor) can be simultaneoulsy measured in an air sample. Almost any gas that absorbs infra-red light can be measured by this method. If, for example, the sample contains NH_3, it will absorb an amount of infrared light at an NH_3-specific wavelength (976 µm) proportional to the concentration of NH_3 in the sample. When gas molecules absorb this infrared light, their temperature rises as the molecules increase in kinetic energy, resulting in a pressure wave inside the acoustic cell. The audible pressure pulses corresponding to the light pulses are detected by a microphone located inside the chamber, and are proportional to the concentration of NH_3 molecules. Measurement accuracy is ensured by the Model 1412's ability to compensate for temperature and pressure fluctuations, water-vapor interference and interference from other gases known to be present. The Model 1412 has range of 0-2000 ppm, which makes it suitable even for the most extreme cases expected in NAEMS (poultry houses during periods of lower winter ventilation). Use of the INNOVA Model 1412 is discussed in further detail in SOP G7.

2.3.1.2 Hydrogen Sulfide

Hydrogen sulfide (H_2S) will be measured in real time with a pulsed fluorescence SO_2 detector (TEI Model 450I), in accordance with USEPA Method EQSA-0486-060 and EMTIC TM-006C. H_2S is converted to SO_2 through exposure to a molybdenum-based catalyst operating at a temperature of 325-370°C in a converter (Thermo Electron Model 340). Corrections for SO_2 present in the original sample are made by shunting one subsample so that it bypasses the converter. This value is subtracted from the result with the converted subsample to calculate the H_2S concentration. This system and its use are described further in SOP G5.

2.3.1.3 Hydrocarbons (Total Non-methane VOC)

Concentrations of total non-methane hydrocarbons (NMHC) will be measured using one of two methods. The first of these methods is the INNOVA Model 1412, equipped with a 987-µm filter. Because this filter will also read methane in the air sample, it is necessary to measure CH_4 (at 968 µm), and subtract the total CH_4 from the total hydrocarbon concentration detected at 987 µm. The remaining two filter spaces in the Model 1412's filter wheel will, at some sites, be used to measure ethanol (at 974 µm, after correction for NH_3, which also absorbs IR light at this wavelength), and methanol (at 936 µm). Further details on the quantitation of these gases with the Model 1412 are provided in SOP G7.

In the second method, concentrations of non-methane hydrocarbons (NMHC) will be measured using the TEI Model 55C, which incorporates a back-flush gas chromatography (GC) system with a proprietary column, which is capable of achieving complete separation of methane from all other hydrocarbons, including C_2 compounds. An FID detector provides automated measurement of both methane and non-methane hydrocarbons. The detection limit of the method is 20 ppb for methane and 50 ppb for NMHC (as propane). The range of the instrument (for both analytes) is from 0 to 5000 ppm. This instrumentation is discussed in SOP G6, and will be used at one swine site (IN3B), two dairy sites (CA5B and IN5B), and one layer site (IN2B) as a check on the performance of the INNOVA. Doing so may require rotation of units, but it will be possible to have a 55C at each of these sites for a minimum of 8 to 12 months.

2.3.1.4 Individual VOCs

Two different methods will be used to analyze barn air samples for individual component VOCs. As described above, these methods will be used to quantify those VOCs that are determined (in consultation with EPA) to be present at levels that warrant monitoring.

VOC samples on sorbent tubes (See above and SOP V1) are subjected to a brief dry purge (as part of addition of an internal standard) to remove most water vapor, and are then thermally desorbed, in what is referred to as the primary desorption step. Analytes driven off the tube in the primary desorption step are refocused on a secondary trap (the cooled injection system), which concentrates them into a very small volume. Rapid desorption of the trap (the secondary desorption step) follows, and then injection/transfer of target analytes into the GC. The above steps are accomplished using a GERSTEL TDS (ThermoDesorption System) 2 unit, and/or a GERSTEL TDS A 20-tube autosampler unit. Identification of target compounds is accomplished by comparing their GC retention times and mass spectra (determined using an Agilent Model 5975 MSD) with those of authentic standards. Quantitation of each compound is then accomplished by comparing the response (preferably peak area of its primary characteristic ion, but peak height may also be used) relative to that of an internal standard (1,4-dichlorobenzene-d_4, naphthalene-d_8, and/or acenaphthene-d_{10}). This methodology (SOP V4) is based on: USEPA Compendium Methods TO-17 ("Determination of Volatile Organic Compounds in Ambient Air

Using Active Sampling onto Sorbent Tubes") (USEPA 1999b); TO-15 ("Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)") (USEPA 1999b); and Method 8270C ("Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)") (USEPA 1996b). Because of possible contamination of sorbent tubes that can occur over long periods of storage between sampling and analysis, all sorbent tube phenol/VFA samples will be analyzed within 30 d of sample collection, in accordance with Compendium Method TO-17. The initial characterization of the site will include a TO-17 "uncharacterized atmospheres" test (SOP V1), which will determine the net amount of analytes sorbed per unit volume of air for 1-L and 4-L sample volumes. The linearity (or absence thereof) of these results will allow the analyst to determine whether the sampling tubes would become saturated at the higher sampling volume. If, in subsequent tests, the amount of analyte recovered from a tube is more than 25% higher than the highest amount that is known to be possible without saturating the tube (i.e. allowing breakthrough of analytes to occur), that test must be repeated with a lower sampling volume.

Samples collected in canisters (SOP V2) are analyzed similarly, except that dry purging is not conducted. Canisters are leak-checked after arrival in the laboratory, and are pressurized (if necessary) with humidified ultra high-purity nitrogen. An aliquot of sample (250-500 mL) is withdrawn from the canister, and introduced into a solid multisorbent concentrator. Sample water content can be reduced, if necessary, by dry purging the concentrator with helium, while retaining target compounds. The analytes are thermally desorbed from the concentrator into a cryofocusing unit coupled to a gas chromatograph (GC) inlet. The remainder of the analytical process is the same as described above for sorbent tube samples. This methodology, which is fully described in SOP V6, is based on USEPA Compendium Method TO-15 ("Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)") (USEPA 1999b), and Method 8270C ("Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)") (USEPA 1996b). Several loss mechanisms exist for analytes collected into sampling canisters, including physical adsorption, dissolution into separate water phases, chemical reactions, and biodegradation of analytes. Compendium Method TO-15 states that most VOCs can be recovered from canisters near their original concentrations after storage times of up to 30 d; thus, the period between collection and analysis of canister samples will never exceed 30 d.

2.3.1.5 Amines

The chromatographic separation of individual amines in collected air samples is achieved using a column packed with cation-exchange resin, as described in SOP V5. The amines, which are protonated in the acidic trapping solution, display varying affinity for the resin, and are therefore separated as the mobile phase moves through the column. The column that is used, the Dionex IonPac® CS17, is a hydrophilic, carboxylate-functionalized cation exchanger that is specifically designed for analysis of amines. The overall Ion Chromatography (IC) system (Dionex Corporation, Sunnyvale, CA) consists of a Model AS40 autosampler, Model GP50 gradient pump, Model CD25 conductivity detector, Model LC20 column enclosure, IonPac® CS17 cation exchange column, IonPac® CG17 guard column, Cation Self-Regenerating Suppressor (CSRS®

ULTRA), and Cation Trap Column (4-mm CTC-1). The mobile phase consists of a mildly acidic (dilute methanesulfonic acid) solvent/water mix. Temperature control of the column is included to improve reproducibility of retention time. Detection is based on conductivity increases monitored in the mobile phase as the individual amines elute from the column. This method is adapted from USEPA's CTM-027 ("Procedure for Collection and Analysis of Ammonia in Stationary Sources"), with modifications based on Dionex product-application literature. Amines samples will be analyzed within 30 d of their collection. SOPs V3 and V5 include provisions for assessing if the bubbler trapping system has become saturated (i.e. if the concentrations of analytes are the same in each of the two sequential trapping bubblers). If this occurs, the sample must be collected again, with a reduced sampling volume.

2.3.1.6 Carbon Dioxide

Concentrations of CO_2 will be measured at some sites using 10,000-ppm (1%) or 5,000-ppm (0.5%) photoacoustic infrared CO_2 analyzers (Model 3600, Mine Safety Appliances, Co., Pittsburgh, PA). The sensor utilizes dual frequency photoacoustic infrared absorption and is corrected for water vapor content. This instrumentation is discussed in SOP G3. However, since this instrument is no longer in production, sufficient quantities are not available for all NAEMS sites. Thus, CO_2 levels at all other sites will be determined using the INNOVA Model 1412 Multi-gas Monitor (Section 2.3.1.1 & SOP G7).

2.3.1.7 Gas Cylinder Compositional Verification

Fourier Transform Infrared (FTIR) spectroscopic methods will be used to analyze the concentrations of certified standard gases in cylinders purchased from outside vendors, and to ensure that the gas cylinders that are used for calibrations and/or performance checks of gas analyzers and other analytical instruments contain gases at their stated concentrations. The FTIR gas spectrometer (Nexus 670, Thermo Electron Corporation, Palatine, IL) consists of a KBr beamsplitter, a mercury cadmium telluride High D* (MCT-High D*) detector (cooled with liquid nitrogen), an IR source, a heated stainless steel gas absorption cell, an electronic package, and a computer. The sample gas can be delivered to the gas absorption cell either directly from the gas cylinder (continuous purge mode), or from a sample bag to the vacuumed gas cell (batch mode). The latter is used if the gas cylinder is not available onsite with the FTIR, but must be used judiciously, as data exists to show that Tedlar sample bags do allow substantial losses of certain gases (e.g. ammonia), even after short periods of time. Using OMNIC QuantPad software (Thermo Nicolet Instrument Corporation, Madison, WI), quantitative analysis methods can be created which allow analysis of spectra from gas- or condensed-phase samples using the Classical Least-Squares (CLS) quantitative analysis algorithms. FTIR methodology, discussed in detail in SOP G12, is taken from USEPA Test Method 320 ("Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy").

2.3.1.8 Manure Characterization

Several manure parameters that are known to influence emissions, particularly emissions of NH_3 and H_2S, will be determined. Manure pH will be determined (SOP M2) in accordance with USEPA Method 9040C, “pH Electrometric Measurement” (USEPA 2004), which is suitable for aqueous wastes and those multiphase wastes (including manures) where the aqueous phase constitutes at least 20% of the total volume of the waste. Any dried manure samples that consist of <20% water will be equilibrated with water (SOP M2) for 30 min, at which point the pH of the resultant slurry will be taken. The content of total and volatile solids in manure samples will be measured (SOP M3) using USEPA Method 1684 (2001 Draft version), which includes a drying step at 103ºC to 105ºC to drive off all of the water in the sample. This step allows for the determination of total solids. Following cooling, the total-solids portion of the sample is heated to 550ºC, in a step that causes the volatile solids to be released. Total N and NH_3 contents of manures are determined using micro-Kjeldahl techniques, as described in SOP M4 and SOP M5, respectively. The digestion methodology described in these SOPs is taken from USEPA Method 1687 (2001 Draft version), and the distillation and titrimetric analysis are taken from USEPA Method 351.3 (USEPA 1974).

2.3.2 Analytical Failures

Individual site PIs will be responsible for the operation of the gas analyzers, and for addressing and documenting analytical failures. In general, when failure of a gas analyzer occurs, the problem must be corrected as soon as possible, but the data captured (if any) by the improperly-operating instrument cannot be recaptured, and must be flagged as lost or invalid. Analyses of VOCs and amines will be conducted at PAAQL; thus, documentation and troubleshooting will be the responsibility of PAAQL personnel (specifically, Dr. Changhe Xiao, who will serve as VOC Manager for NAEMS). When an individual analysis of amines (collected in bubblers) or canister-sampled VOCs fails, these samples can be re-run after the problem is corrected; thus, they can still result in valid data. However, samples of VOCs from sorbent tubes are destroyed in the analytical process – as such, if an analysis of one of these samples fails, that sample is lost. Unless a duplicate sample was taken at this location and time (as is done with a minimum of 10% as a QA/QC measure, as described in SOP V1), no valid data can be obtained from this sample. Manure characterization will be conducted by a subcontracted commercial laboratory (Midwest Laboratories, Omaha, NE); the staff at this laboratory will document and address all analytical failures. In general, sufficient manure sample should be available that re-analysis is possible after addressing the cause(s) of analytical failure.

2.3.3. Sample Disposal

The exhaust streams of the gas analyzer chambers (consisting of any sampled gas that remains at the conclusion of the analysis) will be conveyed through flexible tubing to an exhaust port which is part of the air exhaust system of the OFIS. In the cases of most of the analyzers, the exhaust contains only sample, and is therefore identical in composition to the air at the sampling point (i.e. in the barn); however, in the case of the TEI Model 17C, the exhaust does contain significant concentrations of ozone. As discussed in SOP G4, incorrect plumbing between the analyzer and the OFIS exhaust port could lead to elevated ozone levels in the trailer, causing a potentially significant safety hazard.

VOC samples collected on sorbent tubes are destructively analyzed, so disposal of these is not an issue. Liquid waste from the bubblers used for amine sampling will be disposed of through the Purdue University Department of Radiological and Environmental Monitoring, which is charged with disposal of chemical wastes under the guidance of the Purdue University Chemical Hygiene Plan.

Manure samples will be autoclaved or otherwise sterilized prior to disposal, which will be the responsibility of Midwest Laboratories.

2.4 Quality Control Requirements

Quality assurance and quality control measures will be performed throughout the sampling, measurement, and data processing procedures. These include real-time monitoring of the entire measurement system, review of measurement data and test notes in a timely manner, and quality control of specific equipment. This last element includes periodic calibration or precision checks using certified calibration gases with known concentrations, and proper maintenance of the instruments (Section 2.5). The QA/QC also includes the use of properly maintained and reliable instrumentation, approved analytical methodologies and standard operating procedures, external data validation, well-trained analysts, audits, and documentation.

2.4.1. QC Procedures

QC activities are used to ensure that measurement uncertainty is maintained within acceptance criteria for the attainment of the DQIs. All necessary regularly-scheduled QA/QC activities for a particular site will be contained in a “Site Maintenance/Calibration Schedule” spreadsheet that will be developed by PAAQL personnel and provided to each site. This spreadsheet will then serve as documentation that the QA/QC activities have been performed. Site personnel will initial and date the appropriate box on the spreadsheet whenever an activity is completed. The spreadsheet is printed out and posted on the wall of the OFIS or maintained electronically.

2.4.1.1 Calibration

Calibration is the comparison of a measurement standard or instrument with another standard or instrument to report, or eliminate by adjustment, any variation (deviation) in the accuracy of the item being compared. The purpose of calibration is to minimize bias. Calibration requirements and procedures for the critical field, laboratory equipment and other sensors are discussed in detail in Section 2.6 of this QAPP, and in the various SOPs referenced in Section 2.6.

2.4.1.2 Bias Checks

In this section, we used the equations presented in the CFR Title 40, Part 58, Appendix A, Section 5. (Quality Assurance Requirements for State and Local Air Monitoring Stations (SLAMS)). Four different types of precision checks will be used in this project:

1. Certified calibration gases as known standard to check the responses of gas analyzers. All atmospheric gaseous measurements will be traceable to dual-analyzed and certified standards. The certified gas standards will be traceable to NIST, and are described in Section 2.6.
2. Precision check standards that will be used with analyses of VOCs (by GC/MS and IC) and manure and other solid and liquid samples for N and NH_3 contents. The former of these will be prepared using chemical stocks that are the highest commercially-available grades. The latter (standards for manure N content, pH, and solids content) will be NIST-traceable. Details of these standards are provided in the individual SOPs.
3. Check of accuracy using the sampler flow rate check (for TSP, PM_{10}, and $PM_{2.5}$)
4. Collocated sampler reference methods (for $PM_{2.5}$).

<u>Bias of Gases and Accuracy of PM Samplers (TEOMs) Using Flow Rate</u>

For each precision check of a gas analyzer using calibration gas(es) of known concentration or PM sampler (TEOMs) using a standard flow rate, the percent relative bias (or accuracy in the case of PM samplers) d_i is calculated with equation 2.1:

$$d_i = \frac{Y_i - X_i}{X_i} \times 100\% \qquad (2.1)$$

Where:

X_i = True value of the parameter (certified gas concentration or standard flow rate)

Y_i = Reported value of the parameter (gas concentration or flow rate measured by the primary instrument, which is that used to officially report the data for the site)

The average (D) of several biases can be obtained using equation 2.2.:

$$D = \frac{1}{k}\sum_{j=1}^{k} d_j \qquad 2.2$$

To obtain the weighed average of averages when each individual average is the average of different number of percent differences (bias) use equation 2.3:

$$D = \frac{n_1 d_1 + n_2 d_2 + ... + n_k d_k}{n_1 + n_2 + ... + n_k} \qquad 2.3$$

Where n_k represent the number of averages used to obtain d_k.

For gas analyzers, the true values of the parameter are the concentration of certified calibration gases.

2.4.1.3 Precision Checks

Precision is defined as the measure of mutual agreement among individual measurements of the same property, usually under prescribed similar conditions. To meet the data quality objectives for precision, it is necessary to ensure that the entire measurement process is within statistical control.

Precision is calculated using the following methods:
- Response check at certified concentrations (for gas analyzes)
- Collocated samplers (for TEOMs used to measure TSP, PM_{10} and $PM_{2.5}$).

Gas Measurement Precision

To calculate the precision using precision checks (called audits in the CFR), we need to calculate the percent difference (di) for each precision check using equation 2.1. Then we calculate the standard deviation using equations 2.4, 2.5, or 2.6:

$$S_j = \sqrt{\left(\frac{1}{n-1}\left[\sum_{j=1}^{n} d_i^2 - \frac{1}{n}\left(\sum_{i=1}^{n} d_i^2\right)^2\right]\right)} \qquad 2.4$$

$$S_a = \sqrt{\left(\frac{1}{k}\sum_{j=1}^{k} S_j^2\right)} \qquad 2.5$$

$$S_a = \sqrt{\left(\frac{(n_1-1)S_1^2 + (n_2-1)S_2^2 + ... + (n_k-1)S_k^2}{n_1 + n_2 + ... + n_k - k}\right)} \qquad 2.6$$

Equation 2.4 is used for a single analyzer. Equation 2.5 is used to obtain the average standard deviation (S_a) when the S_j values were obtained using the same number of individual precision checks. This equation can be used to obtain the quarter or annual average S_a for an analyzer using the individual or quarter standard deviations. Equation 2.6 is used to obtain a weighed S_a when different number of precision checks were used to calculate each S_j.

For each pollutant, the 95 Percent Probability Limits for the precision of an instrument are calculated using equations 2.7 and 2.8:

Upper 95 Percent Probability Limit = $D+1.96S_a$ 2.7

Lower 95 Percent Probability Limit = $D-1.96S_a$ 2.8

To calculate the average of averages (D) use equation 2.2.

PM Measurement Precision

For manual methods, the precision for each set of collocated PM samplers when the collocated instrument is not an FRM (for example, when two TEOMs are collocated to measure TSP, PM_{10}, or $PM_{2.5}$), the percent relative difference d_i is calculated with equation 2.9 (Section 5.5.2 of 40CFR58, App. A):

$$d_i = \frac{Y_i - X_i}{\left(Y_i + X_i\right)/2} \times 100\% \qquad 2.9$$

Where:

X_i = Value recorded by the collocated sampler (the sampler used as reference)

Y_i = Value recorded by the primary sampler (the sampler used to report data for the site)

The coefficient of variation (*CV*), for a single check is calculated by EPA by dividing the absolute value of the percent relative bias, d_i, by the square root of two:

$$CV_i = \frac{\left|d_i\right|}{\sqrt{2}} \qquad 2.10$$

Precision of a single instrument, *j*, during the quarterly, *q*, is calculated with:

$$CV_{j,q} = \sqrt{\frac{\sum_{i=1}^{n_j} CV_i^2}{n_{j,q}}} \qquad 2.11$$

Where:

$CV_{i,q}$ = Precision of a single instrument at a quarterly basis

$n_{i,q}$ = Number of precision checks

The 90 percent confidence limits for the single instrument’s CV are calculated with:

$$Lower\ \ Confidence\ \ Limit = CV_{j,q}\sqrt{\frac{n_{j,q}}{\chi^2_{0.95,n_{j,q}}}} \qquad (2.12)$$

$$Upper\ \ Confidence\ \ Limit = CV_{j,q}\sqrt{\frac{n_{j,q}}{\chi^2_{0.05,n_{j,q}}}} \qquad (2.13)$$

Where,

$\chi^2_{0.05,df}$ = The 0.05 quantiles of the chi-square (χ^2)

$\chi^2_{0.95,df}$ = The 0.95 quantiles of the chi-square (χ^2)

2.4.1.4 Corrective Actions and Interpolation of Data Points

Correction actions that will be taken for any instrument if the quality control checks fail are described in detail in Section 2.6 of this QAPP. The procedure for interpolating data in between sampling points is given in SOP B4; for the purposes of the NAEMS, the maximum interval that interpolation will be applied to is 300 min. SOP B4 similarly states the procedure for correcting data taken between a passed precision check and one that is out of the control limits.

2.4.1.5 Control Charts

Control charts will be used extensively. They provide a graphical means of determining whether various phases of the measurement process are in statistical control. Control charts are described in SOP Q1. Control limits will be set for each measured parameter that is being tracked with control charts; values outside these limits will trigger corrective action.

2.4.2. Real-time Measurement Checks

Measurement limits (MQOs) defined in the data quality objectives for each individual variable (Section 1.4) will be used for monitoring and reviewing the continuously measured data.

2.4.2.1 Visual Alarms and Remote System Check

All of the continuous measurement variables will be displayed real-time by the AirDAC software (SOP B2) in the on-site computer. Pre-set minimum and maximum ranges for individual variables will be checked by AirDAC at every data point (i.e. every second). If the measured variable exceeds the pre-set limits, a visual alarm will be displayed indicating the name of the variable, its current value, and its pre-set range.

Two hours of historical data will also be displayed in graphical form on the site computer for all measurement and control variables. Abnormal measurements will be easily identified in the history display. For example, signals from disconnected or unresponsive sensors will be displayed as a flat line.

Alarms and history graphs will allow quick identification of any problems with the instruments or the data-acquisition hardware and help to fix them. See SOP B2 for further details.

Research personnel, both local and at PAAQL, will check the on-line display via high-speed internet at least once daily, particularly on days when local site personnel do not visit the site.

2.4.2.2 Email Alarms

AirDAC allows configuring whether an alarm email should be sent for each individual out-of-range variable, and whether the sampling location at which the out-of-range variable was encountered should be indicated when this alarm occurs. AirDAC will be configured such that emails will be sent to notify the responsible site personnel whenever an out-of-range measurement is detected for the selected variables, so that instrumentation problems can be promptly addressed. At minimum, all instruments involved in the collection of Category 1 data (as defined in Table 1.4.1.) will be included in the alarm list. A second email message will be sent when the problem is resolved, and the measurement is again within the acceptable range for the particular instrument.

2.4.3. Quality Control Measures for Specific Equipment and Procedures

1. Measurements of certified zero air will be included as field blanks for all gas analyzers. Precision checks of gas analyzers, using both zero air and a span gas, will be conducted at least weekly. More frequent precision checks will be applied to newly-installed analyzers to monitor their stability. There are usually two different causes for “out of tolerance” zero or span responses. One is sudden failure of the instrument, and another is the normal drift of the instrument sensitivity. Data will be invalidated for instrument failures. Data will be flagged going back to the last good precision (z/s) check, but can be corrected to compensate the drift by using z/s check results during data processing, if it has drifted steadily in one direction. A replicated multipoint calibration of all gas analyzers will be performed at the analyzer’s initial setup at the site, and will be repeated whenever the precision checks for any individual analyzer are beyond the acceptable limits. Calibration records will be maintained in the project log book and electronic field notes. Further details on the multipoint calibration procedure are given in SOP G8, and details about the precision checks of gas analyzers are given in SOP G9. If the analyzer’s response to the calibration gases is beyond the adjustable range using the built-in adjustment feature and its responses to calibration gases are not consistent, the analyzer will be sent back to the manufacturer for repair. A spare unit will be provided by PAAQL, or by the manufacturer, to avoid interrupting the on-going measurement.

2. If possible, the compositions of gases in the gas cylinders that are used for calibration of the gas analyzers will be checked using Fourier Transform Infrared (FTIR) spectroscopy, in accordance with SOP G12. At minimum, all gases that are suitable for IR quantitation that are sent to each site at the beginning of the study will be checked with FTIR, to verify their compositions and concentrations per the supplier’s certification. Later cylinders can then be checked on-site against these known cylinders using the individual gas analyzers. Procedures will be instituted (SOP G2) to ensure that sufficient gas remains in a given cylinder to conduct this comparison with its replacement, and that the existing cylinder is not replaced until one with suitable composition and concentration is received to take its place. If the gas concentrations obtained by the FTIR check are not within ±5% of those certified by the gas provider, the gas provider will be contacted for further verification or re-certification, if necessary.

3. Vane anemometers will be subjected to initial performance checks that will include checks of the starting torque and transducer output as a function of rotational speed. Each anemometer will be periodically spot-checked in the field and compared to factory-specified values. Further details are provided in SOP A3. If the anemometer’s performance does not meet the factory specifications, it will be repaired or replaced.

4. Proper operation of all fan stage monitoring equipment, anemometers, vibration sensors, current switches and rpm sensors will be visually verified once a week. Any abnormality will be addressed as soon as possible either by repair or replacement. Output from rpm sensors will be compared with that from an optical tachometer, if available.

5. Each FANS unit will be calibrated at the UIUC BESS Lab annually to ensure that it is functioning properly. If possible, a new (field) FANS measurement will be performed on any individual fan that has undergone any maintenance that is likely to significantly change its performance (such as installation of a new motor, cleaning, or belt tightening). Producers will be asked to keep belts tightened by using automatic belt tighteners on their fans, to minimize this last source of error.

6. Zero checks, and precision checks (based on the agreement of several collocated anemometers) will be performed on the ultrasonic anemometers that are used for naturally ventilated barns. Each of these is described in detail in SOP A6.

7. Thermocouples will be calibrated before and after the 24-month data collection period, and in-place spot-checks of each sensor (by comparison with a NIST-traceable temperature standard) will be conducted every six months (SOP E1). If the error of a thermocouple is >±2 °C, further checks will be performed on the thermocouple wire and the data acquisition hardware. Problematic thermocouples will be replaced. Non-working thermocouple channels in the analog data acquisition module will be replaced by reserved working channels.

8. Temperature and relative humidity probes will be tested with a NIST-traceable standard, as described in SOP E2. Probes that do not meet the criteria specified in SOP E2 will be replaced and repaired.

9. Calibrations of the differential pressure transmitters will be conducted before and after the study. Zero checks will be conducted monthly, and span checks against a reference standard (either a recently calibrated sensor, an inclined manometer, or a precision micromanometer) will be conducted quarterly. Alternatively, sensors (three or more) can be collocated to verify that they agree within this limit. See SOP A5 for further details. If the error of a transmitter is >±10 Pa, further checks will be performed on the transmitter. If the error cannot be corrected by adjusting the internal calibration potentiometers, the transmitter will be replaced and repaired.

10. All National Instruments FieldPoint analog input modules used for data acquisition will be manufacturer-calibrated and come with NIST-traceable calibration certificate to

ensure accurate, reliable analog measurements. The manufacturer's calibration is valid for two years after the manufacturing date. The channels on the modules will be checked with 0 VDC and 5 VDC after installation on-site to assure that no errors were introduced through the installation process (e.g. through improper grounding).

11. Data will be managed to avoid data from being lost. Details are provided in Section 2.9 of this QAPP, and SOP B5.

12. Site personnel will be trained to run all equipment (Section 1.5 of this QAPP).

13. Internal performance and system audits will be performed to evaluate the accuracy of field measurements of NH_3, H_2S and VOCs. The delivery of samples to the analysts in the field will be coordinated by the Project QA Manager on an announced single-blind basis (only QA Manager knows the concentration). The samples will be purchased from a reputable vendor, will be dual-analyzed and certified, and will, if possible, be checked with the FTIR. The samples will be delivered to an inlet of the sampling system, not directly into the analyzer. Acceptable ranges provided by the manufacturer of the samples will be used to determine if the measurement system is performing acceptably. If not within the accepted range, corrective action will be performed before further analysis continues.

14. Surge suppressors will be used to protect the PC and the instruments (SOP U1). An uninterruptible power supply with battery backup will be used to prevent damage to sensitive equipment and data loss in case of power failure (SOP U6).

15. All VOC sampling (sorbent tubes, canisters, and bubblers) will include suitable field, laboratory and trip blanks, as described in the respective SOPs (V1, V2 and V3). The number of blanks and the methods to prepare and handling them are based on USEPA methods. Pumps and mass flow meters used for collection of VOC samples (via the bubbler or sorbent-tube method) will be calibrated according to manufacturer's instruction, and flow rates will be noted at the beginning and end of each sampling time (at minimum). Pumps that do not hold the required flow rate (within 10%, as per SOPs V1 and V3) for the entire sampling time will be repaired and re-calibrated. Analyte concentrations will be calculated based on a sampling volume that represents the average flow rate during the sampling period.

16. GC/MS analyses will incorporate extensive QA/QC procedures, including: a) daily instrument performance checks, b) daily single-point (mid-range) calibration checks, c) full five-point calibrations initially and whenever significant maintenance is performed, d) periodic system precision checks, and e) initial demonstrations of each analyst's proficiency. Internal standards will be included in all samples and standards. Details on these QA/QC procedures are provided in SOP V4 and SOP V6.

2.5 Instrument/Equipment Testing, Inspection, and Maintenance

All analytical equipment will be properly maintained, and tested regularly to ensure proper function, following the manufacturer's recommended intervals and acceptance parameters. Equipment will be repaired as soon as possible upon discovery of a problem. Manufacturer's instructions for routine maintenance of equipment will be followed. All testing, inspection and maintenance activities will be documented in the field project log book or electronic field notes.

All instruments and equipment will be inspected for damage and tested before usage. The SOPs and manuals for the instruments and equipment give procedures on inspecting and testing the specific equipment (including calibration and zero/span checks, and any other necessary checks). In general, the inspection procedure is as follows:

- Check the shipping container for damage.
- Remove the instrument with extra care from the shipping container and set on a table or bench that allows easy access to the front, rear, and sides of the instrument/equipment.
- Check the outside of the instrument for any damage.
- Remove the instrument cover to expose the internal components and visually check for possible damage during shipment. (Remember when working with electronic components the operator must be grounded)
- Check that all connectors and printed circuit boards are firmly attached.
- Check all wiring for damage.
- Check for missing parts
- Check that there are no useful parts remaining in the interior of the box.
- Do not discard the box until the instrument has been verified totally. Keep the box in case the instrument needs to be returned.
- Do not install or operate the instrument if damage is suspected.
- If damage has occurred, document the damage in the field notes and take photographs of the damage. Contact PAAQL, site PI, and the carrier about the damage.
- Install the unit in a dry and secure place

The instruments and equipment will be tested, either at PAAQL or by the site PI, prior to usage to ensure good working condition. This applies to all newly-purchased equipment, and to pre-existing equipment used in the NAEMS. The gas analyzers will be calibrated and tested with precision checks according to procedures in SOPs G8 and G9. Any other analyzer-specific tests are described in the analyzers' respective SOPs. All instruments, equipment, and gases for which certifications are provided by the manufacturer or supplier will have the certifications on file at PAAQL and in the OFIS at the site at which they are being used. Any instrument or piece of equipment that needs recalibration and certification will be shipped back to the manufacturer for the certification. Table 2.5.1 lists the acceptance criteria of the instruments and equipment (both new and used) when initially tested at PAAQL before being sent to the field site for use in the NAEMS. All inspections listed in Table 2.5.1 will be documented in the electronic field notes.

Table 2.5.1. Acceptance criteria of the instruments and equipment.

Equipment to be Tested	SOP	Parameter	Acceptance Criteria
GSS			
Pumps	G1	Flow rate	10 L/min
Solenoids		Switching	Pass / fail
Mass flow meter		Flow rate	0 -10 L/min
RH/T		Temperature	-10-40°C
RH/T		RH	20 to 95% RH
Pressure meter		Pressure	±5 psi
Leak test		Flow rate	<60 mL/min @ -6000 Pa
Temperature		Temperature	30-60°C
TEOMs (TSP, PM_{10}, $PM_{2.5}$)			
Flow rate standards	P1	Accuracy	±2% of full scale @ 20 L/min
$PM_{2.5}$ Partisol			
Flow rate standards	P3	Accuracy	±2% of full scale @ 20 L/min
Temperature standard		Resolution & accuracy	±0.1°C (res); ±0.5°C (acc)
Pressure standard		Resolution & accuracy	±1 mm Hg (res); ±5 mm Hg (acc)
Beta Gauge			
Flow rate standards	P4	Accuracy	±2% of full scale @ 20 L/min
RH/T Sensor	E2	Range	-40-120°C & 20-95% RH
Activity Sensor	S3	Signal	Pass / fail
Vibration Sensors	A7	Signal	Pass / fail
Wind Anemometer & Vane			
Wind speed	E4	Range	0-25 m/s
Wind direction		Range	0-355°
Solar Sensor	E3	W/m^2	0-1300 W/m2
Ultrasonic Anemometer			
Zero	A6	Velocity	<0.4 m/s (all 3 dimensions)
Drift		Precision	SD of collocated sensors <0.1 m/s
DAQ System			
Transformers	B1	24 VDC & 5 VDC	Pass / fail
Fieldpoint modules	B1	Signal	Pass / fail
AirDAC (Software)	B2	Signal processing	Pass / fail
TEC 450I			
Analog output	G5	Signal	0-10 VDC or 4-20 mA
Calibration (zero air, SO_2, H_2S)		AirDAC reading (ppm)	Pass / fail
Linearity		RSD	±5%
Precision		R^2	>98%
Response times (to H_2S)		t(95%)	<180 s
Response times (Downfall)		t(95%)	<120 s
MSA 3600 CO_2 MONITOR			
Analog output	G3	Signal	0-10 VDC or 4-20 mA
Calibration (zero air, CO_2)		AirDAC reading (ppm)	Pass / fail
Linearity		RSD	±5%
Precision		R^2	>98%
MSA 3600 CO_2 MONITOR			
Response times (to CO_2)	G3	t(95%)	<100 s
Response times (Downfall)		t(95%)	<100 s

Table 2.5.1. Acceptance criteria of the instruments and equipment (continued).

Equipment to be Tested	SOP	Parameter	Acceptance Criteria
INNOVA 1412			
Linearity	G7	RSD	±5%
Precision		R^2	>98%
Response times (all tested gases)		t(95%)	<300 s
Response times (Downfall)		t(95%)	<120 s
Environics Diluter			
Calibrate MFCs	G11	Flow	100-110% of full rated flow
FTIR			
Power supply	G12	Function	Pass/fail of standard diagnostic tests.
HeNe laser			
Light source			
Electronics			
Beamsplitter and detector			
Desiccant		Condition	Pass/fail “check desiccant” test
Detector signal		Intensity	Comparison with usual level
Filter prior to FTIR		Condition	Visually clean
GC/MS			
Injection port inertness and column performance (SPCCs)	V4 & V6	Peak geometry	Normal peak area or height response, no peak tailing
Response Factors (RF) of SPCCs		RF (peak area vs. concentration)	RF ≥ 0.05
Spectrum of PFTBA		*m/z* ratios	See ion profile criteria in SOP V6
Sorbent Tubes			
Cleanliness & conditioning	V1	Concentration of target analytes in zero air	<0.2 ppbv for all analytes
Recovery		% Recovery	90 - 110% for all analytes
Canisters			
Cleanliness of canisters & sampling train	V7	Concentration of target analytes in zero air	<0.2 ppbv for all analytes
Recovery		% Recovery	90 - 110% for all analytes
Sampling train leak test		Pressure stability	Stable for 1 - 2 min
Canister leak test		Pressure stability	Pressure (60.8 in Hg) remains ± 4.08 in Hg for 24 h
Canister pressure check		Pressure	(0.002 in Hg
Critical orifice & flow controller		Flow rate	2-4 sccm
Analyte stability		Analyte recovery after 5d, 10d, 20d, & 30d	Recovery remains ≥80%
Pressure gauge		Reading	0

The various instruments and equipment will be inspected on a regular basis after they are deployed to the field, to ensure that all components remain in proper working order throughout the course of the study. The site PIs and their personnel are responsible for the testing, inspection, and maintenance of the instruments, equipment, and OFIS. The schedule for inspecting the various pieces of equipment, the parameters that must be checked, and how to appropriately document the inspection are provided in Table 2.5.2.

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS.

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
Thermocouples	E1	Daily	Signal (-20 to 40°C)	Locate & fix problem, then recalibrate as necessary	Field notes
RH/T Probe	E2		Signal (20-95% RH) (-20-40°C)		
Wind Anemometer & Vane	E4		Signal (0-25 m/s) (0-360°)		
Solar Sensor	E3		Signal (0-1300 W/m^2)		
Roof-Mounted Weather Station	E5	Quarterly	Damage	Repair damage	
TEC 4501	G5	Daily	Signal & Analyzer Alarms	Check connection; Address alarms, PC; MPC	
Pressure		At every calibration & precision check	400-1000 mm Hg	Check for blockage	
Sample flow			0.35-1.4 L/min	Check pump	
Frequency			10-50 KHz	Replace lamp	
Lamp voltage			500-1200 V	Adjust into normal operating range	
MSA 3600 CO_2 Monitor	G3	Daily	Signal	Check connection & flow; PC; MPC	
INNOVA 1412	G7	Daily	Signal & Analyzer messages	Address Error message; Reset analyzer; PC; MPC	
Environics Diluter	G11	At every Calibration & precision check	Communication to computer; Delivery of gas to the GSS	Check connection & flow; Ensure cylinders are connected correctly & open	

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
TEOMs (TSP, PM$_{10}$, PM$_{2.5}$)	P1	Daily	Signal	Check connection & flow	Field notes
Filters			Particulate loading	Change filter at 70% loading (Maximum)	
Pump			Signal, L/min	Check connection & flow; Precision check; Calibration	
PM$_{2.5}$ PARTISOL	P3	Every site visit	Signal	Check connection & flow	
Cassette & rubber seals		Daily	Clean/inspect cassette & rubber seals	Clean & replace as necessary	
Inlet water jar			Water	Drain	
Pump			L/min	Repair and retest	
Perform a leak test		Monthly & every 5 samples	Flow	Find & fix leak; repeat leak test	
O-rings, gaskets and seals	P3	Monthly	Dust, deterioration, damage	Clean or replace as necessary	
Sampler clock time			Correct time	Correct	
Single-point flow check			Flow	Locate problem, repair & retest	
Temp. & pressure sensors			Check Temperature & Pressure	Locate problem, repair or replace, & retest	
Sampler interior & inlet		Every 6 Months	Verify as-is condition of sampler interior, inlet	Clean, locate problem, repair & retest	
WINS impactor & leak test			WINS impactor & leak test	Locate problem, repair & retest	
Main computer board battery			Check	Replace	

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
Beta Gauge	P4	Daily	Signal	Check connection, flow, fix the problem	Field notes
Activity Sensors	S3		Signal	Locate problem and repair or replace	
Vibration Sensors	A7				
Pressure Sensors	A5				
GSS	G1				
Filters			Sample pressure drop ≤ -8000 Pa	Replace filter in barn; Replace filter in OFIS; Check sample line for damage & blockage	
Sampling pump			Signal (Flow 3-8 L/min)	Locate problem and repair or replace	
Pressure sensor			Pressure (Pa) (±5 psi)		
Mass flow meter			Flow rate (L/min)		
Humidity / temperature sensor			Signal (20-90% RH) (-20-40°C)		
Fan			GSS Temperature		
Solenoids			Signal; Sample flow; Pressure		
Bypass pump		Weekly	Is the pump on?		
ULTRASONIC ANEMOMETERS	A6	Daily	Signal, flow rate		
OFIS					
Shelter structure	U1	Daily	Check for damage	Locate damage and repair	Field notes
AirDAC hardware	B1		Computer & Fieldpoint modules, transformers		
FieldPoint modules			Signal		
Computer			Power on?		
E-mail data			Check list of outgoing emails & verify that the data has been received.		

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
OFIS					Field notes
HVAC	U1	Daily	Temperature ≥ barn dew point?	Locate damage and repair	
Heated raceway	U3		Signal (T)	Locate problem and repair or replace	
OFIS filters	U1	Weekly	Clogging of filter with dust	Clean	
AC filters					
Carbon filter (air recirc.)		Monthly		Replace	
Surge protected power strip		Monthly	Plugged in? Are instruments plugged into the surge protectors?	Locate problem and repair or replace	
UPS	U6		Instruments plugged in (via surge protectors)? Test battery		
Site Inspection					
Tubing & wiring	U2	Daily	Signal, Pressure drop, Flow rate change	Locate problem and repair or replace	
Tubing	U2	Weekly	Damage to tubing		
Fans			Is the fan on? Check AirDAC for fan or sensor signal	Inform the farm of the problem to get it fixed	
Fan motors			Power to fan		
Belt			Broken belt		
Fan housing			Damage to fan housing		
Shutters			Shutters undamaged & functional		
Curtains			Holes in the curtain; Is the curtain closed properly?		
Water			Leaking and/or wet spots in pit		

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
FTIR Spectrometer	G12	Daily (every 4 h if continuous sampling)	Background spectrum	Check cell temperature, pressure and alignment. Correct problem and take a new background	Field notes
Purge gas flow rate		Daily	Flow rate	Set at 30 scfh.	
Detector signal			Signal intensity	Add enough liquid N_2 to cool detector, realign	
Leak check			Pressure ratio change ≤4%	Check tubing connections, fix and retest	
Span gas concentrations		Monthly	Span gas concentrations	Check connection & flow; check detector signal, and recalibrate	
Filter prior to FTIR			Visual	Replace filter	
Gas absorption cell		Yearly	Compare detector signal before and after removing gas absorption cell	Ship to factory for cleaning & realignment	
VOC Sampling Equipment					
Sample sorbent tubes	V1	Every sampling event	Flow rate	Recalibrate/ repair pump/ MFM	Field notes, sorbent tube log
Sample sorbent tubes			Contaminants in chromatogram	Recondition tube & retest	
Canisters	V2	Every sampling event	Initial pressure (≤ 0.05 in Hg)	Do not use canister; Return to lab for testing & repair	
Mass flow controller			Constant flow (±10% for 24 h)	Return sampling train to lab for repair, cleaning or replacement of the orifice	
Canisters			Final pressure (7 in Hg)	Invalidate sample if > ±10% off	Field notes, canister log

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
VOC Sampling Equipment (cont.)					
Canister & sampling train certification	V7	Every time the canisters & sampling train are prepared for a sampling event	Humidified zero air blanks <0.2 ppb_v for any of the target compounds; % recovery of target compounds between 90 % to 110%	Clean & retest	Field notes
Sampling train leak test			Pressure stable for 1 - 2 min	Check & tighten all connections; retest for leaks	
Canister leak test			Pressure (60.8 in Hg) remains within ± 4.08 in Hg for 24 h		
Canister (Pressure check)			Pressure (0.002 in Hg)	Locate leak & repair	
Critical orifice & flow controller			Flow rate (2-4 sccm)	Replace orifice	
Canisters - analyte stability	V3	Before first use of canister & after every 10th use	Concentration of any single target analyte does not decrease >20% over 5d, 10d, 20d, & 30d.	Reclean & retest; remove from service if fails twice.	
Bubblers		Every sampling event	Stable flow rate (1.0 L/min)	Check pump, repair, recalibrate	
Bubblers			Pressure (leak test) 10 in Hg	Fix leak, retest, or use different bubbler	
Bubblers			Blank (lab or field) must not have analyte > the MDL	Return to lab; clean & retest	

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
GC/MS					
Visual inspection	V4 & V6	Monthly	Condition (visual)	Locate problem; repair or replace parts	Lab notebook
MS Tuning		Daily	Peaks in tuning standards display proper m/z ratios; peak width at half peak height is correct to within 0.1 amu	Recalibrate and tune	
Column			Normal chromatogram (peak shape, sensitivity, retention time, etc.)	Trim 0.5 - 1 m from column front; Replace inlet liner & septum and clean inlet; Replace column	
Inlet septum			Condition (visual)	Replace	
Response Factors (RFs) of system performance check compounds (SPCCs)			RFs for SPCCs are ≥0.05	Clean injection port; Trim or recondition column; Replace column; Retest	
Single-point calibration			Daily RRF is within ±30% of mean RRF in most recent full calibration	Clean ion source; Change column; Clean injection port; Perform a full calibration	
Foreline Pump		Weekly	Oil level & pressure	Add or replace oil	
TDS leak test		After every servicing of the system	Total flow rate & pressure	Check for leak and fix; Check flow settings	
Laboratory & field blanks		Lab: Two per sampling event Field: Min. two per sampling event, plus one for every 10th canister	No target analyte present at > 3X MDL; No non- target compounds with RT and mass-spectral features that would interfere with analyses	Clean injection port; Clean ion source; Recondition, trim, or change column; Recalibrate	

Table 2.5.2. Inspection schedule for on-site and lab equipment for the NAEMS (cont.)

Item	SOP	Inspection Frequency	Inspection Parameter	Remedial Action	Documentation
GC/MS (cont.)					
System precision checks		Once every tenth batch of samples, or quarterly	Agreement between six calibration check standards	Clean injection port & ion source, change & condition column, check source for contamination; recalibrate	Lab notebook
lnlet gold or stainless steel seal		Every 6 months	Visual	Replace	
IC system					
Visual Inspection	V5	Monthly	Condition (visual)	Repair or replace parts	Lab notebook
Eluents		Daily	No bubbles	Degas eluents	
System pressure			Within range	Locate and clear blockage	
Chromatograph baseline			Low and stable	Check for air bubbles/leaks; Check CSRS & proportioning valve; Prime pump; Flush detector cell;	
Leak check			No leaks	Check lines, connections, valves & seals; Repair/replace	
Peak resolution		Daily	Good peak separation	Check for overloading; verify pH; Flush/replace column	
Internal standard			90 - 110% recovery	Check sample loop, column, CSRS, detector cell; Clean or replace	
Gradient Pump			Proper pressure & flow	Check for dirty, blocked, leaky, or defective piston seals, valves or inlet filters. Check/ re-prime pump; Verify pressure limits; Check fuse, pressure transducer	

The instruments and equipment will require regular maintenance for proper operation and valid data. To perform regular maintenance, a supply of consumables such as filters and calibration gases must be maintained in the OFIS. Spare parts are critical for continuous operation of the instruments and equipment. The critical spare parts and the locations where spare parts are to be stored (e.g. at PAAQL or at the field site) are given in the SOPs for instrumentation and equipment. Critical spare parts will be located in the OFIS. A complete list of spare or replacement parts is also provided in the instrument and equipment manuals. Copies of these manuals will be kept at each field site. All vendors of the instruments and equipment are available to order spare parts. Vendor phone numbers, websites, and addresses are listed in the instrument and equipment manuals; the most commonly used vendors (in most cases, the instrument suppliers themselves) are also listed at the end of each instrument SOP, in the "Contact Information" section. A maintenance and calibration schedule, which will include the tasks listed in Table 2.5.3, will be maintained in each OFIS, either in hard copy form on the wall or electronic form in the site PC. Site personnel will initial and date each entry on the schedule as certification that the tasks were completed in a timely manner.

Table 2.5.3. NAEMS maintenance schedule for instrumentation and equipment.

Item	SOP	Frequency	Task
RH/T Probe	E2	Weekly	Cleaning
Wind Anemometer & Vane	E4	Quarterly	Performance check
Solar Sensor	E3	Monthly	Cleaning
TEC 450I	G5	Monthly	Visual inspection
External dust filters on analyzer		Weekly	Clean
Lamp voltage			Check & replace as necessary
Exhaust tubing			Inspect & clean as necessary
Flow check		6 months	Leak test
MSA 3600 CO$_2$ Monitor	G3	Monthly	Visual inspection
Exhaust tubing		Weekly	Inspect & clean as necessary
Sample flow		6 months	Check
Exhaust flow			Check
Internal filter		Annually	Inspect & replace as necessary
INNOVA 1412			
Ventilation filter on analyzer	G7	Monthly	Inspect & clean as necessary
Stainless steel frit			Clean
External dust filter			Clean/Replace
Leak test (sample inlet & outlet)			Test inlet and exhaust flow
Leak test (analyzer manifold)		6 months	
Environics Diluter	G11	Monthly	Visual inspection
Flow calibration		Annually	Check MFC flow
TEOMs (TSP, PM$_{10}$, PM$_{2.5}$)	P1	Monthly	Visual inspection
Screens		Every site visit	Clean
Inlet head		Weekly	Clean
Filters		+50% loading	Replace
Stored data		Monthly	Download
Flow rate verification		60 days	Verification
Leak test		60 days	Check
Air inlet system		60 days	Clean
In-line filters		6 months	Change
Analog board		6 months	Recalibrate

Table 2.5.3. NAEMS maintenance schedule for instruments and equipment (continued)

Item	SOP	Frequency	Task
TEOMs (cont.)			
MFM & MFC	P1	Annually	Audit MFM, calibrate MFC
Pump		Every 10,000 hours	Rebuild
PM$_{2.5}$ Partisol	P3	Monthly	Visual inspection
WINS impactor well		Every 5 samples	Service
Air intake filter and fan		Monthly	Clean
Interior of sampler		Monthly	Clean
PM$_{10}$ inlet, downtube, WINS		Every 14 samples	Disassemble and clean
Large in-line filter		Every 6 months	Replace
Pump		Every 10,000 hours	Rebuild
Beta Gauge			
Inlet head	P4	Biweekly	Check/clean
Visual inspection		Monthly	
Inlet			Clean
Filter tape			Check & replace as necessary
Airflow		Quarterly	Check
Temp & barometric pressure			Check
Pump		Every 10,000 hours	Rebuild
Activity Sensors	S3	Monthly	Check alignment, clean as needed
Vibration and/or rpm sensors	A7/A11	Weekly	Compare to fan status & stage signals
GSS	G1	Monthly	Visual inspection
Filters			Check, replace every 6 months or as necessary
Leak check		Bimonthly	
Bag Test (NH$_3$)		Every 6 months	
Sample & bypass pumps		Every 10,000 hours	Rebuild
Exhaust & manifold pressures		Annually	Verify
Pressure sensor & MFM			Calibrate
Ultrasonic Anemometer	A6	As needed	Clean
OFIS HVAC	U1	Weekly	Check OFIS and AC filters, clean as needed
OFIS Computer	B5	Monthly	Backup all data files
OFIS Power (UPS)	U6	Weekly	Self-test
FTIR Spectrometer	G12	Monthly	Visual Inspection
Detector signal		Daily	Check
Purge gas flow			
Filter prior to FTIR		Monthly	Replace
Desiccant	Manual	Every 6 months	Check
Power supply		Whenever system is not performing properly	Run diagnostic tests
HeNe laser			
Light source			
Electronics			
Beam splitter and detector			
Gas absorption cell	G12	As needed/annually	Clean and realign
IC System	V5	Monthly	Visual inspection
Piston seals (salt buildup)		Daily	Rinse before and after use
Vacuum degas assembly			Thoroughly flush with deionized water
Cation Trap Column			Flush at end of day
Seals (primary and rinse seals)		Every 6 months	Replace in each pump head

Table 2.5.3. NAEMS maintenance schedule for instruments and equipment (continued)

Item	SOP	Frequency	Task
Mass Spectrometer	V4 & V6	Monthly	Visual inspection
Mass Spectral Detector (MSD)		Daily	Tune
		As needed	Lubricate side plate or vent valve O-rings; Replace filaments & electron multiplier horn
Ion source		As needed	Clean
Pump	Manual	First oil change	Tighten foreline pump oil box screws
		Every 3 months	CI MSD using ammonia reagent gas
		Every 6 months	Replace the pump oil
Gas Chromatograph	V4 & V6	Monthly	Visual Inspection
Inlet liner		Weekly	Check liner; replace as needed
Liner O-rings		Monthly	Replace if worn
Syringe needle or syringe		Every 3 months	Clean or replace
Inlet hardware		Every 6 months	Check for leaks and clean
Split vent trap		Every 6 months	Replace
Gas purifiers		Every 6-12 months	
GC hardware		Annually	Replace worn, scratched or broken parts
Flowmeter		Every 2 years	Recalibrate
Ferrules		When changing or trimming the column	Replace

2.6 Instrument/Equipment Calibration and Frequency

Multipoint calibration of the gas analyzers will be conducted according to Table 2.6.1, using the Environics Series 4040 Computerized Gas Dilution System (SOP G11) with a certified calibration gas and zero air (SOP G8). Each instrument will have an associated quality control spreadsheet that records its calibrations, precision (zero/span) checks, calibration curves, and maintenance history (SOP's G8, G9, & Q1). Accuracy and precision of the analyzers will be determined from these measurements. The concentrations selected for the multipoint calibrations will be 30, 60, and 90% of the analyzer range.

Routine zero/span checks (precision checks) (SOP G9) will be conducted according to Table 2.6.1 by introducing a certified calibration gas, the concentration of which is approximately 70% of the maximum measured gas concentrations, into the in-barn sampling port. Using this method, the calibration gas will flow through the same plumbing that the samples flow through to the analyzers in the OFIS. Any analyzer that fails the precision check (i.e. is outside the 10% control limits) must be subjected to corrective action, followed by a new multi-point calibration and a repeat of the precision check.

Control charts (SOP Q1) will monitor the zero and span drift performance of each analyzer. The control chart is used as a quality assurance tool to assess data quality, measurement variability, and to evaluate long term trends in the performances of instrument/equipment. Control charts provide a graphical presentation of the zero/span responses over time, which can be applied to gas analyzers and to other measurement devices. Control charts maintain data quality by using control limits (upper and lower limits). If the drifts become excessive and fall outside the control limits, a corrective action must be taken to maintain data quality.

Bag tests will also be conducted to assess the performance of the entire system with respect to precision and response (equilibration) time, and as a check for problems (leaks, obstructions, etc) with the sampling lines themselves. Because NH_3 is the worst-case analyte in terms of loss in sampling systems, this method will be conducted with NH_3. Fifty-Liter Tedlar bags will be filled with NH_3 at a concentration that is similar in magnitude to concentrations being measured in the barn, yet different enough that the two sources can be distinguished. For example, in a barn with average NH_3 concentrations around 25 ppm, a suitable bag test concentration might be around 35 ppm. The gas will be introduced at each of the sampling points, and the concentration obtained by the gas analyzer will be compared to that obtained when the same NH_3 concentration is introduced to the analyzer manifold (M_a) of the GSS. The sampling time for the bag test must be the same as that which is actually used for sampling barn exhaust (10 min). Discrepancies between the concentrations obtained from the sampling points and the concentration at the M_a must agree to within 10%, or corrective action must be taken to isolate the problem on the line(s) in question. All information collected from the bag tests will be recorded, along with the date of the test, in the electronic field notes for the particular location.

Certifications for calibration gases will be according to EPA protocol (except for NH_3, which will be dual-certified by NIST-traceable gravimetric formulation), and analysis based on the vendor reference standard, where available, for a given concentration. The certified calibration gases used at all sites will be zero air, NH_3 in N_2, SO_2 in N_2, H_2S in N_2, and CO_2 in N_2. At some sites (those where a range of VOCs are measured), calibration gases will also include CH_4/propane (blend) in N_2, ethanol in N_2, and/or methanol in N_2. As described above, the compositions of the initial gas standard cylinders (NH_3, SO_2, CO_2) will be verified by FTIR (SOP G12). Copies of calibration gas certifications will be kept in the OFIS at the site, and at PAAQL. The concentration used for a given cylinder will be that certified by the gas supplier. The approximate measurement ranges (expected maximum and minimum concentrations), and the calibration gas concentrations suitable for these analyte concentrations, are listed in Table 2.6.2. If, during the course of the NAEMS, the maximum encountered concentration of any analyte is substantially different than the expected value, and this difference is persistent and/or affects multiple sampling points, the concentration of the calibration gas will be adjusted accordingly. If the maximum encountered concentration is higher than expected (higher than that of the calibration gas), a higher-concentration calibration gas will be substituted. If the maximum encountered concentration is much lower than expected (less than 10% of the concentration of the calibration gas, as this would be at the limit of the Environics system to dilute the calibration gas), a lower-concentration calibration gas would be required.

The concentration of each cylinder that is sent out to the site with the OFIS will be checked at PAAQL using FTIR Spectroscopy (SOP G12), to ensure that the concentration certified by the supplier is accurate. Subsequent cylinders of the same gas that are received directly from the manufacturer/supplier at each site will then be compared (using the appropriate gas analyzer) against the cylinder being replaced (which must not be either expired or below the 150 psi threshold, as indicated in SOP G2). Thus, a cylinder with a concentration traceable to an FTIR verification will always be used to compare with an incoming cylinder.

The performance of each gas analyzer must fall within the limits established in Table 2.6.1. If the gas analyzer does not fall within those limits, it must be recalibrated. After calibration, if the gas analyzer still does not fall within the performance limits of Table 2.6.1, the analyst will consult the relevant maintenance steps in Section 2.5 above, and the relevant sections of the SOP for that particular analyzer. The instrument should be sent to PAAQL or the manufacturer for further repair if it cannot be fixed in the field. The gas-dilution system (Environics Series 4040) will also be subjected to flow calibration (SOP G11), at the frequencies listed in Table 2.6.1.

Table 2.6.1. Calibration schedule, types, and objectives for gas measurements.

						Criteria				
QA Tool	**Acceptance Type**	**Reps.**	**Points**	**Interval, d**	**Variable**	**NH_3**	**H_2S**	**CO_2**	**NMHC***	**Corrective Action**
Multipoint Calibration	Precision, %	2	4	180	RSD	±5	±5	±5	±5	Recalibrate
	Linearity, %	2	4	180	R^2	>98	>98	>98	>98	Recalibrate
Precision Check	Calibration drift, %	1	2	7	Δs	±10	±5	±5	±10	Fix and recalibrate
	Zero drift, %FS	1	2	7	Δz	±5	±5	±5	±5	Fix and recalibrate
	Sampling system bias, %	1	2	30	Δs	±10	±10	±10	±10	Fix sample system
	Downfall, zero gas, s	1	2	30	t(95%)	<300	<120	<100	<140	Fix analyzer
	Response, span gas, s	1	2	30	t(95%)	<120	<180	<100	<140	Fix analyzer
Bag Test	Bias, %	1	1	60**	RSD	±5	±5	±5	±5	Fix and recalibrate
	Equilibration time	1	1	60**	t(95%)	Within equilibration time set in AirDAC software				Find error in system
Control Chart	Zero gas repeatability, %	-	-	-	RSD	±5	±5	±5	±5	Fix and recalibrate
	Zero gas accuracy, %FS	-	-	-	Δz	±5	±5	±5	±5	Fix and recalibrate
	Span gas repeatability, %	-	-	-	RSD	±5	±5	±5	±5	Fix and recalibrate
	Span gas accuracy, %FS	-	-	-	Δs	±10	±10	±10	±10	Fix and recalibrate
External Audit	Performance audit, %	1	1	365	Δs	±10	±10	±10	±10	Find error in system
MFC Calibration	Diluter flow	1	1	365	Flow	100-110% of MFC's full rated flow				Adjust and recalibrate

*Includes total NMHC and individual HCs (e.g. ethanol, methanol)

**Initial bag tests are done with all gases at the longest sampling line. Subsequent bag tests are done with NH_3 only.

Table 2.6.2. Concentrations and compositions of calibration gas cylinders needed for the NAEMS. Each cylinder concentration can be diluted to 10% using the diluter.

Analyte	Expected Measurement Range (ppm)			Maximum Calibration Gas Concentration Needed (ppm)			Specs for relevant commercially available (Praxair) gases			
							Balance	Full Range	Certification	
									Analytical[1]	Months
	Dairy	Poultry	Swine	Dairy	Poultry	Swine				
Ammonia	0-50	0-200	0-100	50	200	100	Nitrogen		±1%	6
Hydrogen Sulfide	0-1	0-1	0-10	4	4	10	Nitrogen	4 ppm to 300 ppm	±2% (4 - 25 ppm)	12
Carbon Dioxide[2]	0-10,000	0-10,000	0-10,000	10,000	10,000	10,000	Nitrogen	0.3% to 50%	±1%	36
Methane	0-100	0-10	0-1000	100	10	1000	Nitrogen	1 ppm to 1000 ppm	±1% (1 - 100 ppm)	36
									±2% (>100 ppm)	36
Nitric Oxide	0-1	0-1	0-1	4	4	4	Nitrogen	10 ppm to 2.9%	±1%	24
Sulfur Dioxide	0-1	0-1	0-1	5	5	5	Nitrogen	2.5 ppm to 4%	±2%	6
Propane	0-10	0-10	0-10	10	10	10	Nitrogen	1 ppm to 13%		36
Methanol	0-10	0-10	0-10	10	10	10	Nitrogen	1 ppm - up		6
Ethanol	0-10	0-10	0-10	10	10	10	Nitrogen	1 ppm - up		6

[1] Certified accuracy in the concentration range(s) relevant to NAEMS

[2] Must contain 2.5% CH_4

The TEOM $PM_{2.5}$ and Model 2000 measurement systems will be calibrated prior to the beginning of the study, and then verified according to the schedule presented in Table 2.6.3 below. The analyst will consult the maintenance steps in Section 2.5 of the QAPP, and the relevant sections of SOP P1 (TEOM) or P3 (Model 2000) if the limits listed in Table 2.6.3 cannot be met by the instrument. If, after maintenance is completed, the instrument still does not have readings within the required limits, the instrument will be removed. If the instrument cannot be fixed onsite, it will be returned to PAAQL or Thermo Fisher for further service. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic fieldnotes for the particular location.

Table 2.6.3 Calibration schedule, types, and objectives for PM_{10}, $PM_{2.5}$, and TSP measurements.

Parameter	QA Tool	Acceptance Type	Points	Interval, d	Criteria Variable	Limits	Corrective Action
Flow rate	Control chart	Accuracy	48*	60	% of target**	±5%	Recalibrate
Flow rate	Control chart	Stability/ precision	48*	60	RSD %	≤ 2%	Fix problem and recalibrate
Mass flow meter	Verification	Accuracy, %FS	1	60	Standard (TS)	≤ 5% of TS	Fix problem and recalibrate
Mass flow meter	External audit	Accuracy, %	1	365	Δs	±5% of TS	Find error in system
Leak test	Verification	Maximum leakage flow	1	60	L/min	0.15	Locate and repair leak; repeat leak test
Mass Concentration	Collocated identical monitor	Precision	1	365	Δs	≤ 25%	Report differences, recalibrate, use additional samplers

*24 h of 30-min averages as recorded internally by the TEOM.

**Target flow rates for the TEOM are 13.7 and 3.0 L/min.

The filter-weighing microbalance of the TEOM sampler will be calibrated with a NIST-traceable pre-weighed filter prior to the initiation of the study. TEOM airflows will be measured and calibrated using precision airflow calibrators (Raeco M-30 Mini-Buck Calibrators, 100 ccm-30 L/min flow rate). For TSP and PM_{10} measurements, flow rate audits (Section 8.6); leak checks (Section 7.6), mass transducer calibration verifications (Section 8.5), and downloading of stored internal data (including time and date setting/checks) (Section 4.10) will be conducted according to the periodic maintenance table in SOP P1. The electronic barometric pressure sensors in the TEOM units at each site will be compared with each other. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic field notes for the particular location.

Comparison and verification of TEOM TSP, $PM_{2.5}$ and PM_{10} mass concentrations will be conducted by collocating two of the TEOM samplers at the site. Gravimetric FRM samplers will not be used at each site for the comparison because they provide only a very limited number of results for the comparisons, thus lacking the dynamic diurnal PM concentration information. Furthermore, the FRM sampling inlets are often not suitable for high PM concentration sampling, and the barn ceiling heights do not allow its use in many locations. The FRM (Partisol) will be used to verify the TEOM TSP results at one location per species. The IN5B site will represent dairy PM. The IN2B site will represent poultry PM (both layers and broilers), and the IN3B site will represent swine PM. The FRM units will fit at these sites. The comparison will be conducted during the first quarter after all sites are set up, for a total of one week at each site.

The analyst will consult the maintenance steps in Section 2.5 of the QAPP and the relevant sections of SOP P3 if the performance of the Partisol instrument does not fall within the limits established in SOP P3. If, after maintenance, the Partisol instrument continues to display readings outside the required limits, the Partisol instrument will be removed. If the instrument cannot be fixed on site, it will be returned to PAAQL or the manufacturer (Thermo Fisher) for further service.

Thermocouples (Type T) measuring ambient (inlet), fan exhaust, raceway and OFIS temperatures will be calibrated prior to commencing the study. Hot (50-60 ºC) and ice water baths and precision ASTM alcohol thermometers will be used for calibration, as described in SOP E1. Subsequent calibration checks (Table 2.6.4) will be conducted with NIST-traceable temperature probes. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic field notes for the particular location.

The analyst will consult the maintenance steps in Section 2.5 of the QAPP, and the relevant sections of SOP E1 if the temperature readings do not meet the performance limits established in Table 2.6.4. If maintenance on the thermocouple does not yield satisfactory performance, the thermocouple wire will be removed and replaced with a new wire, following the setup procedures in SOP E1 and Section 2.1 of this QAPP.

Table 2.6.4. Calibration schedule, types, and objectives for temperature measurements.

				Interval, d				Limits			
QA Tool	**Acceptance Type**	**Reps**	**Points**	**Exhaust**	**Inlet**	**Lab**	**Criteria Variable**	**Exhaust**	**Inlet**	**Lab**	**Corrective Action**
Multipoint calibration	Precision, °C	2	3	730	730	730	SD	±0.5	±0.5	±2	Recalibrate
	Linearity, %	2	3	730	730	730	R^2	>99	>98	>95	Recalibrate
Calibration check (Omni RH/T Probe)	Calibration drift, s	1	1	60	60	180	Δs	±1	±1	±2	Fix and recalibrate
Calibration check (Thermocouples)	Calibration drift, s	1	1	180	180	180	Δs	±2	±2	±2	Fix and recalibrate
Temperature calibration check (Ultrasonic anemometer)	Calibration drift, s	1	1	365	365	-	Δs	±2	±2	-	Fix and recalibrate
Control chart	Repeatability, °C	-	5	-	-	-	SD	±1	±1	±2	Fix and recalibrate
	Accuracy	-	5	-	-	-	Δs	±1	±1	±2	Fix and recalibrate
External audit	Performance audit, °C	1	2	365	365	730	Δs	±1	±1	±2	Fix and recalibrate

The capacitance-type humidity/temperature sensors will be factory-calibrated prior to commencing the study, and will be checked periodically (Table 2.6.5) with a NIST-transfer device (mercury- or alcohol-filled psychrometers, depending on the site) . All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic fieldnotes for the particular location.

If the RH/temp sensor is not within the limits set in Table 2.6.5 at the beginning of the study, the analyst will consult the steps in found in the Quality Control and Quality Assurance Section of SOP E2. If the sensor is still not within the established performance limits of Table 2.6.6, the sensor will be replaced and returned to the manufacturer.

Table 2.6.5. Calibration schedule, types, and objectives for humidity measurements.

QA Tool	Acceptance Type	Reps.	Points	Interval, d	Criteria Variable	Limits	Corrective Action
	Response time, s	2	1	730	T	100	Fix and recalibrate
Calibration check	Calibration drift, %RH	1	1	60	Δs	±10	Fix and recalibrate
Control chart	Repeatability, %RH	-	5	-	SD	±10	Fix and recalibrate
	Accuracy, %RH	-	5	-	Δs	±10	Fix and recalibrate
External audit	Accuracy, %RH	1	1	365	Δs	±10	Find error in system

The differential pressure transmitters will be factory-calibrated using NIST-traceable standards prior to shipment. The calibration of the differential pressure transmitter can be verified with the use of a micromanometer, an inclined manometer, or an identical pressure transmitter that has been properly calibrated, or by collocating 3 or more sensors in the same location. Performance verifications of the differential pressure transmitter will be conducted according to Table 2.6.6 and the calibration section of SOP A5. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic field notes for the particular location. Barometric pressure sensors within the TEOMs and Beta Gage at each site will be compared with each other to ensure that they are all functioning properly.

If the differential pressure transmitter does not meet the performance specifications set forth in Table 2.6.6, the analyst will consult the maintenance steps in Section 2.5 of the QAPP, and the relevant sections of SOP A5. If the differential pressure transmitter cannot be fixed in the field, the instrument will be sent back to the manufacturer.

Flow rate and leakage tests of the GSS will be conducted according to Sections 9.4 and 9.5 of SOP G1, respectively, using the GSS pump. Both leak checks and flow checks will be performed after construction of the GSS is completed at PAAQL, after initial GSS installation at the site, and after any significant changes to the system. The GSS pressure will be verified according to the intervals and limits established in Table 2.6.6, and the flow of the GSS will be verified according to the intervals and limits established in Table 2.6.9. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic field notes for the particular location.

The analyst will consult the maintenance steps in Section 2.5 of this QAPP, and the relevant sections of SOP G1 if the performance of the GSS does not fall within the limits established in Table 2.6.6.

Table 2.6.6. Calibration schedule, types, and objectives for pressure measurements.

Pressure Type	QA Tool	Acceptance Type	Reps	Points	Interval, d	Criteria Variable	Limits, Pa	Corrective Action
Barn static	Multipoint calibration	Precision	2	3	365	SD	±1	Fix and recalibrate
Barometric (PM monitors)		Verification	1	1	90	Δs	±1000	Fix and recalibrate
Lab		Verification	1	2	730	Δs	±5	Fix and recalibrate
GSS manifold		Verification	1	1	365	Δs	±200	Fix and recalibrate
Barn static		Linearity, %	2	3	365	R^2	>97%	Fix and recalibrate
Barn static	Precision check	Calibration drift	1	2	90	Δs	±2	Fix and recalibrate
Barn static	Zero check	Zero drift	1	1	30	Δs	±2	Fix and recalibrate
Filter differential		Verification	1	2	365	Δs	±10	Fix and recalibrate
Barn static	Control chart	Repeatability	-	5	-	SD	±2	Fix and recalibrate
Barn static		Accuracy	-	5	-	Δs	±2	Fix and recalibrate
Barn static	External audit	Performance audit	1	1	365	Δs	±3	Find error in system

All solar radiation sensors used under SOP E3 are calibrated against an Eppley Precision Spectral Pyranometer by the manufacturer (LiCOR) prior to shipping. Once the solar sensors have been deployed, their proper calibration will be verified in the field through comparison with a similar solar sensor that has been calibrated at the factory, but has not been used in the field. All verifications will be conducted according to the schedule established in Table 2.6.7, following the steps found in SOP E3. If the solar sensor is not within the limits established in Table 2.6.7, the analyst will consult Section 2.5 of this QAPP and the relevant sections of SOP E3. If the sensor cannot be fixed in the field, it will be replaced and sent to PAAQL or LiCOR. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic field notes for the particular location.

All wind direction and speed sensors (Wind Sentrys) will be calibrated by the manufacturer before shipment. The wind speed calibrations will be verified with a Model 18802 Rotational Calibration Unit, and a Model 18314 Anemometer Torque Disc will be used periodically to verify that the bearings have not degraded. All verifications will be conducted according to the schedule established in Table 2.6.7, following the steps found in SOP E4. All information collected from the calibration checks will be recorded, along with the date of the calibration, in the electronic field notes for the particular location.

If the instrument fails to meet the performance limits established in Table 2.6.7, the analyst will consult the maintenance steps in Section 2.5 of this QAPP, and the relevant sections of SOP E4. If the wind speed and direction sensor cannot be fixed in the field, it should be sent to PAAQL for further repair and/or return to the manufacturer.

Table 2.6.7. Calibration schedule, types, and objectives for meteorological measurements.

Measurement Type	QA Tool	Acceptance Type	Reps	Points	Int., d	Criteria Variable	Limits	Corrective Action
Wind direction	Compass	Accuracy	1	4*	365	Δs	±5	Rotate until criteria met
Air velocity (vane anemometer)	Torque disk	Free rotation	1	2	90	Δs	≤1.2 g-cm	Replace bearings
	RPM anemometer drive	Accuracy	1	4	90	Δs	±1%	Fix and calibrate
Solar radiation	Collocate second sensor	Accuracy	1	2 d	365	Δs	±5%	Fix and recalibrate

*E, W, N and S

All National Instruments FieldPoint analog input modules used for data acquisition will come with NIST-traceable calibration certificate to ensure accurate, reliable analog measurements. This certification is valid for two years, which will cover the duration of the project.

Vane anemometers will be calibrated by the manufacturer before shipment. The performance of the vane anemometers will be verified using a Model 18802 Rotational Calibration Unit and a Model 18310 Anemometer Torque Disc according to the “Calibrations” section of SOP A3. If the anemometer does not fall within the limits established in Table 2.6.8, the analyst will consult Section 2.5 of this QAPP and the relevant sections of SOP A3. If the sensor cannot be fixed in the field, it should be replaced and sent to PAAQL for repair and/or return to the manufacturer.

The FANS analyzers are calibrated by the manufacturer before shipment. Calibrations after the manufacturer’s initial calibration will be conducted at the University of Illinois (Urbana-Champaign) BESS Lab. All calibrations and verifications of the FANS analyzer will be conducted according to Table 2.6.8 below.

The 3-D sonic anemometers used to measure airflow in naturally-ventilated barns will be subject to the tests (zero checks and field intercomparisons between collocated instruments) described in SOP A6, at the frequency listed in Table 2.6.8. Zero checks will be conducted by enclosing the anemometer (in place) in a cardboard box. Field intercomparisons are described in SOP A6.

Table 2.6.8. Calibration schedule, types, and objectives for airflow measurements.

Measurement Type	QA Tool	Acceptance Type	Rep.	Pnts	Int., d	Criteria Variable	Limits	Corrective Action
Airflow	Multipoint calibration	Verification of fan curve	1	3	365	Δs	±5%	Adjust fan performance curve
Fan test chamber	Calibration of FANS	Performance audit	1	6	365	Δs	±5%	Recalibrate the FANS
Fan status	Visually observe on/off status	Verification	1	-	7	Δs	±1%	Fix the problem
GSS	Leak test	Check	1	1	60	Δs	±10% FS	Find & fix leak
GSS airflow	Mass flow meter	Verification	2	2	365	Δs	±0.2L/min	Recalibrate
Ultrasonic anemometer (zero)	Box	Zero check	1	1	90	Δs	<0.1 m/s	Return to vendor, replace
Ultrasonic anemometer (precision)	Field intercomparison	Verification	1	60 min	90	SD	±0.4 m/s	Recalibrate

Analytical instruments used in the laboratory quantitation of VOCs (GC/MS and IC systems) will have calibration curves (five points, at minimum) associated with each batch of samples, where a batch is defined as a maximum of ten samples collected during the same sampling event. For GC/MS analysis, a daily single-point calibration check, equal in concentration to that of the middle standard in the five-point curve, will be conducted daily before any samples are run. This calibration check must meet the criteria described in SOP V4 (sorbent tube samples) or V6 (canister samples) before the stored calibration curve is considered valid for the samples being analyzed. The process for introducing standards for GC/MS analysis of VOCs in canister samples is described in SOP V6, while those for VOC samples on sorbent tubes is given in SOP V4. Calibration standards for ion chromatographic quantitation of volatile amines will be run in duplicate, and will bracket the sample batch. IC standards are discussed in further detail in SOP V5. In all three cases (canisters, sorbent tubes, and amine bubblers), the lowest concentration of the standard curve will be about ten (10) times the detection limit for each target analyte. Procedures for determining the detection limit are given in the respective SOPs.

When analyzing manure, feed, bedding, milk, and eggs for their N and (in the case of manure) NH_3 contents, Midwest Laboratories will employ a five-point calibration curve (SOPs M4 and M5). Similar to the VOC analyses, the lowest concentration on this curve will correspond to a level ten (10) times the detection limits of the analytical methods. Calibration standards for determination of manure solids content are discussed in SOP M3. Electrochemical pH meters will be calibrated at pH 7 and 4 for acidic samples, or 7 and 10 for alkaline samples, as described in SOP M2.

2.7 Inspection/Acceptance of Supplies and Consumables

All atmospheric gaseous measurements will be traceable to dual-analyzed and certified standards. The certified standards will be traceable to NIST. EPA web sites documenting the performance of major gas-cylinder vendors, based on the results of a round robin test conducted every two years, will be consulted as part of the vendor-selection process for gases. The NH_3 span gas will be dual-certified by NIST-traceable gravimetric formulation and analysis based on vendor reference standard. FTIR spectroscopy will be used to verify concentrations of all cylinders that are initially sent to each individual site, so that incoming cylinders can then be compared against them using the individual gas analyzers.

All consumable supplies, spare parts, and newly-purchased instruments will be inspected immediately upon receipt, and returned to the vendor if found unusable. This will be the responsibility of the PI and/or site engineer for materials and supplies delivered directly to them or to the field site, and the responsibility of PAAQL personnel for supplies sent directly to Purdue. All shipping packaging will be inspected for damage as an indicator of possible damage to the product. Copies of all certifications of analysis, inspection, calibration, performance, etc, that are provided by manufacturers will be forwarded to the NAEMS QA/QA Manager, Dr. Juan Carlos Ramirez, who will maintain them for the duration of the project, and for at least six years thereafter. Signed packing slips for all supplies will constitute certification of inspection and acceptance, and will also be kept on file by Dr. Ramirez.

A supply of spare parts in working condition will be maintained to ensure continuous data collection. Each individual SOP lists the consumable supplies (including tools and spare parts) that must be kept on hand, either on-site (i.e. with each individual instrument) or centrally (i.e. at PAAQL to support the entire network of instruments). Also, SOP U1 lists general consumables that should be kept in the OFIS at each site.

At the initiation of the study, PAAQL personnel will equip each site's OFIS with spare parts, tools, and consumable supplies, and will advise site PIs about other supplies to purchase. This will be conducted before the OFIS is transported to its site. Individual PIs and their site engineers will be responsible for ensuring that the site-specific spare parts stocks (and the stocks of general consumables for the OFIS, as listed in SOP U1) are maintained in accordance with the individual SOPs. Dr. Bill Bogan of PAAQL will, as the NAEMS Operations Manager, have the responsibility of maintaining the centralized stock of spare parts and consumables at Purdue.

Consumable supplies will be stocked in "last-in, last-out" order, and will be kept under controlled indoor conditions (in labs at PAAQL or at the PI's University, or in the environmentally-controlled OFIS at the site itself). Both PIs/site engineers (for on-site consumables) and PAAQL (for in-house consumables) will maintain Microsoft Excel spreadsheets with the expiration dates of all consumables that will expire during the course of the project (i.e. before the conclusion of the data-collection phase in 2009). These spreadsheets will be checked (i.e. sorted by the expiration date column in ascending order) on a weekly basis, at minimum, to rapidly identify any soon-to-expire items, and ensure that any consumable supply that expires prior to use is replaced in a timely manner. PIs/site engineers or PAAQL personnel (as appropriate) will also ensure that all consumables that will expire during the course of the project are clearly labeled with their expiration date (on each individual or discrete container), so that expired supplies will not be inadvertently used. To reduce the amount of expired unused supplies that must then be disposed of, all supplies with expiration requirements will be ordered in the smallest quantity that will meet the needs of the project and avoid repetitive ordering.

These same guidelines, as described in their Corporate QA Manual, are followed by Midwest Laboratories for their inventory control.

2.8 Data Acquisition Requirements (Non-Direct Measurement)

Not applicable to this project.

2.9 Data Management

The objective of data management is to ensure data security, easy identification and retrieval, and efficient publication.

2.9.1. Overview of Data Flow

Figure 2.9.1 illustrates the flow of data and data files. Originally, the majority of the data will be acquired by the data acquisition system and automatically saved in the site PC. Data acquisition and control system configuration data will also be automatically saved. Instrument calibration/precision-check and test notes (field notes) will be entered manually by typing or entering in electronic files. Farm management data, if its electronic version is not available, will be entered into the site computer manually. Other project-related data (e.g. manure analysis results) will also be entered manually (in this case, by Midwest Laboratories personnel, as the data will be obtained by PAAQL in spreadsheet format).

The data stored in the site PC will be backed up according to a regular schedule (SOP B5). Acquired data will be sent to the Site PI and Site Engineer, and to PAAQL, via automatic email every day at midnight. Newly- and manually-entered data, including test notes at the site, will be sent to the same recipients at the end of the day’s work using manually controlled email software (e.g. Outlook Express). The data received by the administrative server will be backed up automatically everyday into the ABE Department’s backup device at Purdue University.

The Purdue data analyst will pre-process the measurement data (SOP B3) to produce data graphs and summarized results, including hourly and daily means of all measurement variables, within two (2) working days. This will provide a quick review of the data and a check on the measurement systems’ performance. The results (daily graphs of all measurement variables, at a minimum) will be sent to the site personnel for their review, and for storage on the site computer. Site personnel will also have access to the data pre-processing software in the event tabular data or re-formatted data is desired on the site computer. Within 2 working days of receiving the data, the data analyst will also review the data in conjunction with the site fieldnotes and make note of any inconsistencies or suspected problems with the data set. These data analysis notes will be stored in tabular form in a spreadsheet on a continuous basis, and serve as a reference for flagging invalid data during data processing. The current data analysis notes will be sent to the site personnel to alert them of suspected problems, confirm events recorded in the fieldnotes, and serve as reminders of outstanding items that need to be resolved.

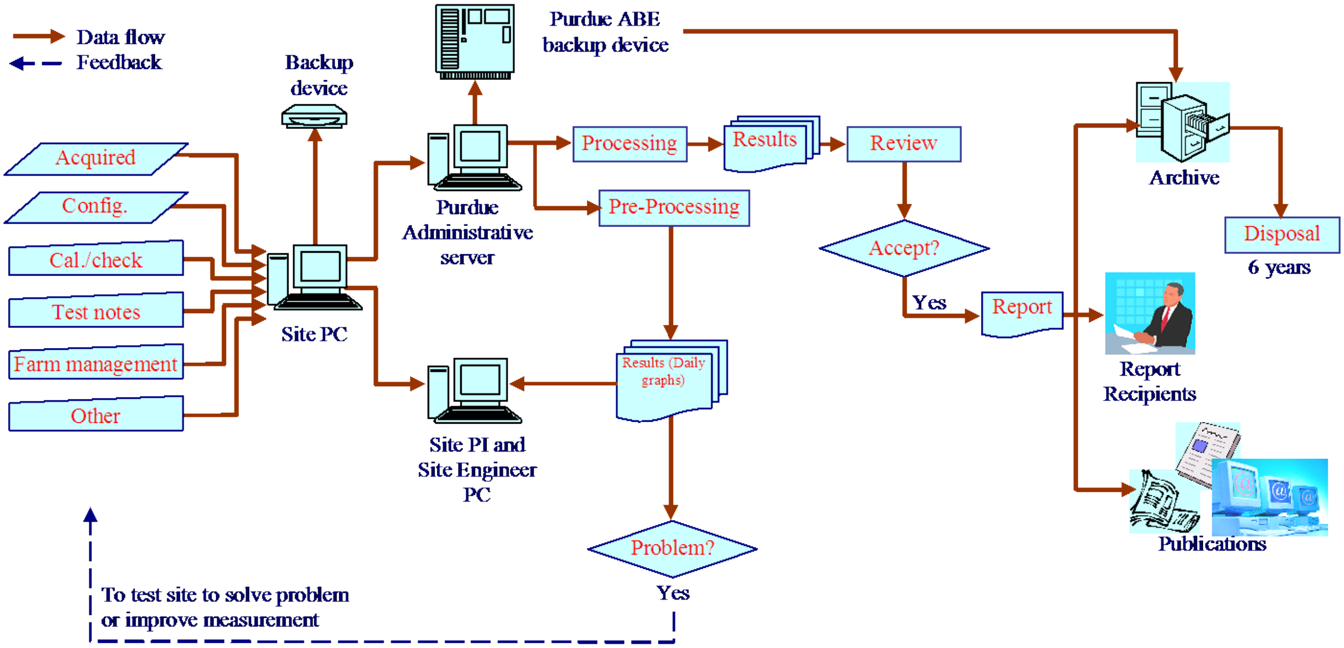


Figure 2.9.1. Diagram of data flow.

The graphs and summarized data will be archived at PAAQL, the Site PI's university, and the site computer, and used as reference throughout the study and during final data processing at PAAQL. The final data processing procedures are described in SOPs B4 and B6. The Site PI will be involved with the final data processing to various degrees, depending on the PI.

The quarterly results of the data will be reviewed by a second data analyst using CAPECAB software. The primary data analyst will also present the results for review by the Site PI, Site Engineer and SA. A report will be generated documenting the results and significant events that affected the data results, data completeness and data quality during the quarter. Corrective actions will be taken if any data quality objectives are not met. The SA will forward the quarterly report for each site to EPA within one quarter of the end of the data collection period.

The final report for the project will be written based on accepted final results and distributed to report recipients. All raw data and processed data will be provided to EPA, and will also be archived for at least six years before disposal.

2.9.2. Data Handling Equipment

An on-site computer with CD or DVD rewritable drive and/or a portable hard drive, and a second hard drive will be used to acquire, store, back up, and transfer data. The purpose of the rewritable/portable drive is to back up data files to disks that can be used for off-site backup. The second hard drive is used to back up all files in the first hard drive. More detailed information on data handling equipment can be found in SOP B5.

An administrative server in the Agricultural and Biological Engineering Department at the Purdue University West Lafayette campus will be used to store and archive all NAEMS-related data. All files on the administrative server are backed up by the Purdue University Engineering Computer Network on a daily basis.

File binders and file cabinets will be used to classify and store hard copies of data table, data graphs, and quarterly and final reports.

2.9.3. Individuals Responsible for Data Management

The Site PIs will be responsible for managing the data generated at the site, including backing up, occasional pre-processing (as necessary), archiving, and delivering to the administrative server.

The data analysts at PAAQL will be responsible for managing the data received from all sites including inspecting, pre-processing, processing, and archiving data.

2.9.4. Classification and Organization of Electronic Files

In the data acquisition computer at each individual site, all project-specific files will be arranged in a single default folder called *YY*X*n*, where *YY* is a two-letter abbreviation for the state, X is a numeric code for the animal type (1 = broiler, 2 = layer, 3 = finisher, 4 = sow, 5 = dairy) and *n* is “A” for area sites, or “B” for barn sites. For example, the three sites in California are identified in this filing system as CA1B (broiler, barn), CA2B (layer, barn) and CA5B (dairy, barn).

All project-related electronic files are classified into four categories, according to their importance and recoverability. All files are saved in an organized folder structure (SOP B5).

2.9.5. Data Security

All project computers and servers are protected. Data security will be accomplished through a variety of measures.

2.9.5.1 Passwords

All users of the project computers must be authorized and receive a password necessary to log on. Those authorized to access research data will use strong passwords, which will be changed on a regular basis (quarterly, at minimum). Only authorized personnel will have access to the site computer. The site PI and site engineer will have the password to remotely connect to the site computer. The project managers and data analysts will have passwords to the computers that are connected to the administrative server. No one person is authorized to change original raw data files, as explained in SOP B5.

2.9.5.2 Data Access Privileges

Different privileges are given to each authorized user, depending on that person's need. Data integrity and security software will be selected and used for the data security and audit trail. The following privilege levels are defined:

- Data entry privilege: The individual may see and modify only data within the system that he or she has entered. After a data set has been "committed" to the system by the data entry operator, all further changes will generate entries in the system audit trail.
- Report privilege: This privilege permits generation of data summary reports available under the system. No data changes are allowed without additional privilege.
- Data administration privilege: This privilege allows change of data as a result of QA screening and related reasons. All operations resulting in changes to data values are logged to the audit trail. The data administrator is responsible for performing the following tasks on a regular basis:
  - Merging/correcting the duplicate data entry files
  - Running verification and validation routines and correcting data as necessary
  - Generating summary data reports for management.

2.9.5.3 Datalogging

Data security in the data acquisition system in the site computers will be accomplished through the use of access control to the computer. All NAEMS trailers are expected to be locked when the site personnel are not present. Visitors to the site will be expected to sign a visitor log, and/or be recorded in the electronic fieldnotes. Remote access to the site PC via PCAnywhere is password-protected. All site PCs will have firewalls, spyware protection, and up-to-date virus scanning software.

At midnight of each day, the day's data file will be e-mailed to Purdue University. One recipient of the data file is an automated Eudora system that immediately saves the original data file into a secure directory on the Purdue University Engineering Computing Network. As part of this process, Eudora imprints the file upon receipt with an electronic timestamp that will identify it as the originally e-mailed datafile from the site in question for the day in question. Comparison of this timestamp with the "modified on" date for the file will verify that the raw data file has not been tampered with. Access to this directory is strictly password-protected, and is made available only to PAAQL personnel with clearance to work with NAEMS datafiles.

2.9.5.4 Data Backup

A progressive backup of the on-site project folder, from the primary hard drive of the on-site computer to a secondary hard drive, will be automatically done on a daily basis. Additionally, the on-site project folder will be backed up to a CD or DVD that is kept off-site, every two weeks, or whenever there are changes in Category 2 and/or Category 3 data files, as defined in SOP B5.

Email will be used to deliver electronic files to designated responsible site PI, data analyst and to the administrative server computer, in a timely manner. The emailed files will include AirDAC data files, AirDAC configuration files, manually recorded field notes, and any visual image files. Any project-related paper drawings will be scanned with the on-site scanner, stored in the on-site computer, and emailed. Any project-related digital photos will be transferred to the on-site computer before being emailed.

Files in the administrator server computer at PAAQL will be backed up daily on the Purdue University backup system.

2.9.6. Data Recording

2.9.6.1 Automatic Recording from Continuous Measurement

AirDAC, a data acquisition and control program developed by PAAQL using LabVIEW software (National Instruments, Co., Austin, TX), will be used to acquire data, automate sampling location control, display real time data, and deliver data and system operation status to the investigators. AirDAC will acquire data at 1 Hz, average the acquired data every 15 s and 60 s, and save the averaged data in text format in two separate data files every 60 s. Raw data will also be saved in a secure Purdue ECN directory for security using Eudora. AirDAC will generate new data files every day at midnight and upon start-up of the program. Data file names will be composed of site name and dates. All data saved in the data files will have time stamps. AirDAC is fully described in SOP B2.

2.9.6.2 Manual Data Entry

Data from off-line sample analysis by laboratories, weather data from the nearest weather station, data obtained from the producer, manure characteristics, laboratory notes, and visual observations will be entered and saved within the project folder structure in the on-site computer. The files will be backed up onto the second hard drive and the off-site administrative server.

Entry of these data will be made either electronically if the electronic files are available (e.g. digital photos) or manually. Table 2.9.1 lists relevant SOPs that provide procedures and/or data forms for filling out the manually-entered data. Where appropriate, data forms are included with these SOPs. In other cases, data is entered directly into the electronic field notes.

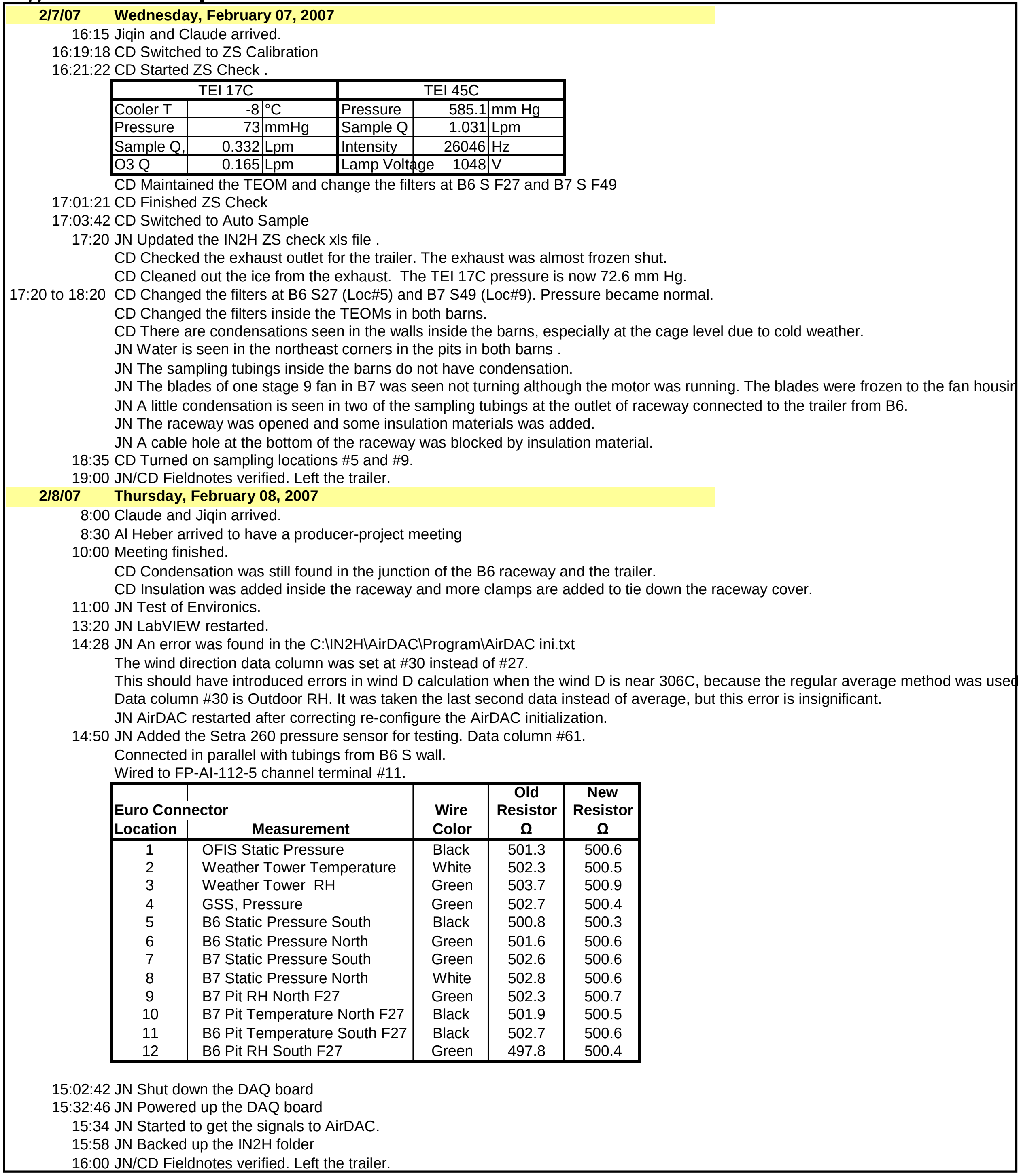
Table 2.9.1. List of the NAEMS SOPs requiring data entry.

SOP	Title	Data description
A1	Laboratory Fan Testing	Barn Airflow
A2	Testing Fans with Portable Tester (FANS)	Barn Airflow
M1	Manure Sampling from Barns	Manure Characteristics
M2	Manure pH Evaluation	Manure Characteristics
M3	Manure Total Solids Evaluation	Manure Characteristics
M4	Manure Total Nitrogen Evaluation	Manure Characteristics
M5	Manure Ammonia Evaluation	Manure Characteristics
P2	Gravimetric Multipoint TSP samplers	PM Measurement
P3	Gravimetric $PM_{2.5}$ Method	PM Measurement
S2	Recording Animal Inventory	Source Information
S5	Nutrient Balance	Source Information
S6	Feed, Bedding, Milk, and Eggs Analysis	Source Information
V1	VOC Sampling Using Sorbent Tubes	Volatile Organic Compounds
V2	VOC Sampling Using Canisters	Volatile Organic Compounds
V3	Amine Sampling Using Bubblers	Volatile Organic Compounds
V4	VOC Analysis Using GC/MS and Thermodesorption	Volatile Organic Compounds
V5	Amines Analysis Using IC	Volatile Organic Compounds
V6	VOC Analysis (GC/MS) of Canister Samples	Volatile Organic Compounds

2.9.6.3.Electronic Field Notes

An example of electronic field notes in the format that will be used for NAEMS is contained in Fig. 2.9.2.

Figure 2.9.2. Sample of NAEMS electronic field notes in Microsoft Excel format.



2/7/07 **Wednesday, February 07, 2007**

16:15 Jiqin and Claude arrived.
16:19:18 CD Switched to ZS Calibration
16:21:22 CD Started ZS Check .

TEI 17C			TEI 45C		
Cooler T	-8	°C	Pressure	585.1	mm Hg
Pressure	73	mmHg	Sample Q	1.031	Lpm
Sample Q,	0.332	Lpm	Intensity	26046	Hz
O3 Q	0.165	Lpm	Lamp Voltage	1048	V

CD Maintained the TEOM and change the filters at B6 S F27 and B7 S F49
17:01:21 CD Finished ZS Check
17:03:42 CD Switched to Auto Sample
17:20 JN Updated the IN2H ZS check xls file .
CD Checked the exhaust outlet for the trailer. The exhaust was almost frozen shut.
CD Cleaned out the ice from the exhaust. The TEI 17C pressure is now 72.6 mm Hg.
17:20 to 18:20 CD Changed the filters at B6 S27 (Loc#5) and B7 S49 (Loc#9). Pressure became normal.
CD Changed the filters inside the TEOMs in both barns.
CD There are condensations seen in the walls inside the barns, especially at the cage level due to cold weather.
JN Water is seen in the northeast corners in the pits in both barns .
JN The sampling tubings inside the barns do not have condensation.
JN The blades of one stage 9 fan in B7 was seen not turning although the motor was running. The blades were frozen to the fan housi
JN A little condensation is seen in two of the sampling tubings at the outlet of raceway connected to the trailer from B6.
JN The raceway was opened and some insulation materials was added.
JN A cable hole at the bottom of the raceway was blocked by insulation material.
18:35 CD Turned on sampling locations #5 and #9.
19:00 JN/CD Fieldnotes verified. Left the trailer.

2/8/07 **Thursday, February 08, 2007**

8:00 Claude and Jiqin arrived.
8:30 Al Heber arrived to have a producer-project meeting
10:00 Meeting finished.
CD Condensation was still found in the junction of the B6 raceway and the trailer.
CD Insulation was added inside the raceway and more clamps are added to tie down the raceway cover.
11:00 JN Test of Environics.
13:20 JN LabVIEW restarted.
14:28 JN An error was found in the C:\IN2H\AirDAC\Program\AirDAC ini.txt
The wind direction data column was set at #30 instead of #27.
This should have introduced errors in wind D calculation when the wind D is near 306C, because the regular average method was used
Data column #30 is Outdoor RH. It was taken the last second data instead of average, but this error is insignificant.
JN AirDAC restarted after correcting re-configure the AirDAC initialization.
14:50 JN Added the Setra 260 pressure sensor for testing. Data column #61.
Connected in parallel with tubings from B6 S wall.
Wired to FP-AI-112-5 channel terminal #11.

Euro Connector Location	**Measurement**	**Wire Color**	**Old Resistor Ω**	**New Resistor Ω**
1	OFIS Static Pressure	Black	501.3	500.6
2	Weather Tower Temperature	White	502.3	500.5
3	Weather Tower RH	Green	503.7	500.9
4	GSS, Pressure	Green	502.7	500.4
5	B6 Static Pressure South	Black	500.8	500.3
6	B6 Static Pressure North	Green	501.6	500.6
7	B7 Static Pressure South	Green	502.6	500.6
8	B7 Static Pressure North	White	502.8	500.6
9	B7 Pit RH North F27	Green	502.3	500.7
10	B7 Pit Temperature North F27	Black	501.9	500.5
11	B6 Pit Temperature South F27	Black	502.7	500.6
12	B6 Pit RH South F27	Green	497.8	500.4

15:02:42 JN Shut down the DAQ board
15:32:46 JN Powered up the DAQ board
15:34 JN Started to get the signals to AirDAC.
15:58 JN Backed up the IN2H folder
16:00 JN/CD Fieldnotes verified. Left the trailer.

As shown in the above example, field notes will be entered into an electronic spreadsheet, in Microsoft Excel format. Each site will keep its own distinct field notes file. The field notes are written in third person, to avoid any potential confusion as to who is referred to in the body of the notes. Field notes are expected to contain, at minimum:

- Times of arrival and departure from the site, and names of visitors
- Descriptions of all work conducted during the visit
- Any raw data that would not otherwise be recorded
- All notes regarding instrument precision checks and/or calibrations
- Times that instrument(s) or sensor(s) are off-line or turned off.
- Any unusual observations or problems, malfunctioning or damaged instruments or sensors, and any corrective actions
- Any deviations from the SOPs or SMP that occur during work at the site
- Any items or notes that would be useful in helping the Data Analyst identify or confirm data flags

2.9.7. Data Transformation

Data transformation is the conversion of individual data points into related values (or possibly symbols) using conversion formulas (e.g., unit conversion or logarithmic conversion).

For continuously acquired data obtained using data acquisition hardware and software AirDAC, the data conversion is done real-time in AirDAC. Analog signal outputs by analyzers and sensors either in voltage or in current each have output signal ranges (e.g., from 0 to 10 VDC or from 0.004 to 0.020 A). Analyzers and sensors also have measurement ranges that correspond to these signal ranges (e.g., 0 VDC = 0 ppm and 10 VDC = 100 ppm for an NH_3 analyzer). AirDAC converts the analog signals from individual analyzers and sensors to measurement values using the following commands and equations:

If (*Abs* = false), Then

$$X = \frac{(S - S_L)\cdot(R_H - R_L)}{S_H - S_L} + R_L \qquad (2.9.1)$$

Else

$$X = \left| \frac{(S - S_L)\cdot(R_H - R_L)}{S_H - S_L} + R_L \right| \qquad (2.9.2)$$

Where:
Abs = A flag signaling whether to take absolute value or not
X = Converted measurement value (the units depend on the analyzer or sensor)
S = Analog output signal received by the data acquisition hardware, VDC or A
S_L = Analog signal of the instrument/sensor at low end, VDC or A

S_H = Analog signal of the instrument/sensor at high end, VDC or A
R_L = Measurement range of the instrument/sensor at low end (units depend on the instrument or sensor)
R_H = Measurement range of the instrument/sensor at high end (units depend on instrument or sensor

For thermocouple signal conversion, $S_L = 0$, $S_H = 1$, $R_L = 0$, and $R_H = 1$.

For signal conversion of activity sensors, which have an offset voltage and the sensor analog output = offset ± S, S_L = offset, S_H = offset + 1, $R_L = 0$, $R_H = 1$, and Abs = true.

For any analyzers and sensors whose converted values need correction or adjustment using a linear model (e.g., correcting analyzer outputs based on calibration coefficients of the analyzer), the following linear equation will be used to perform the adjustment in AirDAC:

$$Y = A \cdot X + B \tag{2.9.3}$$

Where:
A = Slope
B = Intercept

The Y values will be averaged with the following equation:

$$\overline{Y} = \frac{\sum_{i=1}^{n} Y_i}{n} \tag{2.9.4}$$

Where:
$\overline{Y}$ = Average of Y
Y_i = Calculated Y from individual samples that are taken every s (Equation 2.9.3)
n = Number of samples ($n = 15$ for the 15-s data file and $n = 60$ for the 1-min data file)

The value $\overline{Y}$ will be saved in two different data files every 15 s and 60 s, respectively.

For sensors with digital output signals, the signal value S will not be changed when it is converted to Y by setting Abs = false, $S_L = 0$, $S_H = 1$, $R_L = 0$, $R_H = 1$, $A = 1$ and $B = 0$ using Equations 2.9.1 and 2.9.3. The Y will be converted into percentage of time using Equation 2.9.4. For example, if a saved data point shows 50% of time “on” in the 1-min data file, the sensor provided signal that is 30 s “on” and 30 s “off” during the corresponding one-minute period.

For the PM samples obtained with the federal reference method, data transformation will be conducted according to the instrument instruction.

2.9.8. Data Validation

Computer-acquired raw data will be assembled and daily graphs will be plotted. Plotted graphs will be reviewed visually for any malfunctioning sensors, outliers, and missing data primarily by the PAAQL Data Analyst and secondarily by the Site PI and/or other site personnel within two business days (Refer to Section 4.1 and SOP B3). If any error is found, original data will be checked against field notes to find the cause of the error, and any inconsistencies will be reported to the site personnel. Feedback from site personnel to the Data Analyst (if required) will be provided within two business days. All original and final data will be reviewed and/or validated by technically qualified staff, and so documented in the program records. The documentation will include the dates the work was performed, the name of the reviewer(s), and the items reviewed or validated.

Operators visiting a site will record electronic field notes (see above) for the work performed, procedures followed, problems identified, and corrective measures needed. Field notes will be emailed to the site PI and the PAAQL Data Analyst at the end of each site working day and reviewed by both persons. Review of the field notes keeps the site PI and Data Analyst updated on measurement progress, and allows for planning of preventive measures to achieve QAQC objectives. It also helps with troubleshooting of the system and validation of the data (Section 2.9.9).

2.9.9. Data Flagging

Data flags indicating various reasons of data invalidity or suspicion due to special events, failure of QC limits, or contamination will be applied during data processing using CAPECAB software (SOP B6). Data flags consisting of three letters will be used for easy recognition and selection. Data flags are assigned to specific datum in the raw or processed data set. Table 2.9.2 lists the data flags that will be used in the NAEMS.

Data flags will be applied in one of three ways using CAPECAB software (SOP B6): First, for location-specific analyzers and sensors, a set of “suggested” flags will be generated and stored in an information file used by CAPECAB. These suggested flags will include flags of “EQU” for data collected at each location during the equilibrium time for the specific analyzer or sensor, and “MIS” for data missing from the original data files. The suggested flags can be accepted and assigned to the respective data points. Second, automatic flags will be generated and assigned for any datum that falls outside of the expected range of the sensor (HNR, LNR, ONR), or when the data experiences a sudden change in value (SPK, SCV). The settings for the automatic flags are stored in an information file used by CAPECAB. Third, flags can be manually assigned to data, based on information regarding calibration or instrument maintenance in the fieldnotes, or DAQ-related problems. Manually flagged data is recorded in an information file that includes the date and time the flagging was completed, the name of the person setting the flag(s), the start and end date and time of the flag(s), the flag identifier(s), and any related comments regarding the flag. Each of the three flagging methods has a data file associated with it that will be included in quarterly data result reports.

Data can be flagged in the ADPP program, but currently these flags are not transferred into the CAPECAB database for purposes of emission calculations. CAPECAB and ADPP software updates are being investigated to allow for flag information files to be shared between the two programs; however, all data corrections and flagging that affect the reported concentration and emission results will be conducted in CAPECAB.

Table 2.9.2. Data flags.

Description	Flag	Definition or additional description
Valid data	(Blank)	
Hardware related		
Data acquisition system problem	DAQ	Including system failure or malfunctioning that introduces systematic errors
System noise	NOI	Random error introduced by measurement system, usually electronic noises
Failure of instrument/sensor	FLR	Instrument/sensor not working at all
Unstable instrument/sensor	UST	Systematic error introduced
Offline of instrument/sensor	OFF	Instrument/sensor not installed, disconnected, un-powered, or removed
Pegged instrument/sensor	PEG	Out of the instrument/sensor measurement range at the higher or lower ends
Operation related		
Calibration or precision check	CAL	Also applied for data acquired at equilibrium time after calibration or precision check
Equilibrating or warming up	EQU	At switching of sampling locations (for LSAS) or start of instrument power on
Maintenance of instrument/sensor	MNT	
Condensation in sampling lines	CDN	
Insufficient sample flow	FLO	For LSAS and PM samples
Data value related		
Higher than normal range	HNR	Normal range defined and set during DAQ in AirDAC or during data processing
Lower than normal range	LNR	
Out of normal range	ONR	
Spikes	SPK	Fast, exceptional, and short duration changes in data values compared with values before and after that duration and compared with normal value change patterns
Sudden change of values (abnormal change)	SCV	Fast and evident increase or decrease in data values compared with values before that change and compared with normal value change patterns
Other flags		
Incomplete data	INC	1. Occurred in data processing, e.g. data are incomplete when calculating emission rate without air flow rate 2. Data completeness not meet DQO criteria
Missing data	MIS	Data missing from the original data file
Reserved data column	RES	Originally configured in the data files
Previous flag confirmed	PFC	Used as second or third flags

2.9.10. Data Transmittal

Data transmittal occurs when data are transferred from one person or location to another or when data are copied from one form to another. Table 2.9.3 summarizes data transmittal operations.

Table 2.9.3. Data transmittal operations.

Description of data transmittal	Originator	Recipient	QA measures applied
Electronic	Site computer	Backup device	Parity checking; transmission protocols
Continuous measurement electronic data and manually entered electronic data (via internet email)	Site computer	Site PI, Site Engineer, PAAQL administrative server	Parity checking; transmission protocols
Farm management (copy electronic files)	Farm Manager	Site PC	Parity checking; transmission protocols
Farm management (entry of hard copy data to computer by site personnel)	Farm Manager	Site PC	Review and verify all entries
Filter receiving and chain of custody	Shipping and receiving personnel	Site personnel	Review and verify all entries
Test data graphs and summaries (electronic transmittal)	Site PI or Site Engineer	PAAQL administrative server	Parity checking; transmission protocols
Quarterly and final reports (electronic transmittal)	Project SA and EPA	Report reviews and recipients	Parity checking; transmission protocols

2.9.11. Data Reduction

Data reduction involves aggregating and summarizing results so that they can be understood and interpreted. Examples of data summaries include:

- Average pollutant concentrations and other environmental variables, e.g. temperature, relative humidity, weather conditions, etc.
- Average barn ventilation rates
- Average number and weight of animals in the barns
- Average pollutant emission rates from the barns
- Accuracy, bias, and precision statistics based on the measurement data
- Data completeness

The data can be averaged over different time spans, e.g. hourly, daily, monthly, quarterly, or annually. Shorter intervals reveal variations in pollutant concentrations and emission rates (e.g. diurnal patterns).

As described above, raw data are saved in the site PC, transferred daily to PAAQL, and backed up in both the site backup system and the PAAQL administrative server. In the latter case, the timestamp imprinted on the file by Eudora when it is received from the site can be used to verify the originality of the file. Details are in SOPs B2 and B5. The equations/procedures used to calculate concentrations are described in SOP B4. Accurate working files of all documentation, including logbook entries, original data, calculations, deviations from approved procedures, data uncertainties, assumptions, QA/QC results and external performance data, audits, and review, inspection, and validation will be maintained by the respective site PI as appropriate, until they are turned over to the IMC.

All averaging functions are carried out using the CAPECAB software (SOP B6). CAPECAB has a variety of built-in features to maintain data integrity, as described further below.

2.9.12. Data Correction

Data correction will be made during data processing and by operators with administrative privilege of data access. All data correction will be carried out in CAPECAB. Typical reasons for data correction include:

- Corrections of data input due to human error
- Application of revised calibration factors
- Corrections of measurement values based on calibration/precision check results
- Addition of new or supplementary data (e.g. animal number and weight)
- Manual flagging of data as invalid or suspect.

Any correction to data that is made in CAPECAB must be done using one of two options – either a manual flag or an equation. Flags are recorded (see above), and an equation log will be implemented that will record the following information for each equation, similar to that recorded for flags:

- What equation was run, and on what data
- Identity of the person running the equation
- Date and time the equation was run
- Origin (path, filename, etc) for the equation

After correction, original entries (raw data) will always remain legible (for manual corrections) or intact (for computerized corrections). For computerized corrections, the original data and corrected data must be stored separately (i.e. as different data columns in CAPECAB). A utility program will be provided by the CAPECAB vendor that will compare the raw data files in any particular CAPECAB file with those in the original e-mailed text file from the site to verify that the raw data displayed in CAPECAB is, in all cases, the unadulterated raw data received from the site.

2.9.13. Data Analysis

Data analysis involves comparing suitably reduced data with a conceptual model. It includes computation of summary statistics. Data analysis will be performed by PAAQL personnel using data processing software CAPECAB (SOP B6). Details of the various data computations, including equations used, and data reporting are outlined in SOP B4.

2.9.14. Data Tracking

Figure 2.9.1 illustrates data flow in the project. Data are mostly originated from the measurement site and flow to the PAAQL administrative server. Once pre-processed at PAAQL, data is made available to site personnel (Site PI) and PCs. In most cases, the tracking of data and monitoring of the database are updated simultaneously. Reports of data tracking may be generated by any person with report privileges. The reports will include the following:

- Type of data
- Location and date of data origination
- Designated data distribution destination
- Planned date of data transmittal
- Fulfillment of data transmittal

The Site PI and PAAQL Data Manager are responsible for the status of data tracking.

2.9.15. Data Archival and Retrieval

All NAEMS-related files will be archived and kept for a minimum of six years after the conclusion of the project. Retrieval of the data is only for authorized people and will be made from the site computer or administration server. Project records will be maintained in a systematic, logical and appropriately indexed form, and adequately filed for rapid retrieval. Details of data archival and retrieval are described in SOP B5.

The record storage will conform to EPA records management policies (USEPA, 2005). A records management program with the following minimum requirements will be established and maintained.

- Create, receive, and maintain official records providing adequate and proper documentation and evidence of project activities.
- Manage records, in any format, in accordance with applicable statutes, regulations, and EPA policy and guidance.
- Maintain electronic records, including electronic mail records, in the enterprise-wide electronic content management system, when available, and migrate legacy systems, when feasible.
- Print and file records in a paper recordkeeping system if an enterprise-wide electronic content management system is not available.

- Maintain records according to the Agency-wide file structure allowing for timely access and retrieval.
- Secure records to protect the legal and financial rights of the project.
- Follow instructions for disposition of records as specified in the approved records schedules.

No data will be destroyed without EPA approval. At the end of the six-year period, or when appropriate, EPA will be consulted on data archives and given the opportunity to either request transfer of data archives to EPA, or agree with Purdue's assessment that data can be destroyed.

3. Assessment and Oversight

The following subsections describe assessment and oversight measures to be taken during data collection. These actions are separate from the final data validation described in Section 4.

3.1 Assessments and Response Actions

The PAAQL Data Analyst assigned to each site will be responsible for routine assessment and internal QA/QC checks of data collection, evaluation of data in accordance with validation procedures, and for initiating necessary response actions. The routine assessment will include review of data to ensure that instruments are functioning and collecting information. They will assess the data for their representativeness, completeness, comparability, accuracy and precision as outlined in Section 4. Routine assessments will also include review of the QC measures in Section 2.4.3. The Site PI will share in these duties. The PI will initiate his/her own response actions immediately upon discovery of a problem, and will respond to those initiated by the PAAQL Data Analyst, to ensure that the data meet the project DQOs.

The Science Advisor and/or Project QA Manager, with assistance of other PAAQL staff members, will conduct the audit/assessment procedures described in Table 3.1.1. The assessments include at least one field operation assessment of sampling and analysis activities at each site and at the internal and external analytical laboratories that provide analytical services to the project. Performance audit samples will be analyzed during these assessments (Section 2.4.3). The timing of these audits will be coordinated with EPA, and/or its designee, to coincide (if possible) with the external audits (see below). During field oversight, while both the PIs and site engineer are present, the Science Advisor, Project QA Manager, or other designee will visually observe sample collection and analysis to verify that the procedures outlined in this QAPP are being followed and that any corrective action initiated previously is being continued. Field documentation of samples, calibration, QC measures, staff training and corrective action will also be reviewed. In addition, the Science Advisor and/or QA Manager will conduct a review of data and record management systems. This review will verify that the data management procedures (Section 2.9 of this QAPP) and all SOPs, are being followed.

The audit of each location will be conducted and documented using forms adapted from those included in the August 1998 Quality Assurance Handbook for Air Pollution Measurement

(Appendix 15, Section 2). The NAEMS Site Audit Form (Appendix C) documents these assessments and the required response actions. All internal assessment reports will be directed to the SA, who will forward them to EPA. Any issues or anomalies identified in these reviews will be discussed with appropriate site personnel and addressed immediately, and will also be documented on the Site Audit Form. If response actions are taken, the PI will inform the SA/QA Manager of these actions and the results, and will document the actions by returning a copy of the Site Audit Form that has been annotated with his/her responses to the requested corrective actions. The Site PI will keep a copy of this annotated reply for his/her records, and will retain a copy on-site. The annotated Audit Finding Form, with the plan of action, must be delivered (electronically or otherwise) to the SA or QA Manager within 30 d of the issuance of the Site Audit Form. The Project QA Manager will review this information to verify that the QAPP is being followed, and to determine if changes to the QAPP (including the SOPs) are needed. The SA and Project QA Manager will retain copies of all Site Audit Forms and responses. Audits, and their results, will be summarized in the quarterly QA reports.

EPA or its designee will perform its own annual assessment of each site. PAAQL QA personnel will coordinate with EPA QA personnel, so that these audits can be conducted on the same day(s) as a PAAQL internal audit (described above), if this is possible. The EPA QA Assessment Report will be submitted to the SA. The Project QA Manager will send the EPA QA Assessment Report to the site PI and review the required corrective actions with the site PI. Within two weeks, the Site PI will submit a report to the Project QA Manager that outlines his/her response to the EPA assessment. Upon approval by the SA and the Project QA Manager, the Site PI’s response will be submitted to EPA by the SA. The deadline for the submittal of this report is 30 d following the on-site assessment. The Project QA Manager will ensure that these corrective actions are implemented by the Site PI.

The SA has authority to stop work. If the SA is not available or cannot be contacted, the principal investigator (PI) for the site has authority to stop work. The PI will have such authority only during an emergency, either one related to the farm operation (such as a biosecurity breach) or weather (such as tornado or heavy snow that prevents access to the farm, etc). The site PI will email the SA about the decision to stop work, and to explain the justifications for the decision.

3.2 Reports to Management

Table 3.2.1 includes the reports to management with description of frequency, originators and receivers of these reports. These reports will be directed by the project Quality Assurance Manager, to the SA, and he will forward it to EPA and AARC.

If conditions requiring corrective action are identified during a review conducted by the Project QA Manager, a brief report will be issued by the Project QA Manager to the SA and the PI; however, corrective action will be initiated immediately based on verbal discussion during the review. Each site’s PI will generate a quarterly report that contains the following information. PAAQL personnel will combine these reports into one, and will include the results of any audits that were conducted in previous months. Quarterly and final project reports will contain all valid monitoring data expressed as hourly and daily values. The reports will include the following:

1. Executive summary
2. Background and present status
3. Quality objectives for measurement data
4. Numerical and qualitative results of all QC measures for all measurement systems, including comparisons with the applicable acceptance criteria
5. Results of quality assurance assessments
6. Recommendation for further QA work, with suggestions for improving performance and fixing problems with equipment, personnel training, infrastructure needs, etc.
7. Graphical representations of the measurement locations
8. Description of any data that must be invalidated, including reasons for data invalidation and the required corrective action
9. Summary of corrective actions taken during field data collection
10. Discussion of the impact of corrective actions on data quality

Table 3.1.1. Assessment procedures, types, and frequency.

Type of Assessment: Scope	Frequency	Assessment Personnel
Field Operations: 1. Routine Operations 2. Quality Control 3. Preventive Maintenance 4. Record Keeping 5. Data Acquisition and Handling	Annually	SA or designee
Laboratory Operations: 1. Routine Operations 2. Quality Control 3. Preventative Maintenance 4. Record Keeping 5. Data Acquisition and Handling	Annually	SA or designee
Data and Record Management: 1. Data Handling 2. Software Documentation 3. Data Validation and Correction 4. Data Processing 5. Internal Reporting 6. External reporting	Quarterly	SA or designee
Quality Assurance/Quality Control: 1. Status of Quality Assurance Program 2. Audits and Audits System Traceability 3. National Performance Audit Program (NPAP) and Additional Audits 4. Documentation and Data Processing Review 5. Corrective Action System 6. Audit Result Acceptance Criteria	Annually	SA or designee

Table 3.2.1. Required reports to management.

Type of QA Report to Management	Contents	Reporting Frequency					Person responsible for:	
		AR	W	M	Q	Yr	Generating Report	Receiving Report
QA - Corrective Action Request	Description of problem; recommended action required; feedback on resolution of problem	√					**Site PI**	**QA Manager, Science Advisor (SA)**
QA - Control Chart with Summary	Repetitive field or lab activity; control limits versus time. Prepare whenever new check or calibration is done.	√		√			**Site PI**	**QA Manager, SA**
QA - Performance Audit Program Results	Summary of performance audit results					√	**QA Manager**	**SA**
QA - System Audits	Summary of system audit results; recommendations for action, as needed.					√	**QA Manager,**	**SA**
QA - Quality Assurance Report to Management	Executive summary. Precision, bias, completeness and system and performance audit results.				√	√	**QA Manager**	**SA**
Interim Reports	Executive summary. Data summary, Precision, bias, completeness and system and performance audit results				√	√	**SA, Site PIs**	**EPA, AARC**
Progress Report	Executive summary			√			**SA, Site PIs**	**EPA, AARC**

QA: Quality assurance; AR: As required; W: weekly; M: Monthly; Q: Quarterly; Yr: Yearly;

4. Data Validation and Usability

4.1 Data Review, Verification, and Validation Requirements

4.1.1. Monitoring/Sampling Design and Sample Collection

The site monitoring plan (SMP) must be reviewed and approved by EPA prior to implementation at each site. The site PIs are responsible for the proper installation of sampling and measurement equipment as specified in the SMPs and this QAPP. During the monitoring site setup and equipment installation, PAAQL personnel will visit the site to provide technical support and ensure that the sampling systems are established according to the SMP, and that the samples collected or measured are representative. Site audits will also be conducted by PAAQL personnel, as described in Section 3.1, and by an EPA subcontractor.

4.1.2. Sample Collection and Handling Verification

Standard procedures are described in the corresponding SOPs. The monitoring site PIs will ensure that the procedures are followed to ensure proper sampling and handling, and to maintain data/sample integrity. Site audits will also verify that these procedures are being properly followed. The purpose of the audits is to ensure that the monitoring, sample collection, handling and preservation are being performed following the described procedures. Following the audits, a Site Audit Form (Appendix C) will be completed and sent to the corresponding PIs and EPA. Corrective actions must be taken as soon as possible for any significant deviation noted.

4.1.3. Analytical Procedures and Quality Control

All analytical methods and procedures will be conducted according to the SOPs and the corresponding sections of this QAPP. Each site PI is responsible for ensuring that the specified methods and procedures are being followed for those analyses that are carried out on site (e.g. the gas analyzers). Proper installation and maintenance of measurement equipment, on-time sampling and calibration, and all other field and laboratory QC procedures will be ensured by site PIs. Midwest Laboratories will provide QA/QC oversight for the analyses of manure, feed, bedding, milk, and eggs. PAAQL personnel (Dr. Changhe Xiao, acting as the VOC Manager for the NAEMS) will be responsible for auditing the VOC analytical facilities at PAAQL. The audits will also validate the analytical and QC procedures, and any findings relevant to these areas will be included in the Audit Report. Acceptable precision, bias, and other criteria as specified in required measurement and sampling SOPs will be used to verify that the analytical and QC procedures are adequate. If significant deviation is found, corrective actions must be conducted and recorded in the field notes. For the affected data, the site engineer and PI, and related PAAQL personnel (at minimum, the data analyst assigned to that site) will meet to discuss and determine the validity of the data, and flag the data as invalid if that is judged to be appropriate. When flagging data as invalid, personnel must clearly record the data, reason and narrative of the flagging.

4.1.4. Calibration

The specified calibration activities and requirements must be conducted according to the frequency as specified in this QAPP and the SOPs. Verification of such activities is the responsibilities of the site PIs and will also be conducted in the site audits. Verifications include checking the proper multipoint calibration prior to measurement or sampling, proper calibration frequency, appropriate calibration points and range, and acceptable QC checks as specified in the SOPs and QAPP. Significant deviations from the calibration procedures and QAPP requirements will be noted and reported in the Site Audit Form. Corrections must be conducted and recorded in the field notes, so that the calibrations are meeting the specified frequency and requirements. The calibration and precision (zero/span) check data of gas analyzers are required information (SOPs B3 and B6) in the calculation of gas concentrations and emission rates. Thus, the validity of these checks must be verified by PAAQL data processing personnel before any gas data can be reported.

4.1.5. Data Reduction and Processing

All data generated under this QAPP will be reviewed and validated primarily by PAAQL personnel (the data analysts assigned to the particular sites), and secondarily by the PIs responsible for each individual site (Section 2.4.2.). Graphical presentation (daily figures) of the collected data will be generated according to SOP B3. An Excel graph template will be used to organize raw data, assemble one or more data files in a single day, and produce daily figures to allow the PIs and PAAQL data analysts to review data shortly after they are recorded. A custom software program, Calculation of Air Pollutant Emissions from Confined Animal Buildings (CAPECAB, SOP B6) was developed to assemble and review data, and execute the final processing of air emission measurement variables. The data “Flagging” function of the program is used to inspect and assess data validity, and flag data. All data will be initially considered invalid, but will be validated unless field notes, user-specified ranges, ventilation-stage measurements, or outliers imply a reason to flag a datum. By reviewing the figures (SOPs B3 and B6), and cross-checking the correlated variables, personnel can ensure data collected conforms to the sampling design specifications and representativeness.

Data verification will be performed by comparing the data with field notes, farm information (e.g. changes in animal numbers), and weather data to identify any possible human interferences and/or environmental changes that might affect the data. Data verification will also be done by comparing the data with those published and obtained at similar measurement campaigns. Whenever data is flagged as invalid in the data-inspection process, personnel must clearly record the reason and period in the data processing notebook (or electronic file). Also, they must record other information including analyst name, site name, and narrative of the flagging. Data will not be flagged invalid or excluded from database without adequate reason. The CAPECAB program is designed to retain all data (even when they are flagged as invalid), and the flagging can be easily reversed.

One specific case of data verification will be the use of N balances to corroborate, through a theoretical mass-balance, the measured NH_3 emissions from the barns. This is described in SOP

S5, and will be conducted annually (corresponding to the one-year storage times for manure in many of the barns).

Validation will follow these criteria:

1. Data will be invalidated if they are:

- unreasonably low or high compared with normal ranges and if there is supporting evidence that they are not correct (e.g., unresponsive relative humidity sensor inside a barn producing a reading less than 10%)
- obtained during system installation, testing, or maintenance during which uncorrectable errors might be introduced
- obtained when the sensor or instrument is proved to be pegged
- obtained when the sensor or instrument is proved to be malfunctioning (e.g., unstable)
- obtained during sensor or instrument calibration or precision check and before the sensor or instrument reaches equilibrium after calibration or precision check
- obtained when the data acquisition and control hardware and/or software is not functioning correctly

2. Data from the location-shared analyzers/sensors (LSAS), such as gas concentration analyzers and the RH/T sensor installed at the same location as the gas sampling point, will be invalidated if they were obtained when:

- the sampling pump is not operating
- the GSS sampling flow rate does not exceed the total sample flow rate drawn by all of the gas analyzers (since this would allow atmospheric air from inside the OFIS to enter the analyzer manifold of the GSS)
- condensation is present in the sampling system

3. Averaged data for any individual parameter will be invalidated to avoid errors introduced into calculated mean values due to partial-data days (e.g. only a few hours of valid data) that would result in biased time weights (SOP B4):

- Hourly averages will be invalidated if <75% of the data during that hour are valid.
- Daily means will be invalidated if <75% of the hourly average data during that day are valid.
- Monthly averages will be invalidated if <75% of the individual days during that month are valid.
- Average daily means (ADM) will be invalidated if <75% of the daily average data during all measurement days are valid.

For location-shared analyzers/sensors, the 75% valid data criterion is evaluated within individual locations, after proper zero/span data adjustment (SOPs B3 and B6), and interpolations between the valid measurement points. The interpolations are conducted to interpolate between any two or more valid measurement periods that are within 300 min (3000 min for ambient measurements, as these are collected less frequently, and are relatively constant). For example, for a monitoring site that has 12 sampling locations and a 5-min sampling period, air from each location will be sampled/analyzed every 60 min. The missing data between two measurements will be linearly interpolated based on the valid and adjusted concentrations. However, if the next valid measurement at one or more given locations was delayed (due to maintenance, zero/span checks, inlet air sampling) for more than 300 min, the interpolation will not be conducted for those locations. Also, if the gas analyzer is pegged for the first 10 min (at the first location), while the other 50 min of measurements (five other locations) are normal, only the measurement data of the first sampling location is flagged as invalid, and will not be interpolated. If the same pattern happens in enough sampling cycles during a day, so that less than 75% of the data at a specific location is valid, then the daily mean at this location is invalidated. However, the daily means of all other locations would still be valid.

4.2 Verification and Validation Methods

The purpose of verification is to ensure that conclusions can be correctly drawn from the measurement data. The purpose of validation is to determine whether the data satisfy QAPP-defined user requirements.

Verification and validation will be performed by manually checking data entries and data summaries and visually inspecting graphical data plots combined with additional data collecting information, e.g. test activity, barn data, etc. This technique will be used to verify and validate both continuously acquired data (e.g. gas concentrations, ventilation, temperatures, etc.) and manually entered discrete sample data (e.g. gravimetric PM concentration, manure analysis results, etc.). Data pre-processing and processing software ADPP (SOP B3) and CAPECAB (SOP B6) will be used to aid automatic verification and validation of the continuously acquired data by flagging, calculating statistics, and plotting.

4.2.1 Verification Methods

4.2.1.1 Verification of Procedures

Verification of data procedures, including calculating equations, parameters, and sequences, will be performed during preparation of quarterly reports by a second data analyst. A thorough review of the following will be conducted to verify whether the continuously acquired data and/or calculated data were correctly:

- Transformed during data acquisition (Section 2.9.7) and processing (SOPs B3, B4 & B6)
- Reduced during data acquisition (Section 2.9.7) and processing (SOPs B4 & B6)
- Analyzed (SOPs B4 and B6)

If any error is found in the procedures, the cause of the error will be identified. Corrections will be made that may include the following:

- Correct the data format

- Verify and correct software configuration files
- Correct equations or calculation sequences
- Repeat calculation(s) with corrected procedure

After the first quarterly verification and corrections of these procedures, the same verification method will only be applied when there has been change in the data transformation, reduction and analysis procedures.

For discrete sample data, all the calculation procedures will be verified to make sure that no errors were introduced during data reduction and analysis. If any errors were uncovered, recalculation will be conducted after the errors in the procedure are corrected.

4.2.1.2 Verification of Data

Verification of data will focus on data-entry error, outliers, data out of acceptance criteria, and data completeness. Data will be evaluated for compliance with stated objectives for representativeness, precision, and accuracy.

For discrete samples, all raw data that are hand-entered from data sheet and/or typed directly into computer data files will be double-checked against the original recording. If the number of data points is too large for this to be feasible or practical, 5% of the data will be randomly selected for verification.

Summary statistics of the data (including mean, maximum, minimum, and standard deviation) and data completeness will either be calculated manually for discrete sample data or automatically using ADPP (SOP B3) and CAPECAB (SOP B6) software for continuous measurement data.

Graphs plotting hourly, daily, and monthly summary statistics will be used to compare with each other and compare with published data and data patterns. Data outliers include those data that are out of normal range or do not fit into normal patterns. Extremely low or extremely high data will be flagged as LNR (lower than normal range) or HNR (higher than normal range), respectively. Sudden changes in data values will be flagged SPK (spike). Data marked with flags will be further verified for the cause of abnormality. A list of flags and description/definition is found in Table 2.9.2.

Special outliers that cannot be related to specific reasons are subject to further investigation. Any averaged data that do not meet the data completeness criteria (Section 4.1) will be excluded automatically from subsequent data processing by CAPECAB.

Manually or automatically (if calculated with ADPP or CAPECAB) calculated data completeness will be verified against the project measurement quality objectives (Table 1.4.1). Any suspicious completeness data will be subject to further investigation until the data completeness values are correct.

4.2.2 Validation Method

Validation of data will be performed at the measurement data level and at the summary data level. Data will be validated by using the validation criteria (Section 4.1), and by comparison with instrumental performance parameters as identified in the applicable standard operating procedure or instrument operation manual. Data validation will also be performed by comparing the recorded test activity and changes of the barn environment.

Data flagged as invalid will all be checked and verified by a second data analyst. The verification of each variable will be documented. Other flags listed in Table 2.9.2 may also be used, alone or in combination, to invalidate the raw data or summarized data. However, data generated under instrument/sensor or DAQ system with known and correctable bias will be kept valid and corrected, for example, by applying new calibration coefficients.

All invalid data will be kept, but will be excluded from the subsequent data processing and analysis. After the validation process, a summary table of the format shown in Table 4.2.1 will be completed and included in the data report. This table will include a record all flagging-related material and activity, and will therefore identify all data that were deemed to be invalid. In all cases, data deemed to be invalid by the primary PAAQL Data Analyst will be confirmed by a second Data Analyst. The identity of this person will be included for each site in the data report.

Table 4.2.1. Data validation summary.

Data type	Data range (from date to date)	Invalid	Invalidation criteria	Data validator (name, date, affiliation)	Flag Activity Verified (name, date, affiliation)

4.2.3 Authorized Personnel for Verification and Validation

The Site PI and PAAQL data management staff are authorized and responsible for data validation and verification unless an outside institution is authorized by the USEPA. They will be assigned administrative privilege to perform data flagging and correction (Table 4.2.2). Generally, the PAAQL Data Analyst (primarily) and the Site PI and/or Site Engineer (secondarily) will be responsible for data verification, and the PAAQL data management staff will be responsible for data validation. Double verification may be needed for some cases (e.g. data flags).

Table 4.2.2. Data verification and validation tasks and responsibilities.

Data type	Site PI and Engineer		PAAQL data-managers	
	Verification	Validation	Verification	Validation
Continuous measurement data	√		√	√
Discrete sample data	√			√
Manure sampling record	√			√
VOC sampling record	√			√
Farm animal and management record	√	√		
Test notes	√			√
DAQ configuration files	√	√		
Data flags			√	√
Sample chain-of-custody sheets	√			√
Receipt logs	√			√
Instrument check log	√			√
Instrument calibration sheets	√			√
Data processing configuration files			√	√

4.3 Reconciliation with Data Quality Objectives

The DQOs of the NAEMS were developed in Section 1.4. The data quality assessment (DQA) process is comprised of the following steps:

4.3.1 Step 1. Review DQAs and sampling design

Section 1.4 of this QAPP describes the development of the DQOs, and defines the primary objective of the air emission monitoring study and develops limits on the decision errors. The site monitoring plans (SMPs) (Appendix A) contain the details for the sampling design for each site, including the rationale for these designs. Any deviations from the sampling design will be indicated and their potential effect on the DQOs carefully considered throughout the entire DQA.

4.3.2 Step 2. Conduct preliminary data review

A preliminary data and data graph (including control charts) review will be performed to uncover potential limitations to using the data, to reveal outliers, to explore the basic structure of the data, and to look for anomalies in recorded data, missing values, and any deviations from standard operating procedures for all measurement variables.

Summary statistics and graphical presentations will be generated at the quarterly, annual, and biannual (final report) timeframes, and will include only valid samples. Summary statistics for each primary measurement variable (including concentration and ventilation) are numbers of samples, means, medians, standard deviations, coefficients of variation, maxima, and minima. The results will be summarized in a table or tables. Particular attention will be given to the impact on the statistics caused by the observations noted in the quality assurance review.

Graphics and summary tables will be used to show the spatial and temporal variations of the data, and will be assessed by the Site PI and PAAQL.

4.3.3 Step 3. Determine data bias, precision, and completeness

Because the objective of this NAEMS is to determine baseline emissions of different types of sites for modeling purposes, instead of emission compliance, statistical tests will not be used.

Bias, precision, and completeness will be used to evaluate the data. Bias and precision of each individual instrument/sensor are established in Section 2.6, and are determined during instrument/sensor calibrations, precision checks, and/or external audits.

For each precision check of gas analyzers using calibration gases of known concentration, bias $d_{i,}$ *w*ill be calculated using Equation 2.1 in Section 2.4.

For each $PM_{2.5}$ measurement pair, the percent relative bias d_i is calculated with Equation 2.2.

Coefficient of variation (CV), for a single check is calculated with Equation 2.3 in Section 2.4. Precision of a single instrument, *j*, during the quarter, *q*, is calculated with Equation 2.4 in Section 2.4.

Completeness is defined as the measure of the amount of valid data obtained from a measurement system, compared with the amount of data that was expected to be obtained under normal conditions. Data completeness will be expressed as the percentage of valid data obtained from the measurement system. For data to be considered valid, they must meet all the acceptance criteria. Calculations of data completeness are made during data processing.

The following formula will be used to calculate completeness:

$$C = \frac{V}{n} \times 100\% \qquad (4.1)$$

Where,

C = completeness, %.
V = number of measurements judged valid
n = total possible number of measurements.

Results of precision, bias, and completeness calculations will be recorded in the data summary table, and included in quarterly, annual, and final reports.

4.3.4 Step 4. Verify data bias, precision, and completeness

Bias in pollutant concentration measurements and the adjustment of measurement data using precision check data to reduce the bias will be evaluated. Bias is established within ±10%.

Measurement precision is established at a 10% coefficient of variation (CV). Data completeness is established at 75%. For each pollutant measurement instrument, the site PI and the PAAQL data analysts will review the CV and completeness calculated in Step 3 (Section 4.3.3).

Table 4.1 will be completed during each DQA. A check will be placed in each of the row/column combinations that apply. If any of the DQO assumptions are violated, then the site PI and PAAQL will need to reevaluate the DQOs.

Table 4.3.1. Summary of bias, precision, and completeness.

Instrument	Bias <±10%?	Precision <10%?	Completeness >75%?
Analyzer 1			
Analyzer 2			
…			
TEOM 1			
TEOM 2			
…			

4.3.5 Step 5. Draw conclusions about the data quality

If any of the established bias, precision, and completeness assessed in Step 4 is not met, then the test is suspect and will require further investigation.

4.3.6 Action plan based on conclusion from the DQA

All five steps of the process will be completed and Table 4.3.1 will be generated on a quarterly basis. If all answers are "yes" (DQI's are within limits), then the Site PI and PAAQL will assume that the DQO's have been met. If this is not the case, the Site PI and PAAQL will take one of the following possible actions:

4.3.6.1 Re-examine the Measurement Equipment, Material, or Procedures

If the process reveals that the problem is related to the equipment, materials (including calibration gases), or operation procedure (including calibration or precision check procedures), PAAQL will re-examine the selected measurement equipment, verify the accuracy and stability of the calibration gases, and evaluate the standard operating procedures to identify the real cause of the errors. Measures, including changing equipment, re-certifying calibration gases, or modifying SOPs will be taken as necessary. Modification of the procedure or stricter quality control will be implemented.

4.3.6.2 Reducing the QA Requirement

QC is integral to any site monitoring and is particularly important to the project. However, once it is demonstrated that the data collected from the sites are not within tolerable levels of error, PAAQL may consider and request a reduction of QA requirements.

4.3.6.3 Extensive Review of Quarterly Data until DQOs are Achieved

The Site PI and PAAQL will continue to review the quarterly QA reports and the QC summaries until the bias, precision, and completeness limits are attained.

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APPENDIX A –NAEMS Site Monitoring Plans

Barn SMPs are contained in Appendix A. Area-source SMPs are contained in the companion QAPP (the NAEMS Open-Source Component).

SMP	Type	Title
CA1B	Barn	Broiler Ranch in California
CA2B	Barn	Layer Site in California
IN2B	Barn	Layer Site in Indiana
NC2B	Barn	Layer Site in North Carolina
IN3B	Barn	Finisher Swine Farm in Indiana
NC3B	Barn	Finisher Swine Farm in North Carolina
IA4B	Barn	Sow Farm in Iowa
NC4B	Barn	Sow Farm in North Carolina (Barn Component)
OK4B	Barn	Sow Farm in Oklahoma (Barn Component)
CA5B	Barn	Dairy Farm in California
IN5B	Barn	Dairy Farm in Indiana
NY5B	Barn	Dairy Farm in New York State
WA5B	Barn	Dairy Farm in Washington State (Barn Component)
WI5B	Barn	Dairy Farm in Wisconsin (Barn Component)
IA3A	Area	Finisher Swine Basin in Iowa
NC3A	Area	Finisher Swine Lagoon in North Carolina
OK3A	Area	Finisher Swine Lagoon Site in Oklahoma
IN4A	Area	Sow Lagoon in Indiana
NC4A	Area	Sow Farm in North Carolina (Lagoon Component)
OK4A	Area	Sow Farm in Oklahoma (Lagoon Component)
IN5A	Area	Dairy Lagoon in Indiana
TX5A	Area	Dairy Corral Site in Texas
WA5A	Area	Dairy Farm in Washington State (Lagoon Component)
WI5A	Area	Dairy Farm in Wisconsin (Lagoon Component)

APPENDIX B – NAEMS Standard Operating Procedures for Barn Source Measurements

SOP	Title
A1	Laboratory Testing of Ventilation Fan Performance
A2	Measurement of Ventilation Fan Flow Rate Using the Fan Assessment Numeration System (FANS)
A3	Ventilation Fan Air Velocity Measurements Using Open Impeller Anemometry
A4	Fan Airflow Rate Estimation
A5	Measurement of Fan Static Pressure in Livestock Buildings with Setra Model 260 Differential Pressure Transducer
A6	Ultrasonic Anemometer for Non-Ventilated Barns
A7	Fan Status Monitoring Using Vibration Sensors
A8	Ventilation Fan Airflow Measurements Using the Air Velocity Transverse Method
A9	Measurement of Airflow Rate or Calibration of Air Sampling Instruments with Gilibrator 2 Calibration Systems
A10	Calculation of Airflow in Naturally Ventilated Barns
A11	Fan Status Monitoring Using RPM Sensors
B1	Data Acquisition and Control Hardware
B2	Data Acquisition and Control Software (AirDAC)
B3	Air Data Pre-Processing Software
B4	Calculation and Reporting of Air Emissions from Barns
B5	Data Management for Barns
B6	Data Processing Software (CAPECAB)
E1	Temperature Measurement Using Thermocouples
E2	Measurement of Relative Humidity (RH) and Temperature with the Omni RHT-WM Humidity Transmitter
E3	The Measurement of Solar Radiation with the Licor Model 200SL or 200SZ Silicon Pyranometer
E4	Wind Speed and Direction Measurements Using the R.M. Young Model 03002VM Wind Sentry
E5	Roof-mounted Weather Station Tower
G1	The PAAQL Gas Sampling System
G2	Compressed Gas Cylinders
G3	Measurement of Carbon Dioxide (CO_2) with the MSA Model 3600 Infrared Gas Monitor
G4	Measurement of Ammonia (NH_3) Using the TEI Model 17C Chemiluminescence Analyzer
G5	Measurement of Hydrogen Sulfide (H_2S) with the Thermo Electron Corporation Model 450I Pulsed-Fluorescence Analyzer
G6	Measurement of Methane and Non-Methane Hydrocarbons with the Thermo Electron Corporation Model 55C Analyzer
G7	Use of the INNOVA 1412 Photoacoustic Multi-Gas Monitor
G8	Multi-Point Calibration of Gas Analyzers
G9	Precision Checks of Gas Analyzers
G11	Operation of the Environics® Computerized Gas Dilution System

G12	FTIR Verification of Gas Cylinder Concentration
M1	Manure Sampling
M2	Conducting pH Measurements on Manure Samples
M3	Determining Solids Content of Manure Samples
M4	Determining Total (Kjeldahl) Nitrogen Content of Manure Samples
M5	Determining Ammonia Content of Manure Samples
P1	Measurement of Ambient Atmospheric Particulate Matter Using the Thermo Electron Corporation TEOM Series 1400A Monitor
P2	Measurement of Barn Exhaust Total Suspended Particulate Concentrations Using an Isokinetic Multipoint Gravimetric Method
P3	Measurement of $PM_{2.5}$ with the Thermo Electron Corporation Partisol Model 2000 Air Sampler
P4	Continuous Measurement of PM_{10} Particulate Matter Using the Thermo Electron Series FH 62C14 (Beta) Sampler
Q1	Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments
S1	Producer Collaborations at Barn Monitoring Sites
S2	Recording and Tracking Animal Inventory at Livestock Barns
S3	Activity Measurements
S4	Process Relay Monitoring
S5	Nutrient Balance
S6	Determining Total Kjeldahl Nitrogen (TKN) Contents of Feed, Bedding, Milk and Eggs
U1	On-farm Instrument Shelters for Barn Sources
U2	Installation of Barn Measurements
U3	Heated Raceway
U6	The Powerware 9125 Uninterruptible Power Supply
V1	Sampling of Volatile Organic Compounds (VOCs) in Air Samples through Use of Sorbent Tubes
V2	VOC Sampling Using Canisters
V3	Collection of Amines in Air Samples Through Use of Sulfuric Acid-Containing Bubblers
V4	Thermodesorption and GC/MS Analysis of VOCs collected on Sorbent Tubes
V5	Analyzing and Quantitating Amines By Ion Chromatography
V6	GC/MS Analysis of VOCs Collected in Sampling Canisters
V7	Cleaning, Certification and Pre-sampling Preparation of Sampling Canisters

APPENDIX C – Site audit forms for NAEMS

NAEMS Site Audit Form

Date:
Site:
Auditor(s):
Researchers present during visit:

Project Management:

Start date:
Frequency of online data observation:

Analyst(s) training:

Internal supervisory audits:
Data available at site for inspection?
Initial meeting with producer?
Is data being inspected following business day?
Are electronic field notes being maintained?
Is manual entry log book being maintained?

Characteristics of producer collaboration and cooperation:
Is producer providing the following data?
Mortalities:
Animal inventory and weight:
Production (e.g. eggs, milk):
Water and nutrient consumption:

Occurrence of special activities, e.g., generator tests, manure removals or agitation, change in diet and animal health, temperature set points, ventilation interventions, building cleaning, power failures, etc.:

Data Management

All files under one folder in the PC?
Data and files backed up in case of hard drive failure?
Are data files emailed to campus daily?
Are important project files (hard copy and electronic files, including data, program, field notes, emails, etc.) backed up and stored away from instrument shelter (e.g. on campus)?

Instrument Shelter

Describe the electrical grounding system.
Describe the grounding of the trailer, weather tower, feed bins, barns, etc.
Cleanliness and orderliness:
SOPs displayed near instrument?.
Security?

Utilities:
Environmental control:
Electrical power protection:

Gas Sampling System:

Date of last leak test:
Visual appearance:
Pressure =
Flow rate (minimum = 4.0 L/min) =
Is the manual sampling port bled to exhaust?
What is the ambient sampling period?
Has response time been tested?

Number of gas sampling locations?

Description of gas calibration system:

Using mixing manifolds?

How are gas and vacuum sampling lines heated, 3°C above sampled air, etc.:

Control charts available for gas analyzers? .
Calibration records available in shelter?
Log of calibration times?
Are all gas cylinders unexpired?

Calibration Records:

Instrument	Calib.* interval, d		Most recent	Loc	n	r	Notes
	QAPP	Actual					
H_2S							
CO_2							
NH_3							
CH_4							
THC (propane)							
Ethanol							
Methanol							
Bag test							
dP zero check							
dP span check							
TC							
RH/Temp							
GSS MFM							
TEOM vs FRM							
TEOM mass ver							
TEOM airflow							
TEOM leak test							
TEOM barometer							
BG Calibration							
Open anemometer							
Mixing manifolds							

B/A = before and after the test. S/W = once in summer once in winter. FC = at every filter change; Loc = location; n= number of points; r = replications.

Barn Inspection:

Check location of sensors for representativeness:

Vulnerability of sampling lines to condensation:

Equipment protection (from animals, workers):

Are the activity sensors placed to monitor both animal and worker activity?
Inspection of vane anemometer positioning.

What operational data is being gathered?

Maintenance:

	Interval, d (QAPP)	Most recent	Notes
Clean TEOM air inlet			
Clean PM_{10} head			
Replace TEOM filter			
Replace in-line filter			
Replace gas membrane filters			

Weather data:

Temperature: Yes ____ No ______
Humidity: Yes ___ No ______
Wind velocity: Yes ____ No ______
Wind direction: Yes ____ No ______
Solar radiation: Yes ____ No ______
Height of wind sensor:

Fan airflow measurements:

Description of fan monitoring method:

Speed/airflow of variable speed fans:

Which fans have the anemometers?

Have the rpm sensors been checked with optical meters?

Connections verified?

FANS measurements of fan curves:
Date(s):
Replications each point:
Number of static pressures
Number of fans tested:
Notes:

What calibrations or checks were done during this audit?

Appendix D. NAEMS Sample Chain-of-Custody (COC) Form

CHAIN OF CUSTODY SHEET

NATIONAL AIR EMISSION MONITORING STUDY (NAEMS)

(Please print clearly in ink)

Name: ____ Phone: ___________________
Site Location: ____ Email Address: __________________________________
Method of Delivery:____ Tracking Number:________________________________
Sample Set ID (Lab Use Only):_______________

Sample #	Sample Description or Location	Date Sample Taken	Type of Sample*	Collected by (Initials)	Remarks	Condition (Circle one)** (Lab use only)	
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable
						Acceptable	Unacceptable

* e.g. Manure, feed, VOC sorbent tube, VOC canister, VOC bubbler, etc.
** If judged “unacceptable”, note reason in the space provided in the column

Released by: ____ Date: _____/_____/_____
(Signature or client)

Received by:_______________________________ **PAAQL** **Midwest Laboratories** (Circle One) Date: _____/_____/_____

Southeastern Broiler Gaseous and Particulate Matter Emission Monitoring Quality Assurance Project Plan

Southeastern Broiler Gaseous and Particulate Matter Emission Monitoring Quality Assurance Project Plan

Prepared by
Iowa State University
and the University of Kentucky

Foreword

In January 2005, the United States Environmental Protection Agency (EPA) announced a plan, after negotiating with representatives of the animal agricultural industry, to collect scientifically credible data concerning air emissions from livestock and poultry facilities. This effort is titled the Air Compliance Agreement (ACA). Monitoring work performed as part of the ACA will have regulatory significance to future enforcements and decisions made by the EPA in regards to air emissions from animal agriculture. As such, projects within the ACA are required to operate with a Category 1 Quality Assurance Project Plan (QAPP).

The QAPP is defined by the EPA as a tool for project managers and planners to define the type and quality of data needed for environmental decisions, and to describe the methods for collecting and assessing the data. The QAPP integrates technical and quality control aspects regarding planning, implementation, and assessment for a project. The goal is to ensure that the results of a project are of the type and quality needed and expected by the EPA. The four components of the plan are Project Management, Data Generation and Acquisition, Assessment and Oversight, and Data Validation and Usability.

In the fall of 2005, Iowa State University and the University of Kentucky began the implementation of the monitoring system at the sites proposed for use in the ACA study for southeastern broiler operations. This segment of the study will monitor air emissions from two mechanically ventilated commercial broiler houses in western Kentucky. The aerial emissions monitored include ammonia (NH_3), carbon dioxide (CO_2), hydrogen sulfide (H_2S), non-methane hydrocarbons (NMHC), total suspended particulates (TSP), particulate matter of ≤ 10 µm diameter (PM_{10}) and particulate matter of ≤ 2.5 µm diameter ($PM_{2.5}$). The following sections describe the development and implementation of key quality assurance and control components for the project’s Category 1 QAPP as required by the EPA.

Acronyms and Abbreviations

ΔP – change in pressure
µg – microgram
A/O – Analog output
AC relay – Alternating Current relay
ACA – Air Compliance Agreement
ADM – Average daily means
AFO – Animal Feeding Operation
API – Advanced Pollution Instrumentation
ARS – Agricultural Research Service
ASCII- American Standard Code for Information Interchange
ASTM – American Society for Testing and Materials Standards
Atm – atmosphere
Atm – atmospheric pressure unit
Bar – a measurement unit of pressure
BESS – Bioenvironmental Structural Systems
Btu – British thermal unit
C – Celsius
c – critical
Cal-gas – calibration gas
CD – Compact Disc
CDD – Complete-data days
CH_4 – methane
CMOS – Complementary Metal Oxide Semiconductor
CO_2 – Carbon Dioxide
CPU – central processing unit
CS – Current Switch
CV – Coefficient of Variation
DAC/DAQ – Data Acquisition
DC – Direct Current
DHCP – dynamic host configuration protocol
DQO – data quality objectives
EH&S – Environmental Health and Safety
EPA – Environmental Protection Agency
ER – Emission Rate

F – Fahrenheit
FANS – Fan Assessment Numeration System
FEP (tubes) – Fluorinated Ethylene Propylene
FID – Flame Ionization Detector
FS – full scale
GC – Gas Calibration
g – gram
GSS – Gas Sampling System
H_2S – Hydrogen Sulfide
HD – hard drive
Hg – Mercury
hv – App. K wavelength
I/O – input/output
IFAFS – Initiative for Future Agriculture and Food System
WC – water column
IP – Internet Protocol
ISU – Iowa State University
kPa – kilopascals
L – Liter
LED – light emitting diode
LPM – Liters per minute
mA – miliAmps
MAEMU – Mobile Air Emissions Monitoring Unit
mBar – 10^{-3} atmosphere
MC – mass concentration
mL – milliliters
MR – Mass rate
MS – Microsoft
MSDS – material safety data sheet
mV – miliVolts
NA – Not applicable
NAEMS – National Air Emissions Monitoring Study
NAS – National Academy of Science
NH_3 – Ammonia

NI – National Instruments
NIST – National Institute of Standards and Technology
nm – nanometers
NMHC – Non-Methane Hydrocarbons
NPB – National Pork Board
NPT – National Pipe Tapered
NRI – National Research Initiative
NSRIC – National Swine Research and Information Center
OD – Outside Diameter
P – probability of Type 1 error
Pa – Pascals
PC – Personal Computer
PFA (Teflon)
pH – acidity scale
PI – Principle Investigator
PM – Particulate Matter
Ppb – parts per billion
Ppm – parts per million
PSF – pounds per square foot
PSI – pounds per square inch
PTFE (Teflon)
PVC (pipes)
QA – Quality Assurance
QAPP – Quality Assurance Project Plan
QC – Quality Control
R&P – Rupprecht & Patashnick, Co., Inc.
RH – Relative Humidity
RL – relative load
RS (232 mode)
RSC – Rotem Serial Cable
SIT – Sample Integration Times
SN# - serial number
SOP – Standard Operating Procedures
SP – Static Pressure
SP – Static Pressure
SP (control person)
STP – Standard Temperature and Pressure
SW – Sidewall
T – Absolute Temperature
TC – Thermocouple
TE – Tunnel End
TEMP. DIFF. – Temperature Differential
TEOM – Tapered Element Oscillating Microbalance
TF – Tunnel Fan
THAM – Tris hydroxymethyl aminomethance
THC – Total Hydrocarbons
THC (propane)
TM (computation)
TS – total solids
TSP – Total Suspended Particulate
UPS – Uninterruptable Power Supply
USB – universal serial bus
USDA – United States Department of Agriculture
UV – ultraviolet
V – Volt
VAC – Voltage Alternating Current
VDC – Voltage Direct Current
VI – virtual interface
VOC – Volatile Organic Compounds
Ω – Ohms

Table of Tables

Table of Figures

1.0 QA Project Plan Identification and Approval

Title: *Southeastern Broiler Gaseous and Particulate Matter Emission Monitoring*
Funding Agency: *Tyson Foods, Inc.*

The attached **Category 1** QAPP for the above titled study is hereby recommended for approval and commits Iowa State University and the University of Kentucky to follow the elements described within. Funding for this project is provided by a grant from Tyson Foods, Inc.

Robert T. Burns, Project Leader, Iowa State University	Date
Hongwei Xin, Project Leader, Iowa State University	Date
Richard S. Gates, Project Leader, University of Kentucky	Date
Steve Hoff, Project Leader, Iowa State University	Date

EPA APPROVALS

Sharon Nizich, EPA Project Manager	Date
Joe Elkins, EPA QA Officer	Date

2.0 Table of Contents

3.0 QAPP Distribution List

Individuals listed here will receive original and updated copies of the QAPP.

Robert Burns	Iowa State University
Hongwei Xin	Iowa State University
Hong Li	Iowa State University
Lara Moody	Iowa State University
Steve Hoff	Iowa State University
Richard Gates	University of Kentucky
Doug Overhults	University of Kentucky
John Earnest, Jr.	University of Kentucky
Steve Patrick	Tyson Foods
Kevin Igli	Tyson Foods
Steve Key	Tyson Foods
Sharon Nizich	EPA
Joe Elkins	EPA

The final approved QAPP will be available to all members of the project team. A bound copy of the document will be placed at both sites inside the Mobile Air Emissions Monitoring Unit (MAEMU). An electronic copy will be placed on the Internet for download by team members. The project team will be alerted of QAPP updates via an email indicating when and where they can obtain a revised version.

4.0 Project/Task Organization

4.1 Roles and Responsibilities

Principle Data Users
The United States EPA will be the principle users of data resulting from this project. As such, the project is following a Category 1 QAPP.

EPA Participants
Sharon Nizich is the EPA Project Manager for this study. Her role is to ensure that EPA's goals for the project are met and that proper steps and procedures are followed to provide high quality project data.

Joe Elkins is the EPA Quality Assurance (QA) Officer for this study. His role is to ensure that the project meets the QA requirements set forth in this document.

Tyson Participants (funding organization)
Steve Patrick is a contact between the project personnel and Tyson Foods. He will coordinate preparation of the sites, for example, the introduction/installation of power supply and high-speed Internet service for the MAEMU.

Kevin Igli is a contact between the project personnel and Tyson Foods. He is the primary coordinator between EPA and Tyson Foods. He is also the major decision maker on project funding.

Steve Key is the broiler service technician for the sites and assists the project team with production related issues, for example, providing the standard operation procedures of the broiler houses, and data concerning flock production conditions and performance.

Iowa State University and the University of Kentucky (research organizations)
Project Leaders Robert Burns, Hongwei Xin, Richard Gates and Steve Hoff are responsible for directing various actions occurring within the project, reviewing and approving the QAPP, and reviewing, analyzing and reporting the collected data.

Robert Burns is the lead Principle Investigator (PI) for the project. He is responsible for technical decisions made for the project, directing the project team, providing technical expertise, and submitting progress and final reports. He is also responsible for interacting with any media inquiries.

Hongwei Xin is responsible for providing technical expertise, assisting with the selection of monitoring equipment, and assisting with data review, analysis and reporting.

Richard Gates is responsible for coordinating scheduled daily and weekly operational and maintenance activities at the sites in Kentucky, maintaining a response team for flagged data excursions, overseeing regular fan calibration assessment using the Fans Assessment Numeration System (FANS) testing, and providing general logistical and technical expertise.

Steve Hoff is responsible for providing overall technical expertise and technical guidance on particulate sampling, and for assisting with data review, analysis, and reporting.

Hong Li is a research associate working on the project and is responsible for instrument testing and monitoring, data collection and analysis, and data reporting. Li remotely monitors the data collection system inside the MAEMU and performs the data reviews. He works closely with individuals performing the on-site monitoring in Kentucky. He is responsible for documenting the completion of between flock QAPP requirements.

Lara Moody is an extension program specialist. She is the Iowa State University (ISU) QA Manager. She prepares and maintains the QAPP, performs internal audits, and ensures that the QA procedures outlined in this document are performed accordingly.

Raj Raman is an associate professor in the Department of Agricultural and Biosystems Engineering at Iowa State University. He will serve as the supervisor for Lara Moody for matters related to this project and will review the QA Project Reports that she submits.

Doug Overhults is an associate extension professor stationed within 0.5 hour driving distance from the monitoring sites at the Western Kentucky Experiment Station in Princeton, Kentucky. He is responsible for directing regular on-site visits and for assisting with system installation and maintenance. He assists with QAPP documentation and site requirements during periods when animals are in the house and sampling is occurring.

John Earnest, Jr. is an agricultural engineering technician stationed within 0.5 hour driving distance from the monitoring sites at the Western Kentucky Experiment Station in Princeton, Kentucky. He is responsible for ensuring proper operation, regular calibration and maintenance of the measurement instrumentation. Earnest conducts regular site visits (at least once a week) and also assists in system installation. During the time between flocks, Earnest is responsible for litter sample collection. He assists with QAPP documentation and site requirements during periods when animals are in the house and sampling is occurring.

The project organization chart is shown in Figure 4.1.

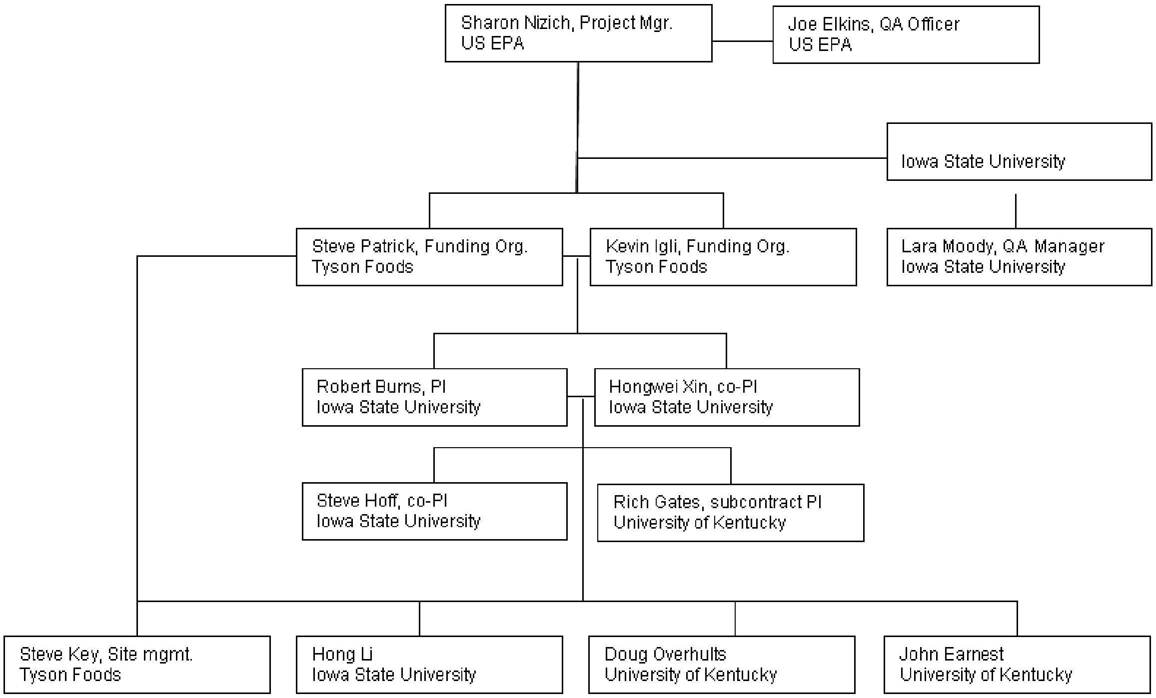


Figure 4.1. Project organization chart.

4.2 Participant Contact Information

Name	**Affiliation**	**Phone**	**E-mail**
Sharon Nizich	EPA	919-541-3078	nizich.sharon@epa.gov
Joe Elkins	EPA	919-541-5653	elkins.joe@epa.gov
Robert Burns	Iowa State University	515-294-4203	rburns@iastate.edu
Hongwei Xin	Iowa State University	515-294-4240	hxin@iastate.edu
Steve Hoff	Iowa State University	515-294-6180	hoffer@iastate.edu
Hong Li	Iowa State University	515-294-8633	lwblue@iastate.edu
Lara Moody	Iowa State University	515-294-7355	lmoody@iastate.edu
Raj Raman	Iowa State University	515-294-0465	rajraman@iastate.edu
Richard Gates	University of Kentucky	859-257-3000 x 127	gates@bae.uky.edu
Doug Overhults	University of Kentucky	270-365-7541 x 237	doverhul@uky.edu
John W. Earnest, Jr.	University of Kentucky	270-365-7541 x 237	jearnest@uky.edu
Steve Patrick	Tyson Foods	479-290-7541	steve.patrick@tyson.com
Kevin Igli	Tyson Foods	479-290-4055	kevin.igli@tyson.com
Steve Key	Tyson Foods	270-521-3038	steve.keys@tyson.com

4.3 Project Investigator and Team Member Qualifications

Resumes for the individuals carrying out the research are included in Appendix V. Below is a summary of the teams qualifications and experience; experience is shown as “barn months”. A "barn month" is calculated as the number of months spent monitoring a particular barn (for example, two broiler houses monitored for three months equals six barn months).

Robert Burns has fourteen years of experience working as an environmental engineer with air quality issues. In addition, he has worked closely with livestock and poultry production systems for the last eleven years. He has a unique combination of knowledge of both air quality issues and animal production systems. Dr. Burns holds a B.S. in Agricultural Engineering, an M.S. in Environmental Engineering and a Ph.D. in Civil Engineering (Environmental Engineering specialization) from the University of Tennessee. He is a licensed Professional Engineer (P.E.) and Certified Crop Advisor (CCA). Robert specialized in Air Pollution Control in both his Masters and Doctoral degrees. During his Masters degree he led the development of stationary and mobile source emissions inventories for volatile organic compounds and nitrous oxides for the State of Tennessee. Burns's Ph.D. focused on the finite difference modeling of photo-chemical formation of tropospheric ozone in the Southeastern United States. During his professional career Burns has published over 75 technical publications dealing with animal waste and air quality management, served as PI or Co-PI on 34 funded grants totaling $3,563,176 and served as a major or co-major professor to 16 engineering masters and doctoral students. In his current position, Burns' research focuses on animal waste management and includes work on measurement and mitigation of air emissions from animal feeding operations, phosphorus recovery, anaerobic digestion and solids separation. Burns's current research team is comprised of fifteen members and is currently working on projects involving the measurement or mitigation of air emissions from poultry broiler, layer and turkey production systems. Burns has a total of 114 barn months of agricultural air monitoring experience, all in broiler production.

Hongwei Xin has nearly 25 years of training and experience in animal environmental engineering research. The commencement of his field experience in monitoring the environment and quantifying aerial emissions for animal feeding operations dated back 17 years when he was a post-doc research associate at the University of Arkansas (1990-1993). At the University of Arkansas he conducted an extensive, automated 3.5-year monitoring of the housing environment, energy use, and production performance of four commercial-scale broiler houses owned by the University of Arkansas and two broiler houses owned by the cooperative producers. Since joining Iowa State University in December 1993, Xin and his associates (graduate students and post-docs) have independently and collaboratively conducted field monitoring on the following animal feeding operations: broilers (USDA-IFAFS project, in collaboration with colleagues at University of Kentucky and Penn State University), swine (farrowing and growing-finishing), pullets and laying hens, and growing turkeys. To date, Xin has totaled approximately 604 barn months of field monitoring for these species, of which 368 barn months were for the measurement of broiler housing air emissions. In addition, Xin has been collaborating with scientists in Brazil and China in monitoring and mitigating emissions of greenhouse gases (CH_4, CO_2, N_2O) and noxious gases (NH_3, H_2S) from animal feeding operations under some conditions that are unique to the respective countries. Since 2004 Xin has been serving as the Chair of the United Egg Producers Environmental Scientific Panel that has the mission to serve as a clearinghouse for the egg industry on the state of air emissions research and as an advisory body to the industry toward seeking practical means to mitigate air emissions from egg operations.

Richard Gates has nearly 15 years of experience monitoring and quantifying gaseous emissions from animal feeding operations. He has over 30 years of experience with broiler, layer, hog (grow-finish) and greenhouse operations, including designing systems for use in the United States, Japan, South Africa and Brazil. He has 216 barn months of experience monitoring broiler operations in Kentucky and Pennsylvania; 4 barn months monitoring layer operations in Iowa, and 12 barn months monitoring slurry from a hog grow-finish operation in Kentucky. He was PI on a recent USDA-IFAFS grant (with ISU and Penn State colleagues) to quantify ammonia emissions from U.S. poultry (layer and broiler) farms.

Steve Hoff has been involved with air quality issues associated with animal agriculture for the past 15 years, with the past 6 years devoted to odor transport; odor modeling; gas, virus and PM emissions; and gas and odor mitigation, all primarily from swine production systems. He has worked continuously on several air quality monitoring projects over the past six years. These in total comprise the following:
PSF Monitoring: 2 lagoon-barn combinations/month x 24 months = 48 barn months
IFAFS Monitoring: 2 barns/month x 20 months = 40 barn months
USDA-NRI A: 1 barn/month x 10 months = 10 barn months
USDA-NRI B: 2 barns/month x 8 months = 16 barn months
USDA-Special Grant: 2 barns/month x 18 months = 36 barn months
NPB: 2 barns/month x 9 months = 18 barn months

Hong Li has 4 years of experience monitoring and quantifying gaseous emissions from animal feeding operations. He has over 8 years of experience in agricultural environmental control. His research area is in environmental controls, air quality, and manure management systems. He has 30 barn months of experience monitoring layer operations in Iowa (USDA-IFAFS project).

Lara Moody has 7 years of experience working as an agricultural engineer in the area of animal waste management. She has 5 years of experience directing waste management laboratory operations and acting as a project coordinator on multiple projects. Research she has participated in focuses on animal waste management and includes work on waste treatment, nutrient management, phosphorus recovery, anaerobic digestion and solids separation at animal feeding operations.

Doug Overhults has over 25 years experience providing statewide Extension education programs related to the design and operation of facilities for swine and broiler production. His primary area of expertise is planning, analysis, and engineering design of efficient animal production facilities, environmental controls, structures, and manure management systems. He has worked extensively with mechanical ventilation systems, cooling systems, and control systems in both swine and broiler facilities. Dr. Overhults has 84 barn months experience in monitoring energy use and the performance of an integrated environmental controller in a broiler facility in Kentucky.

John Earnest has nearly 15 years of experience in utilization, application and design/fabrication of specialized agricultural equipment including energy monitoring equipment, power distribution, chemical application equipment, Global Positioning Systems, and specialized electrical and motor control systems. He had primary responsibility for on-site operation and maintenance of instrumentation and data collection systems for an extensive interior environment and energy use study at a broiler production site over a period of 72 barn months. He also has extensive experience with information technology including data collection and control software, AutoCAD, and ArcView and other Geographic Information System-related software.

5.0 Problem Definition/Background

A comprehensive review by the National Academy of Science (NAS) in 2002 regarding air emissions data pertaining to the U.S. animal feeding operations (AFOs) concluded that such data is lacking under U.S. animal production conditions. The review called for collection of baseline emission data and development of process-based models to predict such air emissions. In response to NAS recommendations, the United States Department of Agriculture (USDA) has made quantification of air emissions from AFOs one of the top priorities in its Initiative for Future Agriculture and Food System (IFAFS) Program and subsequently the National Research Initiative (NRI) Program. As a result, since 2002 great strides have been made toward collection of baseline air emissions from U.S. AFO facilities. Noticeable among the funded studies was the six-state (IA, IN, IL, MN, NC, TX) project on air emissions from cattle, swine and poultry facilities, and the three-state (IA, KY and PA) project on ammonia (NH_3) emissions from layers (in Iowa and Pennsylvania; Liang et al., 2005) and broilers (in Kentucky and Pennsylvania; Wheeler et al., 2006). Due to the unfortunate passing of the key project personnel for the broiler part of the six-state project at North Carolina, data on air emissions from broiler houses experienced difficulties. Hence, there is a lack of air emissions (except for ammonia) data for broiler housing systems. During this time period, more research findings on ammonia emissions from European broiler houses have been reported (Nicholson et al., 2004). However, information regarding emission rates of particulate matter (PM), hydrogen sulfide (H_2S) and hydrocarbons from broiler houses remains meager.

This study will be an integral part of the national air emissions monitoring study (NAEMS) resulting from the ACA that has been reached between the U.S. EPA and certain sectors of the animal industry. It will represent the southeastern broilers air emissions study. The aerial pollutants quantified in this monitoring study include ammonia (NH_3), carbon dioxide (CO_2), total suspended particulates (TSP), particulate matter 10 microns or less in aerodynamic diameter (PM_{10}), $PM_{2.5}$, hydrogen sulfide (H_2S) and non-methane hydrocarbons (NMHC).

The emissions data from this monitoring study is expected to be used primarily by, but not limited to, a) the U.S. EPA for development of emission estimation methodologies or emission factors for southeastern broiler operations; b) governmental agencies for improvement of national air emission inventories, c) the scientific community for development and/or verification of process-based emission models; d) the broiler industry as they continue to strive for lower air emissions through practical mitigation strategies.

There were two possible approaches considered for quantifying emissions from broiler houses. One approach was to monitor one broiler site for two years with a single monitoring system, as outlined in the ACA study. The other approach considered was to monitor two broiler sites with two sets of the monitoring system. The former approach requires less capital investment for the monitoring equipment and setup (since only one set of the monitoring system would be involved). The latter provides a wider spectrum and thus, more representativeness of the data in terms of farm-to-farm variations in flock management, daily operation styles, and bird performance. Statistically, it provides a farm replication. This latter approach also allows collection of twice the emission data of the first approach considered. Hence, we elected to use the latter approach (two barns on two separate sites) in this study.

6.0 Project/Task Description

6.1 Project Objectives

The objective of this study is to determine and report emissions of NH_3, CO_2, TSP, PM_{10}, $PM_{2.5}$, H_2S and NMHC based on semi-continuous pollutant concentrations (measured on 120-second intervals) and fan flow data (measured on 1-second intervals) over a one year period from two broiler houses representative of commercial broiler production in the southeastern United States. It is anticipated that this data will be used to represent southeastern broilers in conjunction with the National Air Emissions Studies.

6.2 Project Description

Two broiler houses associated with Tyson Foods broiler operations in western Kentucky are being monitored in this extensive field monitoring study. The location of the monitored facilities in Kentucky is shown in Figure 6.1, and the location of the specific houses at each site is shown in aerial photos in Figure 6.2. The monitored broiler production houses use tunnel ventilation and box air inlets along the sidewalls (see Figure 6.3), which is representative of the typical production practices in terms of housing style (e.g., tunnel ventilated) and environmental control strategy (e.g., pancake brooder along with space heaters), bird management (e.g., half-house brooding), and typical litter management and handling schemes (e.g., de-caking houses between flocks).

Each broiler house has its own Mobile Air Emissions Monitoring Unit (MAEMU) that houses air pollutant and fan flow monitoring systems and provides an environment-controlled instrument area as shown in Figure 6.4. Air samples from the broiler house sampling points (representing the exhaust air streams) to the instrument trailer/analyzers are protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable. Fan operational status and building static pressure are both continuously (on 1-second intervals) monitored. This data is used in conjunction with individual fan operation curves to calculate the flow rate exhausted by each fan during operation. A real-time data acquisition system (DAQ) program developed using LabView 7 software (National Instruments, Corporation, Austin, TX) is used to acquire data, automate sampling location control, display real-time data, and deliver data and system operation status as shown in Figures 6.5 and 6.6.

Each MAEMU houses a gas sampling system, gas analyzers, environmental instrumentation, a computer, data acquisition system, and other equipment needed for the study. Each building will be sampled continuously for 12 months. Gaseous and particulate matter sampling occurs when the house ventilation system is in operation. Gaseous samples are continuously collected and analyzed every 30 seconds, with every fourth concentration value used to calculate emissions. Using this approach gaseous emissions are sampled continuously on a 120-second interval. All three types of particulate matter (TSP, PM_{10}, $PM_{2.5}$) concentration are being sampled continuously with concentrations recorded on a 1-second interval. The 12-month duration assures this project will meet the objectives of characterizing long-term emissions and to respond accurately to the need for annual emission factors from animal facilities by regulatory agencies and others. Long-term measurements allow the recording of variations in emissions due to seasonal effects, animal growth cycles, and diurnal variations.

6.3 Project Personnel Requirements

The personnel required to sucessfully collect the emissions data at the level of quality that meets the Category 1 QAPP criteria include various professionals/individuals with specific skills. Namely, the project personnel have a strong working knowledge of southeastern broiler production systems, knowledge and experience to design, manufacture, and install the emissions sampling and data collection systems, training in the operation and maintenance of the emissions data collection systems, and knowledge and experience in data analysis and quality assurance. Our project team includes eleven senior project personnel including project investigators, post-doctoral research associates, masters level research associates, a QAQC coordinator and a number of undergraduate students who provide hourly assistance during installation of the air sampling and data collection systems in/for the broiler houses. Section 4.0 of this document provides a detailed explanation of the roles and responsibilities of all the regular project members. Table 6.1 provides a brief listing of the primary personnel requirements associated with each of the major pieces of monitoring equipment used in the project. More detailed descriptions of personnel resonsibilities are provided in Section 4.0.

6.4 Project Equipment Requirements

The primary pieces of equipment utilized in the monitoring study are listed in Table 6.1. In order to collect air emissions data on a continuous basis, all selected monitoring equipment feature automatic operation. This allows for continuous collection of air samples and continuous analysis of sample concentrations. Monitoring of fan operational status and building static pressure is also automatic to facilitate continuous calculation of individual fan airflow. As indicated in Table 6.1, all emissions monitoring data is transferred as a digital signal with the exception of the on/off status of each fan, which is indicated as an analog signal. Detailed descriptions of each piece of equipment selected for this study can be found in Section 12.0 – Sampling Methods Requirements.

Table 6.1. Project measurement equipment and personnel requirements.

Project Measurements*	**Method**	**Data Type**	**Equipment Requirement****	**Personnel Requirement**
NH_3	Automated	Digital	INNOVA 1412	Unit Calibration & Maintenance, Data Transfer, & Data Review
CO_2	Automated	Digital	INNOVA 1412	Unit Calibration & Maintenance, Data Transfer, & Data Review
TSP	Automated	Digital	TEOM 1400	Unit Calibration & Maintenance, Mid-Flock Unit Move, Data Transfer, & Data Review
PM_{10}	Automated	Digital	TEOM 1400	Unit Calibration & Maintenance, Mid-Flock Unit Move, Data Transfer, & Data Review
$PM_{2.5}$	Automated	Digital	TEOM 1400	Unit Calibration & Maintenance, Mid-Flock Unit Move, Data Transfer, & Data Review
H_2S	Automated	Digital	API 101 E	Unit Calibration & Maintenance, Data Transfer, & Data Review
NMHC	Automated	Digital	VIG 200	Unit Calibration & Maintenance, Data Transfer, & Data Review
Barometric Pressure	Automated	Digital	WE 100	Unit Calibration, Data Transfer, & Data Review
Temperature	Automated	Digital	Type T Thermocouple	Unit Calibration, Data Transfer, & Data Review
Static Pressure	Automated	Digital	Setra 264	Unit Calibration, Data Transfer, & Data Review
Ventilation Fan Operation	Automated	Analog Signal	Current Switch	Data Transfer, & Data Review
Relative Humidity	Automated	Digital	HMW 61U	Unit Calibration, Data Transfer, & Data Review
Litter N Content	Manual	Numeric	Rapid Still II and Digester	Sample Collection & Laboratory Analysis

* For detailed information about these measurements, see Section 12.

**For specific information about the required equipment, see Appendix U.

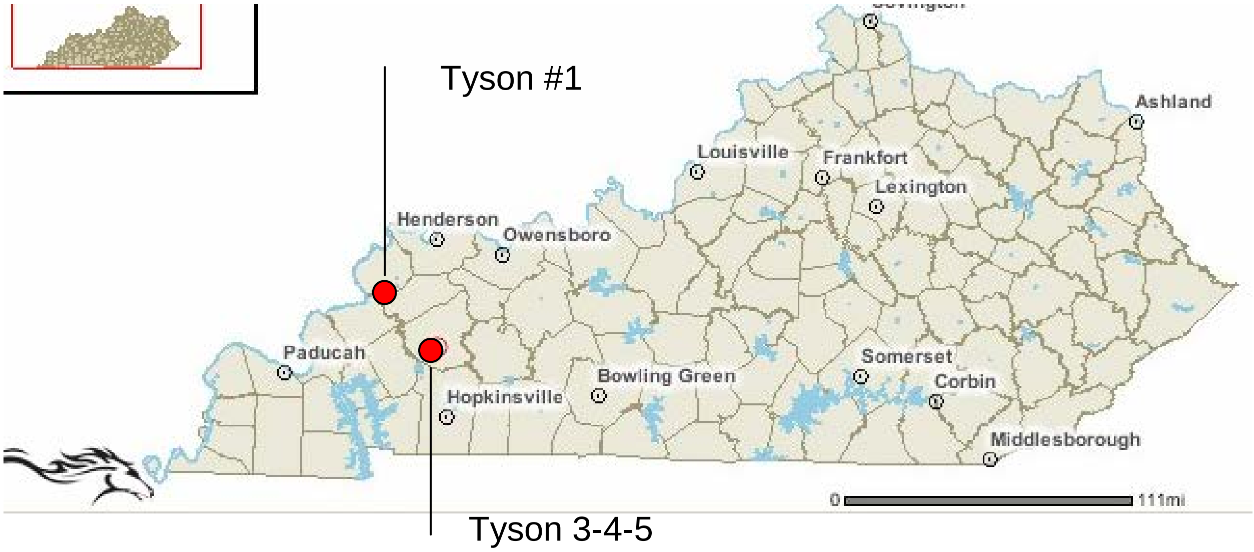


Figure 6.1. Locations of measurement sites in Kentucky.

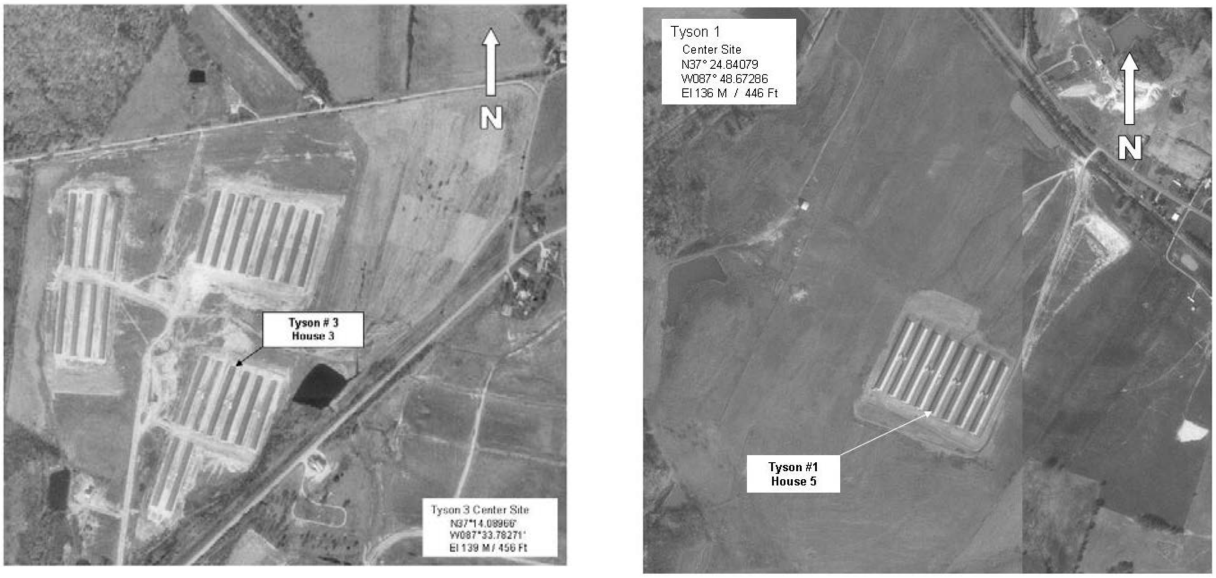


Figure 6.2. Aerial pictures indicating the locations of each monitored broiler house.

Figure 6.3. Tunnel fans and box air inlets representative of typical southeastern broiler facilities.

Figure 6.4. Environmentally controlled Mobile Air Emissions Monitoring Units (MAEMU).

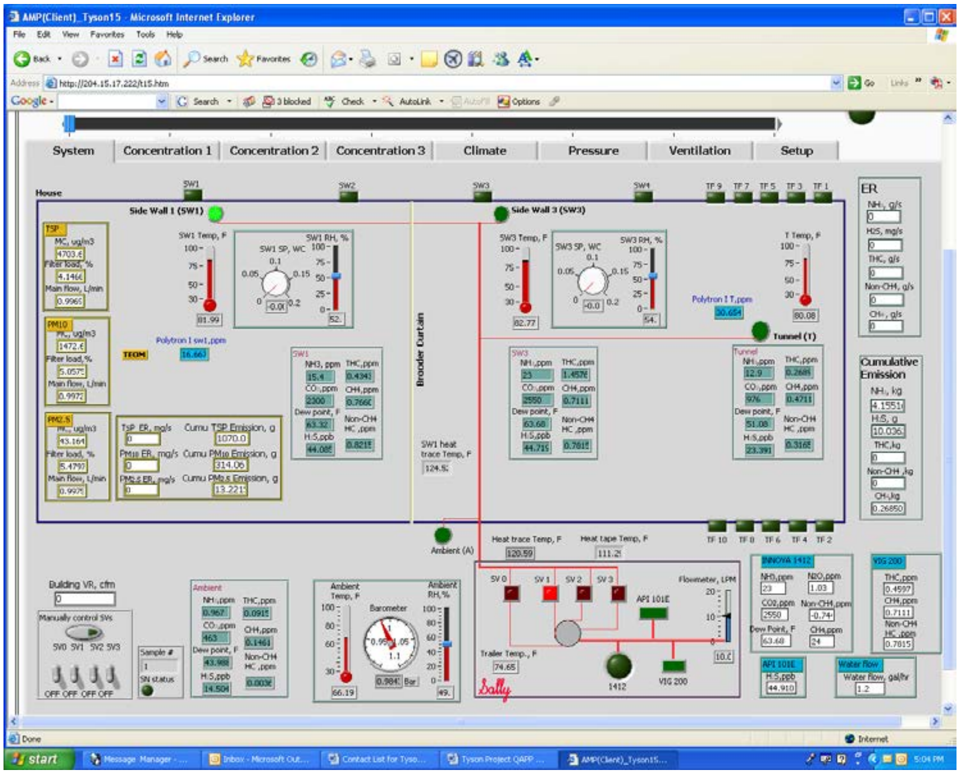


Figure 6.5. Screen display of the broiler emissions monitoring program developed in LabView 7.

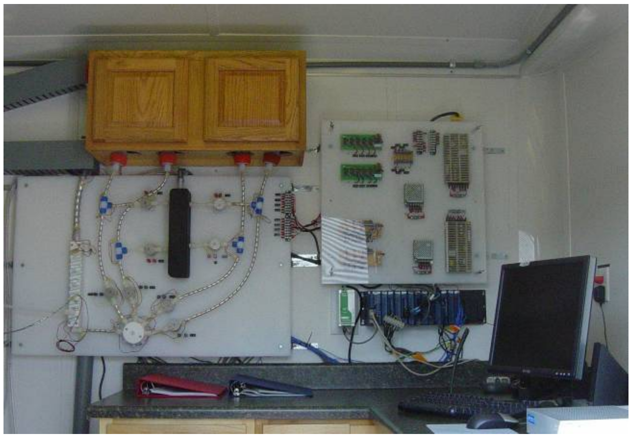


Figure 6.6. View of hardware required to run pollutant sampling system.

6.5 Project Schedule and Milestones (March 2005 to October 2007)

Table 6.2 provides the schedule for this project. Because this project is tied to a broiler NH_3 emissions study that began in the 2nd quarter of 2005, the project schedule outlined in Table 6.2 had to be implemented in order to ensure that the planned monitoring could be completed with the available funding. The original NH_3 monitoring study that began in 2nd quarter of 2005 was expanded in the 4th quarter of 2005 to include CO_2, TSP, PM_{10}, $PM_{2.5}$, H_2S and NMHC as well as NH_3. Monitors for all pollutants were successfully installed at the sites in January 2006. A series of performance tests were conducted in January and February 2006 to confirm that the monitoring systems were working as designed and to determine representative locations for air sampling points and TEOM placement. Study data collection for all pollutants of interest formally began on February 20, 2006 with the placement of a new flock of birds in the houses. Emissions data for all pollutants will be collected through February 2007, or until the flocks of broilers in the houses on that date, have completed the production cycle. In effect, emissions monitoring will be continued until the flocks in the houses on February 20, 2007 have been removed from the houses to ensure that emissions from more than one full year (five to seven flocks) of production is monitored at each of the two broiler houses.

Table 6.2. Project Schedule

	2005	2006				2007		
	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.	4th Qtr.	1st Qtr.	2nd Qtr.	3rd Qtr.
Purchase Monitoring Equipment	X							
Prepare QAPP	X	X						
EPA Review of QAPP		X	X					
QAPP Revisions			X	X				
Prepare Monitoring Trailers	X	X						
On-site Equipment Installation	X	X						
Monitoring System Testing		X						
Collect Data		X	X	X	X	X		
Analyze Data			X	X	X	X	X	X
Mid-Term Progress Report				X			X	
Final Emissions Report								X

Major project milestones are provided in Table 6.3. In addition those milestones that have been completed to date are so noted along with their date of completion.

Table 6.3 Project Milestones

Project Milestone	**Status**	**Completed Date**
Submit QAPP to EPA	Completed	3/01/06
Install all emissions monitoring equipment	Completed	1/06/06
Performance testing of emissions monitoring system	Completed	2/10/06
Begin Collection of Study Data	Completed	3/20/06
Receive QAPP comments from EPA	Completed	4/12/06
Revised QAPP Submitted	Completed	8/03/06
Revised QAPP Approved by EPA		
Mid-Term Progress Report		Due 3rd Quarter 2006
Late-Term Progress Report		Due 2nd Quarter 2007
Final Emissions Report		Due 3rd Quarter 2007

7.0 Quality Objectives and Criteria for Measurement Data

7.1 Data Quality Objectives

Background

The overall objective of this data acquisition project is to generate data of sufficient quality to satisfy the research objectives of the project stated above. Data will undergo quality assurance review, which will assess, among other things, data representativeness, data completeness, comparability, and accuracy (U.S. EPA document QA/G-5).

The intended use of the collected data is to provide an estimation of daily emissions of gases and particulates (emissions of NH_3, TSP, PM_{10}, $PM_{2.5}$, H_2S and NMHC) from commercial broiler production houses in the southeastern U.S. The collected data will provide insight into temporal variability (as birds age, seasonal effects, and other temporal effects) and spatial variability (two houses on two separate sites are monitored). This variability has been previously estimated in earlier studies in Kentucky and Pennsylvania broiler houses (Wheeler et al., 2006) and bird age was found to be the predominant factor in variation over time. Variation between houses (eight houses on two sites in Kentucky, and four houses on two sites in Pennsylvania) was found to be relatively small when other factors were held constant (e.g., bird age).

Data Quality

Data representativeness is ensured by the overall sampling design, which includes high frequency sampling over a 12-month measurement period at two similar broiler operations at different locations. This is described in detail in Section 11 – Sampling Process Design. Underlying theoretical considerations that impact the representativeness of data by direct or component determination are outlined in this section.

“Data completeness is a measure of the amount of valid data obtained from a measurement system, expressed as a percentage of the number of valid measurements that should have been collected” (USEPA. 1998. *EPA Guidance for Quality Assurance Project Plans*. EPA QA/G-5). Data completeness is achieved by ensuring that valid building emission data obtained from the measurement system is no less than 75% of the scheduled sampling. A greater percentage does not seem reasonable with potential lightning strikes, equipment breakdowns, university and broiler integrator schedules, and farm related problems. Using total daily emissions as the primary Data Quality Objectives (DQOs), we thus require a minimum of eighteen hours of sampling for daily emission to be used. Data completeness is ensured by 1) using properly maintained and reliable instrumentation, 2) maintaining a ready supply of spare parts, 3) installing electrical backups such as uninterruptible power supplies, 4) regular calibration checks, 5) frequent remote access to the DAQ computer, and 6) local broiler production management collaboration and cooperation.

Data comparability is maintained by 1) employing equivalent analytical methods (where appropriate and available methods exist), and a sampling protocol used in recent emission studies in confined livestock and poultry facilities, 2) comparison of measurements with previous mass balance and emissions rate measurements reported for poultry buildings, and 3) through the use of common equipment and protocols at both sites.

7.2 Measurement Performance Criteria

According to EPA QA/G-5, p 27:

> "Measurement performance criteria for new data collection efforts are stated in terms of the desired (assumed) level of uncertainty in data that will be used to address the study question or support the decision. When possible, it is desirable to state measurement performance criteria in quantitative terms, such as limits on analytical imprecision, bias and method detection limits, and limits on the overall variance of study results (to include spatial and temporal variability)."

Thus, in the remainder of this section we provide background on the DQO to justify and document our selection of acceptable limits on uncertainty in the emissions data, denoted as ER (Emission Rate), and expressed on a mass of constituent emitted from the building in a consecutive 24-hour period normalized to a per-bird basis. For example, ammonia ER is expressed in kg NH_3 bird^{-1} day^{-1}. This unit is selected so that ER from broiler houses with different numbers of birds can be compared and provide information regarding spatial variability in the data.

Accuracy is a two-part quality indicator and includes both bias (systematic error) and precision (random error). **Accuracy** is a measure of the closeness of an individual measurement or the average of a number of measurements to the true value (EPA QA/G5). Accuracy of the measured value will be expressed in terms of the percentage decrease or increase from the known value and in terms of the absolute difference between the measured and known value. **Precision** is a measure of agreement among replicate measurements of the same property, under prescribed similar conditions (same source). Precision is defined as the standard deviation of replicate measurements of the concentration of a known pollutant expressed as a percentage difference from the known value. Concentration measurement accuracy (bias and precision) is maintained by regular calibration of the instruments that involves challenging the measurement system to perform replicate analyses of samples with known concentrations. Ventilation rate measurement accuracy is maintained by regular testing of fans at the start and end of the study, and a select subset of fans after each flock is completed. In all cases, a clear schedule of calibration is documented and adhered to.

Static Calibration is a formalized methodology for removing measurement bias and quantifying measurement precision (Doeblin, 1990). A static calibration in which measurements are regressed against "true" or standard values with equivalent units, allows for direct quantification of precision from the standard error of the regression, and a hypothesis test regarding whether bias exists (e.g., non-unity slope). If bias exists, it is removed by inversion of the calibration regression, and the standard error of regression is adjusted by dividing by the (non-unity) slope of regression. This standard error (s) can then be utilized to make meaningful statistical bounds on the uncertainty of a measurement post-calibration, for example, by the use of 2-s limits and assuming normally distributed random errors, the point estimate from the instrument is within 2-s limits or ±2.5% of the "true" value. This also assumes that the value(s) for the standard used in the calibration is of much greater absolute accuracy, somewhat problematic for example with calibration gases that are at best 2-3% of stated value.

For example, the FANS system used to calibrate individual ventilation fans has been demonstrated to exhibit an imprecision of 139 m^3 h^{-1} (83 cfm) (Gates et al., 2004) as represented by the (adjusted) standard error of regression for 10 FANS units calibrated at the University of Illinois BioEnvironmental and Structural Systems (BESS) Laboratory. Three sigma (3s) limits (which comprise 99.7% of expected error) on the precision of fan ventilation rate are thus on the order of 417 m^3 h^{-1} (237 cfm), remarkably accurate for fans that nominally run at 17,000 to 34,000 m^3 h^{-1}. To state the FANS accuracy in terms of precision as is defined in EPA QA/G5, requires knowledge of the actual flow rate, since accuracy is expressed on a percentage basis. For example, this 417 m^3 h^{-1} accuracy translates to a 2.4% error for a single sidewall fan at a nominal 17,000 m^3 h^{-1} flow; but 1.2% error for a 48-inch tunnel fan with a nominal 34,000 m^3 h^{-1}. As a consequence, while it may be considered convenient to express the DQOs in terms of percent imprecision, it is important to recognize that small absolute errors in measurement may be expressed as large relative errors on a percentage basis. For example, the same 3s limit applied to a 1,700 m^3 h^{-1} flow rate yields an "imprecision" of 24% using the G5 definition (see Gates et al., 2004, for additional analysis and discussion). A similar statement may be made for each of the concentration measurements in this study.

Because of the continuous nature of our concentration measurements, static calibration is critical, and especially important to remove bias and to reduce the measurement uncertainty to that of the instruments' effective random errors. This can be understood by considering the cumulative effect that a biased concentration reading would have on estimation of daily ER. For sake of brevity, assume constant concentration and constant ventilation rate over a 24-h period, and assume a 10% positive bias in the concentration reading. We would then see a 10% under-prediction of ER for the 24-h period. If instead the measurement error in concentration was 10% of reading, but it was completely random and centered about zero, then we would expect an error in ER of ±5% or less.

Dynamic response of instruments is important for proper sampling frequency for locations within a site. In this study, a single instrument is used to sample gas concentration data from two to four locations on a site (one outside measurement for background and up to three locations within each broiler house). Each instrument may exhibit different transient response characteristics when multiplexed across multiple locations, and to measure different gases. A sufficient number of samples at one location must be taken to ensure that the instrument's settling time is exceeded. **Settling time** is defined as the time required by an instrument to achieve and remain within a specified tolerance band around the assumed constant final value. For example, a 5% settling time means the time required for an instrument to achieve and remain within 95 to 105% of the final value. Our research suggests that the critical gas measurement (with maximum settling time) in this study is ammonia. Figure 7.1 illustrates that a 4% settling time equates to nearly 2 min (Moody et al., 2006). Thus, to ensure that an accurate sample is acquired, repeated sampling at a location should occur for 120 s before multiplexing to another location.

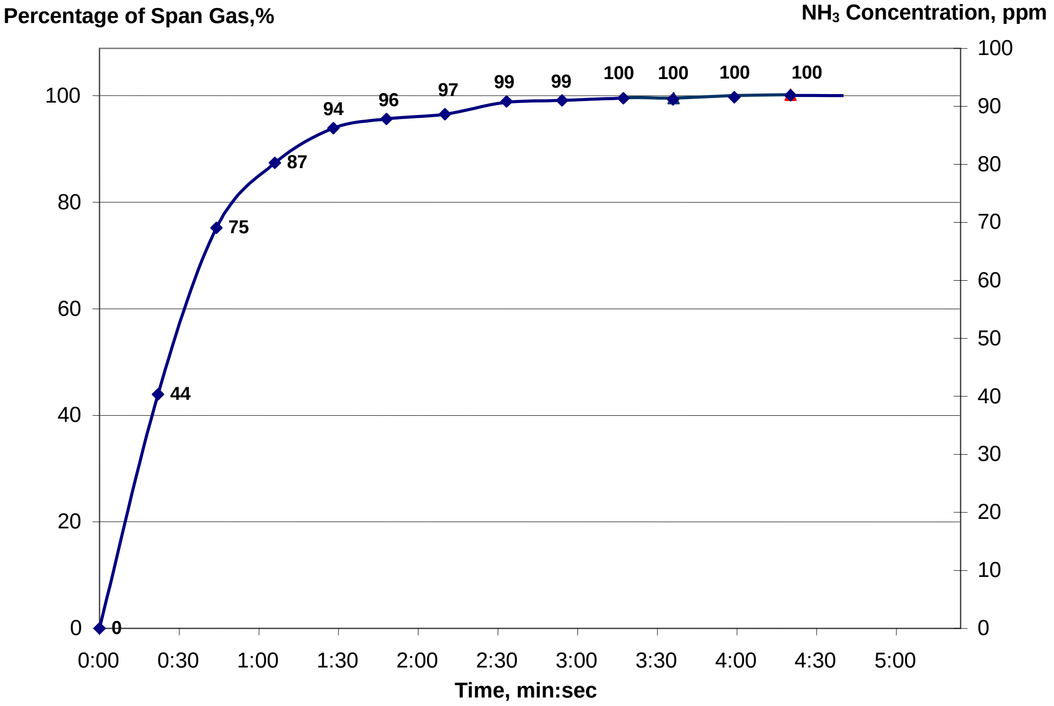


Figure 7.1. INNOVA analyzer dynamic response to step change in ammonia. The settling time is approximately 120 s to better than 96% of true span (100% = 100 ppm).

The dynamic response characteristic exhibited in Figure 7.1 is typical of a first order measurement system (Doeblin, 1990). For first order instruments, a 5% settling time corresponds to 2 time-constants (2τ), which indicates that the time constant for the Innova 1412 is about 65 s when measuring ammonia.

7.3 Component Error Analysis

Component Error Analysis is is a necessary tool to quantify uncertainty when a quantity such as daily emission rate is calculated from multiple measurements, each with its own degree of accuracy. A component error analysis (Doeblin, 1990) is a useful means for providing statistical meaning to a statement on the magnitude of error in the calculation of daily emission rate. This analysis has been performed for an earlier project that measured broiler house ammonia emissions and documented in a Ph.D. dissertation (Casey, 2005). Key assumptions included 2% accuracy on ammonia calibration gas, accuracy on ventilation rate as described above using

FANS and protocol, and either 1% or 3 ppm accuracy on ammonia measurement (to compare effect of electrochemical sensors versus photo-acoustic analyzers). For purposes of this DQO, only the 1% accuracy on gas concentration is of interest since that corresponds to the previously selected gas concentration measurement instrumentation.

A manuscript (in preparation) on this topic, for broiler house ammonia emissions, was used in the following description (Casey et al., 2006). In general, since ER is computed as the sum of multiple ER values obtained from measurements over the course of the day, with each ER computed from the product of ventilation rate and concentration difference, the two key measurements affecting the uncertainty of daily ER are the uncertainties associated with these key measurements. As has been previously discussed, the uncertainty on individual fan ventilation rate is under 3% when using 3-s limits. However, it is likely that uncontrolled factors between calibrations can increase this uncertainty to 10%, and it is likely that the error in ventilation rate will tend to be biased towards over-estimation, i.e., as fans become dirty their performance degrades yet the calibration curves are for clean fans, with resultant over-estimation in emission rate. Concentration data for the various gas and dust constituents in this study are 1% or better (Table 7.1), with a 5% limit for required recalibration.

Table 7.1. Sampling parameter and equipment quality control objectives.

Parameter	Sample Matrix	Analyzer Matrix	Detection Limit	Quantitation Limit	Estimated Precision	QC Check	QC limit	Action
NH_3	Air	INNOVA 1412	0.2 ppm	2000 ppm	±1%	weekly	5%	Calibrate
CO_2	Air	INNOVA 1412	3.4 ppm	34,000 ppm	±1%	weekly	5%	Calibrate
CH_4	Air	INNOVA 1412	0.4 ppm	4000 ppm	±1%	weekly	5%	Calibrate
Non-CH_4	Air	INNOVA 1412	0.02 ppm	200 ppm	±1%	weekly	5%	Calibrate
H_2S	Air	API 101E	0.4 ppb	20000 ppb	±0.5%	weekly	5%	Calibrate
CH_4	Air	VIG 200	0.1 ppm	100	±1%	weekly	5%	Calibrate
Non-CH_4	Air	VIG 200	0.01 ppm	10	±1%	weekly	5%	Calibrate
Temperature	Air	Type T Thermocouple	-40ºC	50ºC	0.5ºC	Every flock	0.5 ^{o}C	Calibrate
RH	Air	HMW 61U	2%	95%	2%	Six months	5%	Calibrate
S. Pressure	Air	Setra 264	2 Pa	125 Pa	±1%	Six months	5%	Calibrate
Barometric pressure	Air	WE100	0.8 bar	1.1 bar	±1%	Six months	5%	Calibrate
TSP	Air	TEOM 1400	0.01 ug/m^3		±5 ug/m^3	Yearly	5%	Calibrate
PM10	Air	TEOM 1400	0.01 ug/m^3		±5 ug/m^3	Yearly	5%	Calibrate
PM2.5	Air	TEOM 1400	0.01 ug/m^3		±5 ug/m^3	Yearly	5%	Calibrate
Fan flow rate	Air				200 m^{3}h^{-1}	Every flock	10%	Calibrate
Fan run time	Air	Current Switch	1.0 Aac	100 Aac		Every flock		Replace on failure

A component error analysis (Casey, 2005; Casey et al., 2006) suggests that if 3-s limits on ventilation rate and 1% accuracy on ammonia can be maintained (this is the standard DQO for this project) then the uncertainty in ER is 2-3%. Uncertainty decreases as the number of fans being used increases, and is largely unaffected by ammonia concentration in the building over the range of 10 to 100 ppm. Increasing both ventilation uncertainty (to 10% of reading) and ammonia concentration uncertainty (to 3 ppm) causes substantially greater uncertainty in ER, with a range from 4.9% (8 fans, 100 ppm) to 19% (1 fan, 10 ppm).

While this analysis was carried out specifically for ammonia, it applies equally to all gaseous contaminants being measured in this study, which have stated accuracies of 1% or better. For particulates the analysis also applies, but since the particulate accuracy is represented in terms of an absolute mass concentration (5 ug/m^3), it is directly applicable to concentrations greater than 500 ug/m^3.

From this component error analysis, it is clear that careful control of ventilation rate uncertainty is critical for controlling ER uncertainty, and has probably contributed to the majority of error in such measurements prior to the implementation of the FANS methodology with regular calibration of individual fans. For this project, uncertainty in ER should be maintained at less than 10% using the instrumentation listed in Table 7.1 and the methodology outlined in the QAPP. Typical uncertainty in ER, based on 2-or 3-s limits, is expected to be under 3%.

7.4 Effect of Background Concentration and Air Density Effects on ER

The component error analysis cited (Casey, 2005; Casey et al., 2006) neglected background ammonia concentration. Other studies have incorporated background concentration but have performed a pseudo-mass balance that neglects effects of differing air densities between outside and inside air. This section outlines the error associated with these two omissions. In general, the impact of these omissions on ER for the methods proposed in this study, are inconsequential. However the ER methodology employed in this study properly accounts for both background concentrations and differences in air density. This analysis is provided to demonstrate the order of errors involved in prior analyses in which they were neglected when quantifying ER errors.

Building emission rate of any substance, ER, is given by:

$$ER_{[g]} = Q_e \left(\frac{[G]_e}{T_e} - \frac{\upsilon_i}{\upsilon_e} \times \frac{[G]_i}{T_i}\right) \times 10^{-6} \times T_{std} \times \frac{P_a}{P_{std}} \times \frac{w_m}{V_m}$$

where:

$ER_{[g]}$ = Gas emission rate for the house, g hr^{-1} house^{-1}
Q_e = Exhaust ventilation rate of the house at field temperature and barometric pressure, m^3 hr^{-1} house^{-1}
$[G]_i$, $[G]_e$ = Gas concentration of incoming and exhaust house ventilation air, respectively, parts per million by volume (ppm$_v$)

w_m = molar weight of the gas, g $mole^{-1}$ (17.031 for NH_3)
V_m = molar volume of gas at standard temperature (0°C) and pressure (101.325 kPa) or STP, 0.022414 m^3 $mole^{-1}$
T_{std} = standard temperature, 273.15 °K
T_i, T_e = absolute temperature of incoming and exhaust air, respectively, °K
P_{std} = standard barometric pressure, 101.325 kPa
P_a = atmospheric barometric pressure at the monitoring site, kPa
ν_i , ν_e = specific volume of incoming and exhaust air, respectively, m^3 moist air per kg dry air, calculated from air temperature and RH

Specific volume of moist air at (T, P_a) is computed from:

$$\nu = \frac{R_{da} T (1 + 1.6078 W)}{P_a}$$

where:

R_{da} = dry air universal gas constant, 287.055 J kg^{-1} K^{-1}
W = humidity ratio, kg water vapor kg^{-1} dry air

Humidity ratio at a given temperature and relative humidity obtained from:

$$W = \frac{0.62198 P_w}{P_a - P_w}$$

$$P_w = \phi P_{ws}$$

$$\ln(P_{ws}) = C_1/T + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 T^4 + C_7 \ln(T)\,; \quad -100 < t < 0\ {}^{o}C$$

$$\ln(P_{ws}) = C_8/T + C_9 + C_{10} T + C_{11} T^2 + C_{12} T^3 + C_{13} \ln(T)\,; \quad 0 < t < 200\ {}^{o}C$$

where:

ø = relative humidity, decimal
P_w = water vapor partial pressure, Pa
P_{ws} = water vapor saturation pressure, Pa
$C_1..C_{13}$ = given e.g. ASHRAE HOF (2005) page 6.2 equations 5 and 6

The specific volume ratio ν_i/ν_e, is:

$$\frac{\nu_i}{\nu_e} = \frac{T_i (1 + 1.6078 W_i)(1 + W_e)}{T_e (1 + 1.6078 W_e)(1 + W_i)}$$

Substitution into the equation for ER gives:

$$ER_{[g]} = \frac{Q_e}{T_e} \left\{ [G]_e - [G]_i \frac{(1 + 1.6078 W_i)(1 + W_e)}{(1 + 1.6078 W_e)(1 + W_i)} \right\} \times 10^{-6} \times T_{std} \times \frac{P_a}{P_{std}} \times \frac{w_m}{V_m}$$

The effect on $ER_{[g]}$of neglecting background concentration $[G]_I$ is quantified in the following table for a broad range in expected indoor and outdoor temperature and humidity ratios. The following points can be made:

1. Neglecting a positive, non-zero background concentration can over-predict ER
2. The specific volume ratio ν_i/ν_e provides a multiplier of 103% to 115% to the background concentration, resulting in potential further over-prediction
3. The greatest over-prediction will occur during the coldest and driest outside conditions coupled with the warmest and most humid interior conditions, and is about 15% for typical Kentucky winter time brooding conditions.
4. Note that the adjustment in the table below is applied to the background gas concentration, not the ER. Thus, the error in ER from neglecting density effects is less than 15% of the back-ground concentration; the error in ER from neglecting background concentration depends on the magnitude of $[G]_e$ and $[G]_i$.

Table 7.2. Temperature and Humidity adjustment ratio of air emissions.

Comment	Humidity Ratio, (kg H_2O/kg dry air)		Air Temperature (K)		Adjustment
	Inlet **W_i**	Exhaust **W_e**	Inlet **T_i**	Exhaust **T_e**	**ratio***
winter brooding	0.000	0.020	263	306	115.0%
winter growout	0.002	0.012	263	293	110.7%
fall/spring brooding	0.004	0.020	273	306	111.0%
fall/spring dry interior	0.004	0.010	273	306	111.7%
fall/spring growout	0.004	0.010	283	293	103.2%
summer brooding	0.010	0.020	293	306	103.8%
summer growout	0.010	0.012	283	293	103.4%

* multiply background [ppm] by "ratio" to get adjustment for air density differences

7.5 Summary

In summary, the **Measurement Performance Criterion for daily ER** obtained in this project has been selected to be better than 10%. To achieve this performance, individual instrumentation performances must be appreciably better so that the combined errors, as described above, result in daily ER estimates with this level of certainty.

8.0 Special Training/Certification

8.1 Field Activities

All individuals involved in data collection are instructed on use of the monitoring equipment and the use of the remote access software to view the current status of the DAQ system in real-time. A set of standard operating procedures (SOPs) were written for individuals involved in the project and they are included in the Appendices of this document. The following is a list of the included SOPs:

1. Appendix B: SOP of Gas Sampling System
2. Appendix C: SOP of Field Estimation of Ventilation Capacity using FANS
3. Appendix D: SOP of INNOVA 1412 Photoacoustic Multi-gas Monitor
4. Appendix E: SOP of Temperature and Humidity Measurement
5. Appendix F: SOP of Differential Static Pressure Transducers
6. Appendix G: SOP of Compact Fieldpoint Modules
7. Appendix H: SOP of Using Remote Panel of Southeast Broiler Emission Monitoring Program
8. Appendix I: SOP of Data Management at ISU
9. Appendix J: SOP of Reporting and Calculation of Containment Concentration, Ventilation, and Emissions
10. Appendix K: SOP of Model 101EUV Fluorescence H_2S Analyzers, API 101E
11. Appendix L: SOP of VIG Model 200 Hydrocarbon Analyzer
12. Appendix M: SOP of Tapered Element Oscillating Microbalance (TEOMs) for TSP
13. Appendix N: SOP of Tapered Element Oscillating Microbalance (TEOMs) for PM_{10}
14. Appendix O: SOP of Tapered Element Oscillating Microbalance (TEOMs) for $PM_{2.5}$
15. Appendix P: SOP of Barometric Pressure Sensor
16. Appendix Q: SOP for use of Rotem RSC-2 Scale System
17. Appendix R: SOP for Fan Current Switch Application

University of Kentucky personnel (John Earnest and Doug Overhults), making one or more monitoring site visits weekly, were trained in the use, maintenance and calibration of all monitoring instruments (gas sampling system, TEOMs, and the overall use and operation of the MAEMU) by ISU project personnel (Hong Li, Robert Burns and Hongwei Xin).

The live production managers and facility managers at each site are trained by project team members Robert Burns and John Earnest, concerning how the in-house components of the monitoring system function. Production managers and facility managers are provided with contact information for project personnel and a list of responsibilities (Figure 8.1).

Dates of the trainings, a list of participants, and the topics included are recorded and filed by the QA Manager each time a session occurs. Because there is a high turnover rate for production facility managers, training sessions are held and recorded on an as-needed basis.

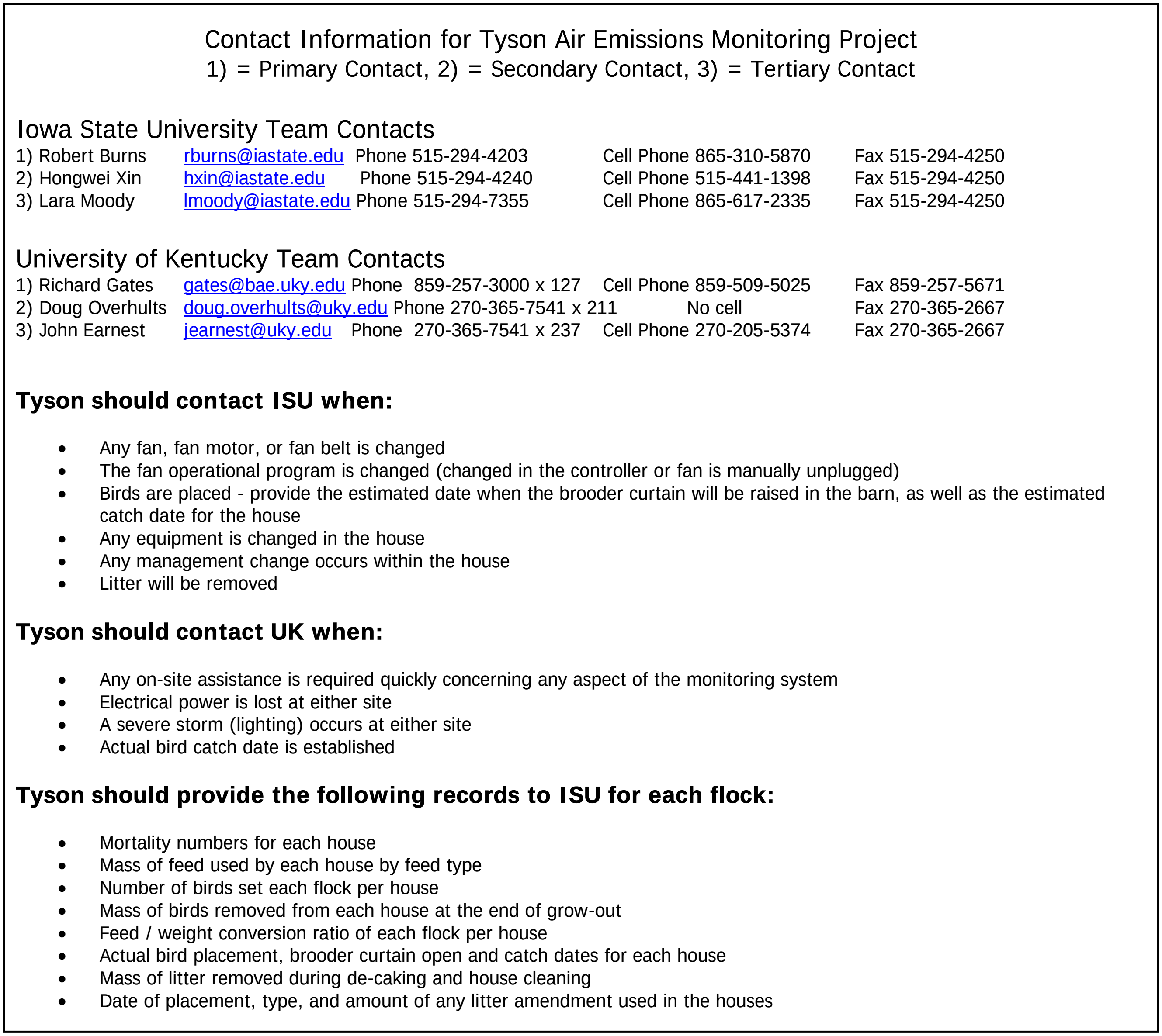
8.2 Laboratory Activities

Laboratory activities for this project include archiving, reviewing, and processing of data and litter sample analysis. SOPs for managing and processing emissions data are included in the following Appendices:

1. Appendix I: SOP of Data Management at ISU
2. Appendix J: SOP of Reporting and Calculation of Containment Concentration, Ventilation, and Emissions

Hong Li is handling all the data management and processing activities. For a description of his qualifications and training that has prepared him to work in this area, please see Section 4.3 of this document.

The litter sample analyses are performed in the ISU Agricultural Waste Management Laboratory. Individuals processing the samples and handling the analyses are trained by the Laboratory Director. Training documentation is archived by the QA Manager.



Contact Information for Tyson Air Emissions Monitoring Project
1) = Primary Contact, 2) = Secondary Contact, 3) = Tertiary Contact

Iowa State University Team Contacts

1) Robert Burns	rburns@iastate.edu	Phone 515-294-4203	Cell Phone 865-310-5870	Fax 515-294-4250
2) Hongwei Xin	hxin@iastate.edu	Phone 515-294-4240	Cell Phone 515-441-1398	Fax 515-294-4250
3) Lara Moody	lmoody@iastate.edu	Phone 515-294-7355	Cell Phone 865-617-2335	Fax 515-294-4250

University of Kentucky Team Contacts

1) Richard Gates	gates@bae.uky.edu	Phone 859-257-3000 x 127	Cell Phone 859-509-5025	Fax 859-257-5671
2) Doug Overhults	doug.overhults@uky.edu	Phone 270-365-7541 x 211	No cell	Fax 270-365-2667
3) John Earnest	jearnest@uky.edu	Phone 270-365-7541 x 237	Cell Phone 270-205-5374	Fax 270-365-2667

Tyson should contact ISU when:

- Any fan, fan motor, or fan belt is changed
- The fan operational program is changed (changed in the controller or fan is manually unplugged)
- Birds are placed - provide the estimated date when the brooder curtain will be raised in the barn, as well as the estimated catch date for the house
- Any equipment is changed in the house
- Any management change occurs within the house
- Litter will be removed

Tyson should contact UK when:

- Any on-site assistance is required quickly concerning any aspect of the monitoring system
- Electrical power is lost at either site
- A severe storm (lighting) occurs at either site
- Actual bird catch date is established

Tyson should provide the following records to ISU for each flock:

- Mortality numbers for each house
- Mass of feed used by each house by feed type
- Number of birds set each flock per house
- Mass of birds removed from each house at the end of grow-out
- Feed / weight conversion ratio of each flock per house
- Actual bird placement, brooder curtain open and catch dates for each house
- Mass of litter removed during de-caking and house cleaning
- Date of placement, type, and amount of any litter amendment used in the houses

Figure 8.1. Information and responsibility sheet provided to project and broiler facility managers.

9.0 Documents and Records

9.1 QAPP Distribution

Following EPA's approval of the QAPP, the plan will be distributed in both an electronic and paper document to all individuals on the QAPP distribution list included in Section 3.0 – QAPP Distribution List. In addition, a bound paper copy of the current approved QAPP will be maintained in each MAEMU as an on-site reference. The QAPP has a date and version number to keep track of the most updated version.

9.2 QAPP Updates

As the project progresses it is anticipated there will be instances where changes to some SOPs and/or data acquisition and collection methods would result in improved data quality. Where the need for such changes is demonstrated, the QAPP will be updated to reflect the improved operational methods. The QAPP format is prepared so individual sections can be updated and replaced without revising the entire document. When a section is revised, a new date and version number will be assigned to that section. All updated sections of the QAPP will be distributed electronically via email to all persons included on the QAPP distribution list included in Section 3.0 – QAPP Distribution List. In addition, the reference copy of the QAPP maintained in each MAEMU will be updated with the revised section.

Before distribution of the updated sections, the revisions will be reviewed by the Project Investigators. Following their review, the revised sections will be submitted to the EPA Project Manager and QA Officer for approval. Because of the QAPP format, individual sections can be reviewed and approved without revising the whole document.

9.3 Identification and Recording of Project Records

In addition to the QAPP, records associated with this project include data generated on-site for gaseous and particulate matter emission rate determination, instrument calibration and maintenance records, quality control sample records, litter sample chain of custody and result records, weekly site visit reports, flock records (for example, number of birds per flock, in and out dates, and mortalities), quality control reports, and corrective action reports. For further information about the records to be maintained see Table 9.1 and Section 20 – Data Management.

All data and records collected for this project are maintained at ISU. All electronic records are maintained in redundancy to ensure that no data is lost due to computer theft or failures. Monitoring data redundancy begins at the field monitoring site in the MAEMU. Raw data is collected and stored on memory in the National Instruments Compact Field Point Modules. Raw data is automatically transferred to a dedicated PC located in each MAEMU. This PC performs pre-processing of data to calculate values required for emissions determinations. The raw data is automatically emailed each day at midnight to a computer dedicated to project data storage located at ISU. The pre-processed data is automatically downloaded from the MAEMU PC to the dedicated ISU project computer each day at 2:00 p.m. Following data quality review, final processing to calculate emissions is completed at ISU by project personnel. Additionally, the University of Kentucky (UK) personnel archive both raw and pre-processed data from the MAEMU PC to a data storage CD on a weekly basis during their site checks.

Table 9.1. Project record identification and handling

Record	Type	Retention	Archival	Disposal
On-site gaseous and particulate matter emission data	Electronic database	On-site computer and ISU computer	ISU computer	Records will be kept for at least 3 years after end of the project
Instrument calibration and maintenance	Paper database	Original database kept on-site, copies maintained at ISU	ISU paper files	Records will be kept for at least 3 years after end of the project
Quality control records	Electronic and paper database	ISU computer and ISU paper files	ISU computer and ISU paper files	Records will be kept for at least 3 years after end of the project
Litter sample results	Electronic database	ISU computer	ISU computer	Records will be kept for at least 3 years after end of the project
Litter sample chain of custody	Paper database	ISU paper files	ISU paper files	Records will be kept for at least 3 years after end of the project
Site visit reports	Electronic database	UK computer and ISU computer	ISU computer	Records will be kept for at least 3 years after end of the project
Flock information	Electronic and paper database	ISU computer and ISU paper files	ISU computer and ISU paper files	Records will be kept for at least 3 years after end of the project
Quality control reports	Electronic database	ISU computer	ISU computer	Records will be kept for at least 3 years after end of the project
Corrective actions	Electronic and paper database	ISU computer and ISU paper files	ISU computer and ISU paper files	Records will be kept for at least 3 years after end of the project

A designated PC at ISU processes the electronic data downloaded from on-site computers. Information on the data handling is detailed in Section 20 – Data Management. In order to reduce the level of manual data processing, automated systems are utilized where appropriate. In order to provide a backup, a hardcopy of automated data collection information is stored for the appropriate time frame in project files. Following data quality review, final processing to calculate emissions is completed at ISU by project personnel.

University of Kentucky personnel prepare written notes in Microsoft Word following each site visit, which document all activities and observations made during the visit. These weekly site visit notes include the results of each week's instrument calibration and checks with calibration gas. These notes are distributed by email to the entire project team on a weekly basis. In addition, these notes are archived in an electronic format at ISU. A calibration record notebook is also maintained at each MAEMU. Records of each required instrument calibration are entered into this notebook during calibration events for each instrument. Following each flock, UK personnel photocopy these calibration records and submit them to ISU personnel, who maintain a paper copy and archive them electronically by entering the records into an electronic format.

As necessary, manual entry field logs are maintained including, but not limited to, site drawings, daily notes about the monitoring operation and the production buildings, results of field quality control measures, and any deviations from this QAPP. These records should be recorded with a pen only.

As part of the project, some production information is being collected. Tyson Foods maintains production records concerning consumed feed weights, broiler market weights, mortalities within each grow-out, and feed conversion rates. ISU monitors water use in the house and will analyze the litter for nutrient content. UK personnel will collect daily bird weight data and feed weight data and submit it to ISU at the end of each flock. This data will be submitted to ISU and maintained electronically. The Tyson production manager at each facility is to record certain activities at the facility that affect air quality in the production house, (for example, generator tests, manure removals, change in diet and animal health, house temperature set points, ventilation interventions, building cleaning, and power failures). See Appendix A for SOP.

Records resulting from this project will be retained for a period of not less than three years following the end of the project. It is the responsibility of the lead PI, Robert Burns, to oversee archiving and disposal of all project records. When records are reviewed, corrections may be required. If any member of the project team needs to perform a data correction, the proposed correction must first be reviewed by a project PI, not including the individual performing the data correction. All data corrections will be recorded in the corrective action report.

10.0 Biosecurity Plan

Biosecurity refers to a set of management practices that reduce the potential for the introduction or spread of disease-causing organisms onto and between sites. Disease carriers can be anything and/or anybody that comes in contact with infected animals, materials or equipment. Bacterial or viral particles transmitted by animals can survive for variable lengths of time almost anywhere under normal environmental conditions. A person or item can become a disease carrier when it comes into contact with contaminated materials such as feces, bedding or air within the area. When a non-disinfected contaminated source leaves one environment and enters another (for example, enters a vehicle to leave the facility), the new area becomes contaminated (Hill, 2003).

Standard operating procedures for the broiler houses in this study require biosecurity practices to be in place that are designed to eliminate, contain, or reduce the exposure and spread of poultry pathogens. For this project, three levels of biosecurity management practices will be in place. Stage 1 procedures should be in place under normal conditions when no disease is present locally or in adjacent regions. Stage 2 procedures should be in place when a disease is present locally or in an adjacent region. Stage 3 procedures should be in place when a disease is present on the farm or a severe disease is present in the immediate area.

During Stage 1 conditions (normal operation), individuals on the project team wear clean clothes and footwear when entering the farm. Personnel wear protective boots, coveralls, hair hats, and gloves. Clothing will not be used at different sites. Shoes are covered with either washable rubber boots or disposable plastic boots. If disposable boots are worn, the used materials are left on the farm. If washable boots are worn, the boots are disinfected before departing the facility. Individuals wash hands before leaving the farm; acceptable methods include waterless gels, disinfecting hand wipes, or soap and water. All reuseable equipment leaving the facility is cleaned and disinfected. Vehicle tires and wheel wells are sprayed with a bio-disinfectant both when arriving and departing the site. Vehicles remain parked in one location until departure from the sight.

During Stage 2 conditions (no disease on site, but disease present in surrounding areas), individuals follow all of the procedures described above, as well as develop a log of visits to and from the two facilities in chronological order.

During Stage 3 conditions (a disease on-site) project team members restrict all visits to the facility, unless a site visit is mandatory. In the case of a site visit during this stage of operation, the visit must be approved by the live production manager. If an individual must visit the facility during this time, they arrive with a prepared biosecurity kit. The kit contains disposable coveralls, boots, hair nets, gloves, hand sanitation items, paper towels, and trash bags in a sealed plastic container. All disposable items must be double-bagged and left on the farm site. Any samples leaving the farm must be double-bagged. The individual’s vehicle should be emptied of all nonessential items before arriving at the farm.

11.0 Sampling Process Design

11.1 Measurement of Gaseous and Particulate Matter Concentrations

The basis for the sampling design of this monitoring is continuous measurement of gaseous and particulate pollutant concentrations and the corresponding building ventilation rates to determine the pollutant emission rate (ER) from two commercial broiler houses for one year. The gases and particulate matter (PM) measured in this project include NH_3, H_2S, CO_2, non-methane hydrocarbons (NMHC), total suspended particulates (TSP), PM_{10} and $PM_{2.5}$.

Two broiler houses, each measuring 13.1m x 155.5m (43 x 510 ft) and built in the early 90s, are being monitored at two farm sites 40 miles apart in western Kentucky. Characteristics for each site are included in Table 11.1. Each house has an initial placement of 25,800 Cobb-Cobb straight-run (mixed sex) broilers in winter and 24,400 in summer, generally grown to 53 days of market age. The houses feature insulated drop ceilings (about R19), box air inlets (15 x 66 cm each) along the sidewalls (26 per sidewall), 26 pancake brooders (8.8 kW or 30,000 Btu/hr each), three space furnaces (65.9 kW or 225,000 Btu/hr each), four 91-cm (36-in) diameter sidewall exhaust fans spaced about 120 ft apart, and ten 123-cm (48-in) diameter tunnel fans. The 91-cm (36-in) fan (SW1) for minimum ventilation is located in the brood end of the houses. Two 24-m (80-ft) sections of evaporative cooling pads are located in the opposite end of the tunnel fans. The houses are also equipped with foggers for additional cooling, if needed. A mixture of rice hulls and sawdust is used as litter bedding.

Air samples are drawn from three locations in each house as well as from an outside location to provide ambient background data (Figure 11.1). One sampling location is near the primary minimum ventilation (36-in) sidewall fan (SW1) used for cold weather ventilation (in the brooding half of the house). The second sampling location is near the fourth sidewall (36-in) exhaust fan (SW3) (non-brooding end). The third location is at the tunnel end (TE). The ambient sample location (A) is between the inlet boxes opposite of the sidewall with the exhaust fans. The quantity of gas in the background (for example, inlet air) is subtracted from that in the exhaust air when calculating aerial emissions from the house.

Placement of the air sampling ports are as follows: for the two sidewall sampling locations, the sampling ports and temperature sensors are located 1.2 m (4.0 ft) away from the fan in the axial direction, 2.3 m (7.5 ft) in the radial direction, and 1 m (3 ft) above the floor; for the tunnel-end sampling location, the sampling port and temperature sensor is located at the center across the house (for example, 6.6 m or 21.5 ft from each sidewall) and 7.3 m (24.0 ft) from the end wall. Figure 11.2 shows the axial and vertical location of the sampling points in relations to the fan centers. Sampling locations and placement of the sampling ports were chosen to maximize representation of the air leaving the houses. Each sample inlet point is equipped with a dust filter to keep large particulate matter from plugging the sample tubing.

The schedules of sampling events and sequences are as follows (refer to figure 11.3). If the ventilation fans at the three in-house sampling locations (SW1-location 1, SW3-location 2 and TE-location 3) are all running, air samples from each location are analyzed sequentially via the controlled operation of the servo values of the gas sampling system (GSS). In this case, sampling/analysis sequence is SW1, SW2, and TE, and the cycle repeats. The time of analysis per sampling episode for each location is 120 seconds (s), involving four consecutive 30-s readings by the INNOVA 1412 multi-gas analyzer. The fourth reading is considered to be the equilibrium value of the location and used in the subsequent analysis of emission rate. The selection of 120-s sample analysis time is based on extensive laboratory tests and field verification with calibration gases and concurrent measurement of the sampling location by INNOVA 1412 analyzers located inside the house and inside the MAEMU. If fans at SW3 or TE are not running (for example, during half-house brood), sample analysis will repeat for the SW1 location only, and the same is true for TE sampling when fans at SW1 and SW3 are not running (for example, during tunnel ventilation mode). Every two hours, air samples from the ambient (background) location are drawn and analyzed for 8 minutes. The longer sample analysis time for the ambient point is due to the longer response time of the instrument when measuring a large step change in gas concentration. Selection of a 2-hour interval for the analysis of the ambient concentrations is due to the fact that ambient conditions remain relatively constant, as compared to the in-house conditions. Such an arrangement helps maximize the number of data points collected for the exhaust air and thus, house emissions.

The sequential sampling makes the assumption that any concentration changes at the given location during the two adjacent measurements (generally 360 seconds) follow a linear pattern. Hence, linear interpolation from the two measured values is used to determine intermediate values for the location, as needed. Use of one sampling location at the tunnel fan end also assumes homogeneity in distribution of aerial concentrations. Examination of ammonia concentrations across the house in this section, through concurrent measurements using four INNOVA 1412 analyzers, has confirmed the validity of this assumption. Moreover, it was assumed that the vertical stratifications in aerial concentrations are negligible when the exhaust fans are in operation. Once again, this assumption has been verified by concurrent measurements of vertical distribution of ammonia and CO_2 concentrations (from floor to ceiling). Incidentally, appreciable vertical stratifications exist when the fans are off. For measurement of emissions, we are only concerned with the concentrations that correspond to operation of the fans.

Air samples will be collected via 0.95-cm (3/8-inch) o.d. and 0.64-cm (1/4-inch) i.d. *Teflon* tubing (Fluorotherm FEP tubing). Individual supply pumps (with all internal wetted parts *Teflon* coated) are used to continuously draw air from each of the sampling locations. Use of individual pumps dedicated to each sampling location eliminates potential residual effects from sharing pumps among sampling locations, this is especially the case between ambient/background air and in-house exhaust air samples. The sampling scheme is designed such that air is continuously drawn from all four sampling points. When a sample point is not being analyzed, the flow is bypassed from the instrument in the MAEMU. This arrangement is designed to minimize the residence time and thus, the sample-to-sample purging time.

Considerable discussion and investigation has gone into the placement of the Tapered Element Oscillating Microbalance (TEOM) particulate matter samplers (TSP, PM_{10}, $PM_{2.5}$) in the house. Since no data was available in terms of TEOM responses to different air velocity fields, as would be encountered in the broiler houses, we conducted an in-house evaluation of the TEOM performance for air velocity ranging from 1.3 – 6 $m \cdot s^{-1}$ (250 to 1200 feet per minute). The results revealed that the TEOM readings are unaffected by the tested air velocity range. Prior to the TEOM tests, we had assumed continuity in PM concentrations from the center of the house to the exhaust. Since we were concerned that the TEOMs might not function properly under high velocity conditions near the exhaust fan, we placed the TEOMs near the center, across the width of the house. Comparison of two TEOM readings near the center versus near the exhaust of the house, revealed that concentrations near the exhaust were generally lower than concentrations near the center. Since velocity showed no impact on the concentration measurement and we are to quantify the emissions going out of the house, we located the TEOMs near the exhaust fan(s). The specifics of TEOM placement are as follows. During the half-house brooding period, the TEOMs are placed near SW1. The TSP TEOM is located 0.6 m (2.0 ft) away from the fan in the axial direction, 1.1 m (3.5 ft) in the radial direction to the left of the fan, and 1.5 m (5.0 ft) above the floor. The PM_{10} TEOM is located 0.6 m (2.0 ft) away from the fan in the axial direction, 1.1

m (3.5 ft) in the radial direction to the right of the fan, and 1.5 m (5.0 ft) above the floor. The $PM_{2.5}$ TEOM is located 0.6 m (2.0 ft) away from the fan in the axial direction, 2.2 m (7.0 ft) in the radial direction to the right of the fan, and 1.5 m (5.0 ft) above the floor. Once the birds are given the full house (between 10-14 days of age), the TEOMs are moved to the TE location. For the TE sampling location, the TSP TEOM is located 4.9 m (16.0 ft) away from the tunnel fan in the axial direction, 11 m (36 ft) from the tunnel end of the house, and 1.5 m (5.0 ft) above the floor. The PM_{10} TEOM is located 0.6 m (2.0 ft) away from tunnel the fan in the axial direction, 9.8 m (32.0 ft) from the tunnel end of the house, and 1.5 m (5.0 ft) above the floor. The $PM_{2.5}$ TEOM is located 0.6 m (2.0 ft) away from the tunnel fan in the axial direction, 8.5 m (28.0 ft) from the tunnel end of the house, and 1.5 m (5.0 ft) above the floor.

All the sampling locations are accessible, although some are relatively easier than others when placing the TEOM units.

Tables 11.2 and 11.3 summarize the variables monitored, the instruments used, and the sampling intervals, for easy reference.

Table 11.1. Characteristics of the broiler houses monitored

	Site 1-5	**Site 3-3**
Species	Broilers	Broilers
# buildings at site	8	24
Year of buildings	1992	1991
Ridgeline orientation	North-South	North-South
Building type	litter	litter
Manure storage, days	~ 1 year	~ 1 year
Animal residence time, days	53	53
Outdoor storage	none	none
Mortality disposal	Composting	Composting
Spacing, ft	60	60
Ridge height, ft	17.2	17.2
Sidewall height, ft	7	7
# air inlets	52	52
Type of inlet	Box	Box
Inlet control method	automatic	automatic
# fans/bldg or room	14	14
Largest fan diameter, in.	48	48
Smallest fan diameter, in.	36	36
# ventilation stages	12	13
Fan company	CanArm	Euroemme
Controls company	Chore-Time	Rotem
Artificial heating?	Yes	Yes
Summer cooling	EP/tunnel	EP/tunnel
Brooding section	South half of barn	South half of barn
24/7 internet	Satellite	Satellite
Distance to site, mi.	30 miles	18 miles
Inventory/building	24,400 (summer) 25,800 (winter)	24,400 (summer) 25,800 (winter)
Building width, ft	43	43
Building length, ft	510	510
Building area, ft^2	21,930	21,930
Shower in/out?	Not required	Not Required
Start date	January 2006	January 2006
Completion date	January 2007	January 2007

Table 11.2. Summary of instruments and sampling intervals used for the monitored variables.

Variables	Analyzer Matrix	Sample Category	Sampling Interval	Critical Nature (c = critical)
NH_3, ppm	INNOVA 1412	Air	30 s	c
CO_2, ppm	INNOVA 1412	Air	30 s	c
CH_4, ppm	INNOVA 1412	Air	30 s	c
Non-CH_4, ppm	INNOVA 1412	Air	30 s	c
H_2S, ppm	API 101E	Air	1 s	c
CH_4	VIG 200	Air	3 min	c
Non-CH_4, ppm	VIG 200	Air	3 min	c
Temperature (°C)	Type-T T.C.	Environment condition	1 s	c
RH (%)	HMW 61U	Environment condition	1 s	c
Static Pressure, Pa	Setra 264	Environment condition	1 s	c
Barometric pressure, kPa	WE100	Environment condition	1 s	c
TSP, $\mu g/m^3$	TEOM 1400	Environment condition	1 s	c
PM_{10}, $\mu g/m^3$	TEOM 1400	Environment condition	1 s	c
$PM_{2.5}$, $\mu g/m^3$	TEOM 1400	Environment condition	1 s	c
Fan ON/OFF	Current Switch	Ventilation	1 s	c

Table 11.3 Sampling intervals for each air sampling location in each the broiler house

Air Sampling Location	Exhaust Fans Running Combinations							
	No Fan	SW 1 or 2	SW 3 or 4	Any Tunnel Fan (TF)	SW 1 or 2 SW 3 or 4	SW 1 or 2 + any TF	SW 3 or 4 + any TF	SW 1 or 2 + + SW 3 or 4 + any TF
SW1	120 s	120 s			240 s	240 s		360 s
SW3			120 s		240 s		240 s	360 s
Tunnel End				120 s		240 s	240 s	360 s
Outside	2 hr	2 hr	2 hr	2 hr	2 hr	2 hr	2 hr	2 hr

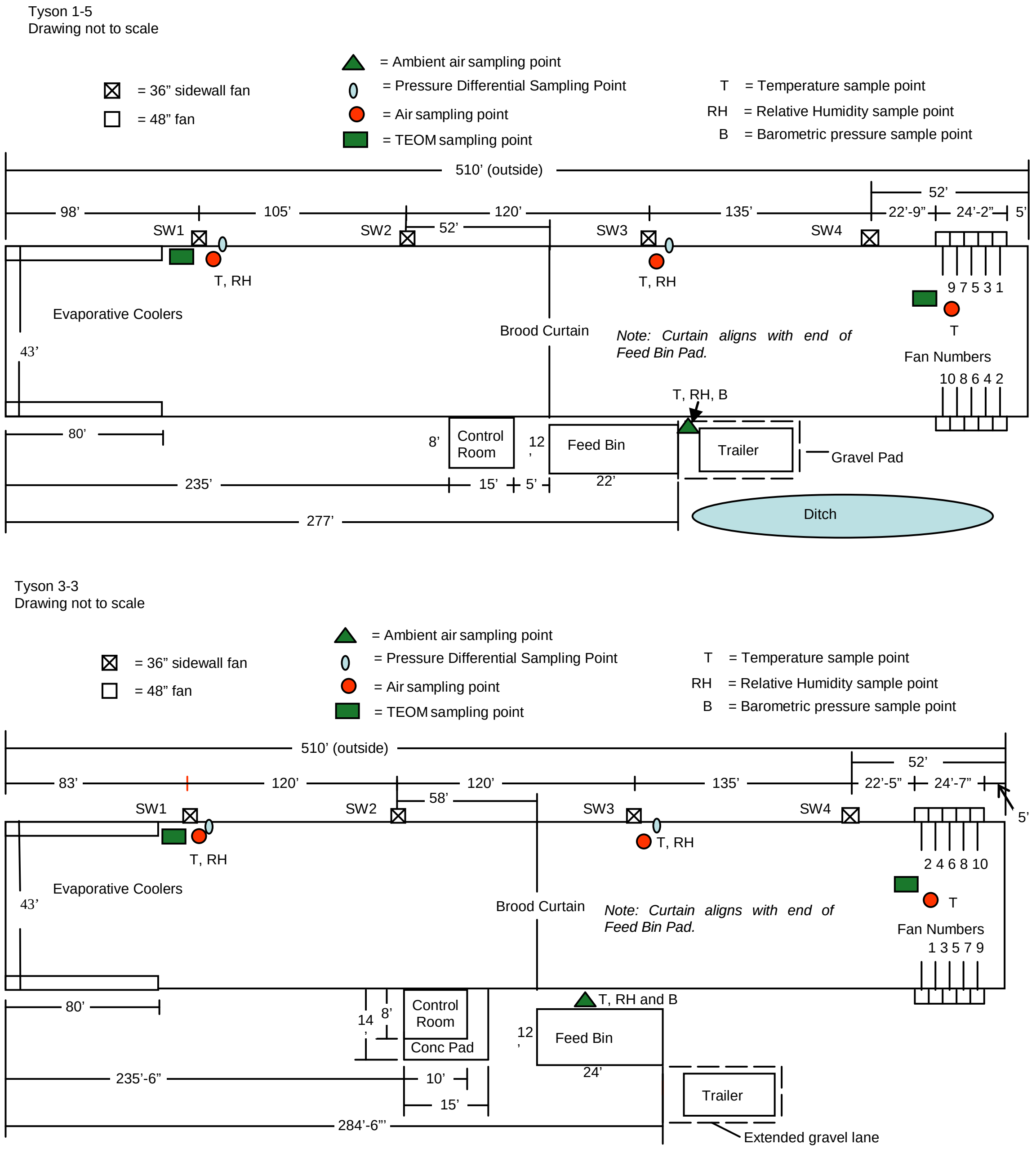


Figure 11.1. Schematic layout of Tyson 1-5 and Tyson 3-3.

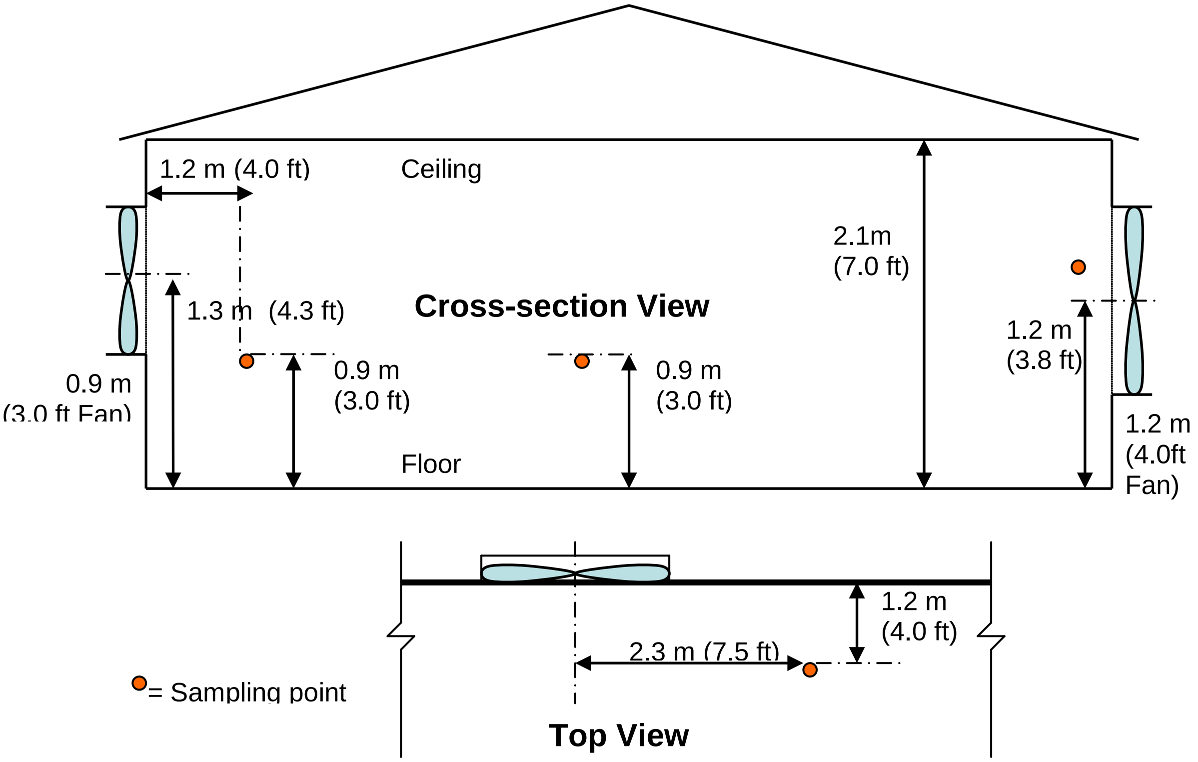


Figure 11.2. Cross sectional view of the sidewall sampling points.

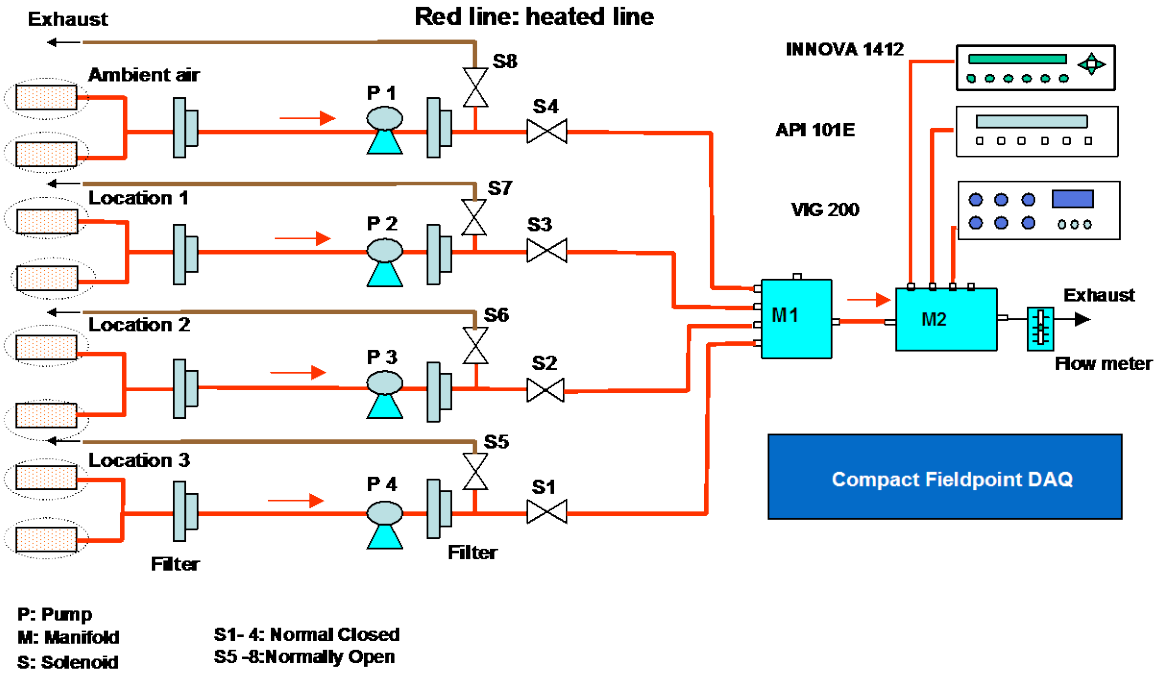


Figure 11.3. Schematic representation of the positive pressure GSS used in the MAEMU for measurement of broiler house air emissions. The GSS features continuous drawing of sample air from all locations with individual pumps. The sample air is bypassed when not analyzed.

11.2 Measurement of Ventilation Rate

Ventilation rates of the houses are measured using the following procedure. First, all exhaust fans have been calibrated in situ, with a state-of-the-art Fan Assessment Numeration System (FANS) to obtain the actual ventilation curves (airflow rate versus static pressure). Guidelines for FANS calibration are presented in Appendix C. This calibration is essential for accurate measurement of the house ventilation rate, because actual fan airflow rates can differ by 10-25% as compared with the default values provided by the fan manufacturer. The deviation arises from the field operational conditions that differ drastically from those under which the default values were established, (for example, loose motor belt, dirty shutter or fan blades). Runtime of each fan is monitored continuously using an inductive current switch (with analog output) attached to the power supply cord of each fan motor (Figure 11.5) as described in Appendix R, and recorded by the compact Fieldpoint modules as described in Appendix G. Concurrent measurement of the house static pressure is made with two static pressure sensors (Model 264, Setra, Boxborough, MA), each for half of the house. While the pressure differential is not expected to differ at the two locations, two sensors are used to provide redundancy in this critical measurement. Summation of airflows from the individual fans during each monitoring cycle or sampling interval produces the overall house ventilation rate. This method of determining dynamic ventilation rates of mechanically ventilated animal confinement has been successfully used in recent AFO air emission studies in the United States.

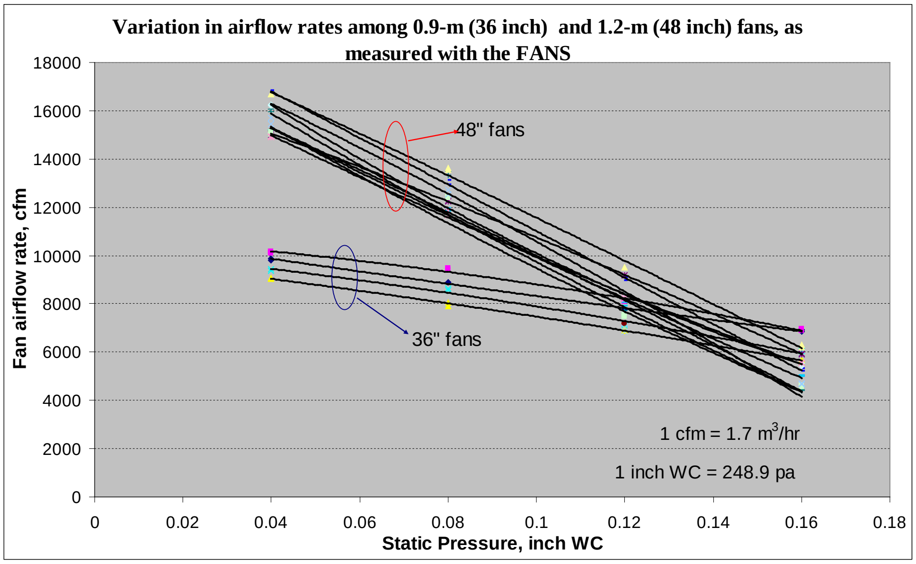
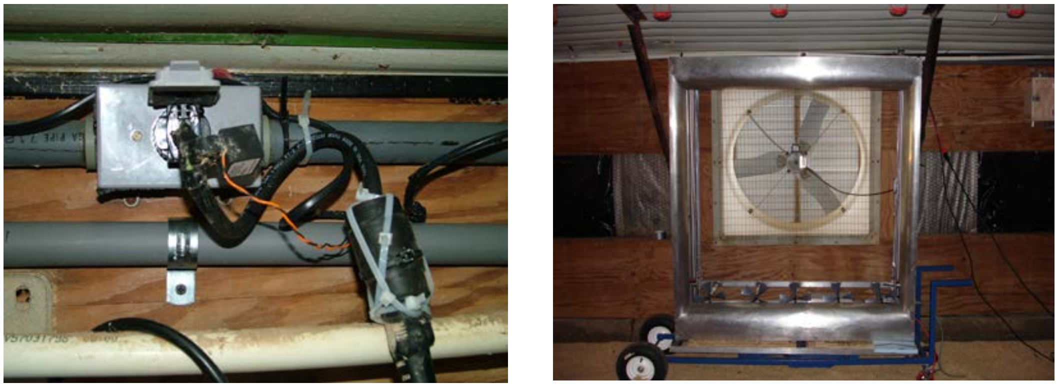


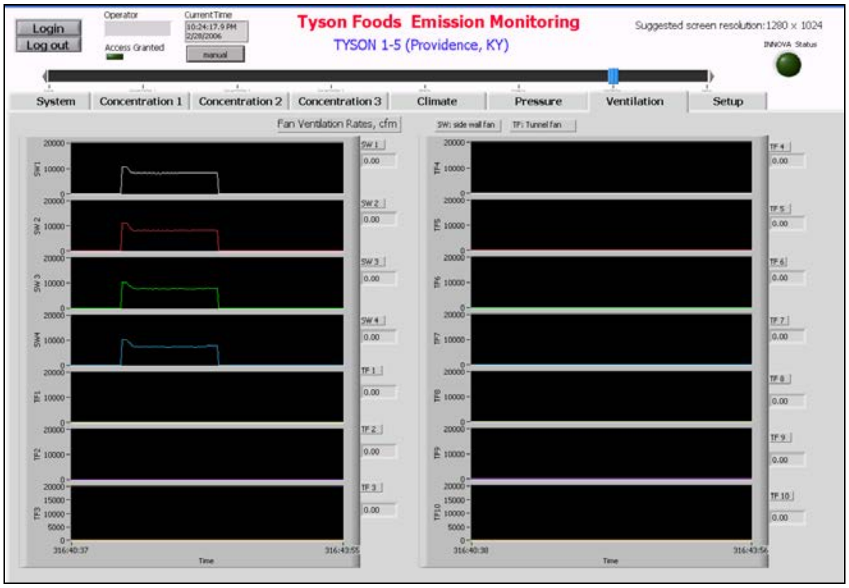
Figure 11.4. Variation in the fan airflow rates among the 36-in and 48-in fans in a Tyson broiler house.

At the beginning of the project, all 14 ventilation fans in each house were calibrated and fan curves were developed. Afterward, three to four fans in each house (less than 20% of total fans) were randomly chosen and tested at the beginning of each flock. If airflow rates of the randomly selected fans deviate from the initial calibration values by 10% or greater, all fans will be recalibrated, and the fan performance curves will be updated and incorporated into the LabView program for real-time ventilation rate monitoring (Figure 11.6).



Fan runtime sensor **Fan calibration by FANS unit**

Figure 11.5. Photographical views of the fan calibration and operation monitoring devices



Tyson Foods Emission Monitoring
TYSON 1-5 (Providence, KY)
Current Time: 10:24:17.9 PM 2/28/2006
Access Granted
Suggested screen resolution: 1280 x 1024

Figure 11.6. Real-time monitoring of fan airflow rate in the LabView program.

In addition to the directly measured ventilation rate, a functional relationship between CO_2 concentration of the house and the measured building ventilation rate at different bird ages has been established for use as a back-up, at least for recovering short-term missing data in the directly measured ventilation rate. The CO_2 balance method has been shown by research team members to be a viable alternative for estimating building ventilation rate under certain circumstances (for example, integration time of 30 minutes or longer). The fan numbers and ventilation stages for Tyson 1-5 and 3-3 are shown in Table 11.4 and 11.5.

Table 11.4. Fan number and ventilation stages for Tyson 1-5

TYSON 1-5	STAGE	# FANs	SIDE WALL FAN #'s	Tunnel Fan #'s	ON (min)	OFF (min)	TEMP. DIFF., °F
Cross Ventilation Mode	1	4SWF	1,2,3,4		0.5	4.5	
		4SWF	1,2,3,4		1	4	
		4SWF	1,2,3,4		1.5	3.5	
		4SWF	1,2,3,4		2	3	
		4SWF	1,2,3,4		2.5	2.5	
		4SWF	1,2,3,4		3	2	
		4SWF	1,2,3,4		3.5	1.5	
		4SWF	1,2,3,4		4	1	
	2	4SWF	1,2,3,4				2
	3	4SWF 1TF	1,2,3,4	1			3
	4	4SWF 2TF	1,2,3,4	2 & 1			4
	5	4SWF 3TF	1,2,3,4	3,2,1			5
Tunnel Ventilation Mode	6	4TF		4,3,2,1			7
	7	5TF		10,4,3,2,1			8
	8	6TF		6,5,4,3,2,1			9
	9	7TF		10,6,5,4,3,2,1			10
	10	8TF		10,9,8,7,4,3,2,1			11
	11	9TF		9,8,7,6,5,4,3,2,1			12
	12	10TF		All			13

Table 11.5. Fan number and ventilation stages for Tyson 3-3

TYSON 3-3	STAGE	# FANs	SIDE WALL FAN #'s	Tunnel Fan #'s	ON (min)	OFF (min)	TEMP. DIFF., °F
Cross Ventilation Mode	1	4SWF	1,2,3,4		0.5	4.5	
		4SWF	1,2,3,4		1	4	
		4SWF	1,2,3,4		1.5	3.5	
		4SWF	1,2,3,4		2	3	
		4SWF	1,2,3,4		2.5	2.5	
		4SWF	1,2,3,4		3	2	
		4SWF	1,2,3,4		3.5	1.5	
		4SWF	1,2,3,4		4	1	
	2	4SWF	1,2,3,4				1
	3	4SWF 1TF	1,2,3,4	10			2
	4	4SWF 2TF	1,2,3,4	9 & 10			3
	5	4SWF 3TF	1,2,3,4	10,9,8,			4
	6	4SWF 4TF	1,2,3,4	10,9,8,7			5
Tunnel Ventilation Mode	7	4TF		10,9,8,7			7
	8	5TF		10,9,8,7,1			8
	9	6TF		10,9,8,7,6,5			9
	10	7TF		10,9,8,7,6,5,1			10
	11	8TF		10,9,8,7,4,3,2,1			11
	12	9TF		10,9,8,7,6,5,4,3,2			12
	13	10TF		All			13

11.3. Determination of Aerial Emission Rate (ER)

The emission rate (ER) of a pollutant from a broiler or any animal house to the atmosphere is the difference between the quantity of the pollutant leaving the house and the quantity of the pollutant entering the house or the background in a given period of time (for example, per minute, hour, or day). Namely,

$$\mathrm{ER} = Q_{\mathrm{STP(e)}}[\mathrm{P}]_{\mathrm{M(e)}} - Q_{\mathrm{STP(i)}}[\mathrm{P}]_{\mathrm{M(i)}} \qquad [1]$$

where $Q_{\mathrm{STP(i)}}$, $Q_{\mathrm{STP(e)}}$ = Incoming and exhaust airflow rate of the house at standard temperature and pressure, respectively, volume hr^{-1} house^{-1}

$[\mathrm{P}]_{\mathrm{M(i)}}$, $[\mathrm{P}]_{\mathrm{M(e)}}$ = Incoming and exhaust mass concentration of the pollutant, respectively, mass per volume of air

When considering the effects of temperature, pressure and moisture on the measured airflow rate, and thus, the volume of the gaseous pollutants, the following equations are used to calculate ER,

$$ER_{[g]} = ([G]_e \times Q_e \times \frac{T_{std}}{T_e} - [G]_i \times Q_i \times \frac{T_{std}}{T_i}) \times 10^{-6} \times \frac{P_a}{P_{std}} \times \frac{w_m}{V_m} \qquad [2]$$

where $\mathrm{ER}_{[g]}$ = Gas emission rate for the house, g hr^{-1} house^{-1}

Q_i, Q_e = Incoming and exhaust ventilation rate of the house at field temperature and barometric pressure, respectively, m^3 hr^{-1} house^{-1}

$[G]_i$, $[G]_e$ = Gas concentration of incoming and exhaust house ventilation air, respectively, parts per million by volume ($\mathrm{ppm_v}$)

w_m = molar weight of the gas, g mole^{-1} (e.g., 17.031 for NH_3)

V_m = molar volume of gas at standard temperature (0°C) and pressure (101.325 kPa) or STP, 0.022414 m^3 mole^{-1}

T_{std} = standard temperature, 273.15 °K

T_i, T_e = absolute temperature of incoming and exhaust air, respectively, °K

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure at the monitoring site, kPa

As described in the previous section, exhaust ventilation rate of the house (Q_e) is continuously measured by monitoring the runtime of individual exhaust fans that have been calibrated in-situ at the beginning of each flock. Although there exists an inherent change in air compositions between the incoming and exhaust air due to animal respiration and manure/litter decomposition, the impact of this change on the mass of dry air flowing through the house is considered negligible. This premise of constant dry air mass throughout the ventilated house leads to the following functional relationship between Q_e and Q_i:

$$\frac{Q_i}{\upsilon_i} = \frac{Q_e}{\upsilon_e} \qquad [3]$$

where υ_i and υ_e are specific volumes of incoming and exhaust air, respectively, m^3 moist air per kg dry air. Refer to Appendix J (SOP of Reporting and Calculation of Contaminant Concentrations, Ventilation and Emissions) for calculation of thermodynamic properties of the moist air. Submitting Q_e into equation [2] yields the following equation for calculation of gaseous ER:

$$ER_{[g]} = Q_e\left(\frac{[G]_e}{T_e} - \frac{\upsilon_i}{\upsilon_e} \times \frac{[G]_i}{T_i}\right) \times 10^{-6} \times T_{std} \times \frac{P_a}{P_{std}} \times \frac{w_m}{V_m} \qquad [4]$$

All the variables of pollutant concentration, fan runtime, static pressure, air temperature and relative humidity (RH) will be continuously measured and recorded at 30-second intervals throughout the one-year monitoring period. The 30-second interval of raw data will be processed to yield hourly emission rates by the following equation:

$$ER_{[g]} = \sum_{k=1}^{n}\sum_{l=1}^{3} Q_{k,l}\left(\frac{[G]_{e(k,l)}}{T_{e(k,l)}} - \frac{\upsilon_{i(k,l)}}{\upsilon_{e(k,l)}} \times \frac{[G]_{i(k,l)}}{T_{i(k,l)}}\right) \times 10^{-6} \times T_{std} \times \frac{P_a}{P_{std}} \times \frac{w_m}{V_m} \qquad [5]$$

where k = number of valid concentration measurements per location within the hour
l = number of sampling locations per house
$Q_{k,l}$ = amount of airflow during the kth time period corresponding to the measured gas concentration at lth location, m^3
w_m = molar weight of the gas, g mole-1 (e.g., 17.031 for NH3)
V_m = molar volume of gas at standard temperature (0°C) and pressure (101.325 kPa) or STP, 0.022414 m3 mole-1
T_{std} = standard temperature, 273.15 °K
T_i, T_e= absolute temperature of incoming and exhaust air, respectively, °K
P_{std} = standard barometric pressure, 101.325 kPa
P_a = atmospheric barometric pressure at the monitoring site, kPa
υ_i, υ_e = specific volume of incoming and exhaust air, respectively, m^3 moist air per kg dry air

Concentrations of the PM have the unit of $\mu g \cdot m^{-3}$. Consequently, ER of PM is calculated with the following equation:

$$ER_{[PM]} = Q_e\left(\frac{[PM]_e}{T_e} - \frac{\upsilon_i}{\upsilon_e} \times \frac{[PM]_i}{T_i}\right) \times 10^{-0.16} \times T_{std} \times \frac{P_a}{P_{std}} \qquad [6]$$

where $ER_{[PM]}$ = PM (TSP, PM_{10}, or $PM_{2.5}$) emission rate for the house, kg hr^{-1} $house^{-1}$

$[PM]_i$, $[PM]_e$ = PM concentration of incoming and exhaust house ventilation air, respectively, µg per m^3 of air at Standard Temperature and Pressure

11.4 Measurement of Air Temperature and Relative Humidity

Indoor and outdoor temperature and RH are measured with robust and stable temperature (type T thermocouples) and RH probes (Vaisala HMW 61 units) that are connected to the PC-based data acquisition (DAQ) system (National Instruments Compact Field Point running LabView 7.1). Analog output of the static pressure sensor is connected to the DAQ system.

11.5 Litter Sampling

Litter from the production houses is analyzed for nitrogen content. Litter is sampled after removal of each flock as described in Section 12.4 – Litter Sampling Methods. Analyzed samples, in conjunction with litter mass removed during cleanout are used to estimate non-gaseous nitrogen movement in and out of the house.

11.6 Schedule of Peer Review Activities

The sampling process design presented here incorporates extensive experience in air emission monitoring accumulated by the research team members over the years. Nonetheless, we have selected two nationally renowned experts (Dr. Jacobson and Dr. Parker) in air quality monitoring to serve as the external peer reviewers of the sampling system and protocols. Upon approval by the EPA, the on-site review by the peer experts will be conducted. The experts have been contacted and alerted about the time sensitive nature of the review, and they are prepared to do so. Prior to the site visit, the reviewers will be provided a copy of our QAPP and any additional information pertaining to the monitoring system that they may wish to have.

11.7 Procedures for Coping with Sample Design Changes

Any proposed changes in the sample design are first discussed among the research team members. Upon agreement among the team, we submit the proposed changes to the EPA Project Manager and QA Officer for their approval. Once approved, the changes will be implemented and documented in the updated QAPP.

Any deviation in system maintenance or operation to ensure the integrity of the sampling system operation and thus, the data collected is reported to the entire research team and documented in the project logbook and the updated QAPP in a timely and meticulous fashion. The QA Manager is promptly notified about the changes as well.

12.0 Sampling Methods Requirements

These methods provide for continuous measurement of the gas concentration, particulate matter concentration, ventilation rate, environment conditions, DAQ recording and litter samples.

12.1 Gas Concentration Analysis Methods

Ammonia. The NH_3 concentrations of background and exhaust air are measured with an advanced photo-acoustic, highly accurate, responsive and stable NH_3 analyzer. This type of analyzer has been widely used by European and Japanese scientists and recently used by U.S. scientists in AFO air emission studies (Battye, 1994). The sampling interval of the advanced INNOVA 1412 photo-acoustic multi-gas analyzer is set at 30 sec/sample for measuring three different air pollutants (NH_3, CO_2, non-methane hydrocarbons) with three individual optical filters (INNOVA filter number: 976, 983, 987 for NH_3, CO_2 and NMHC respectively). The low detection limit for NH_3 is 0.2 ppm with up to 2,000 ppm maximum range. The response time of the INNOVA 1412 is shorter than four sampling cycles (30 s X 4 =120 s) described in Appendix D. In addition, two Drager Polytron I electro-chemical ammonia monitoring units (at location SW1 and TE1 are used as a backup for NH_3 monitoring.

Hydrogen Sulfide. Advanced Pollution Instrumentation, Inc., Model 101E H_2S analyzer is being used to measure the H_2S concentrations of background and exhaust air. The detection limit of the analyzer is 0.4 ppb with maximum range 20,000 ppb. The response time of T95 for both rising and falling is shorter than 100 sec, which was tested in the lab (see Appendix K and API 101E instruction manual).

Non-Methane Hydrocarbons. The VIG Industries, Inc. Model-200 is a microprocessor-based, dual-channel, oven heated methane/non-methane/total hydrocarbon gas analyzer. Designated for use as U.S. EPA Method 18 and Method 25A, it measures total hydrocarbons and methane and non-methane components (VOC) of background and exhaust air (Appendix L). The detection limit is 0.01 ppm for a 0-10ppm range. Total hydrocarbon is continuously measured with a less than 5-s response time of T90. Methane and non-methane hydrocarbon are measured and updated every three minutes. VIG 200s have been used to measure NMHC for a period of two months to date. In this period the units have been unable to meet our data completeness criteria of 75%. As such, we have added the capacity to measure NMHC to the INNOVA 1412 and found the unit to be far more robust and stable than the VIG while providing comparable measurements. The INNOVA 1412 multi-gas analyzer with filter 969 and 987 is used for methane and non-methane hydrocarbon monitoring due to the limits of the VIG 200. The detection limit of filter 969 for methane monitoring is 0.4 ppm with a maximum range 4,000ppm. The detection limit of filter 987 non-methane hydrocarbon is 0.1ppm with a maximum range 1,000ppm.

Carbon Dioxide. The CO_2 concentrations of background and exhaust air are measured with an advanced photo-acoustic, highly accurate, responsive and stable multi-gas analyzer. The sampling frequency of the advanced INNOVA 1412 photo-acoustic analyzer was set at 30 sec/sample for measuring three different air pollutants (NH_3, CO_2, non-methane hydrocarbon) with three individual optical filters. The low detection limit for CO_2 is 3.4 ppm with up to 34,000 ppm maximum range. The response time of the INNOVA 1412 is shorter than four sampling cycles (30 s X 4 =120 s).

12.2 Gas Sampling Collection and Preparation

Individual air samples, as defined in Section 11, for both in-house and background locations are collected using a gas sampling system (GSS) that is designed to collect samples from four locations on a cyclical basis. Three sampling points are located inside each broiler house at two sidewall fans and at the tunnel end. The fourth sampling point is located outside of the broiler house and is used as the ambient measurement point for background concentration determination. The location of the sampling points in Tyson 1-5 and Tyson 3-3 are shown in Figure 11.1. The samples are pumped into the GSS with pumps on the inlet side of the GSS. This arrangement results in the GSS being a positive pressure system. By using this positive pressure approach, if a leak were to develop at any connection point on the GSS it cannot compromise the integrity of the gas sample. A more detailed description of the GSS is provided below and in Appendix B: SOP of GSS.

12.3 Gas Sampling Equipment, Preservation and Handling Time Requirements

Vacuum pumps (P1-P4) with *Teflon* wetted parts will be used to deliver air from the sampling locations via solenoids and a manifold (M1), and transport the air stream to another manifold (M2), which connects to the gas analyzer. *Teflon* or *Teflon* coating will be used in all wetted parts of the sampling system (pump, solenoid valves, manifold, and tubing). Four pairs of 2-way solenoid valves (S1-S8) located in sampling lines are controlled by the DAQ and control unit to allow measurements of gas concentrations by automatic gas sampling from four locations (Figure 11.3). To avoid the malfunction of solenoid valves due to overheating, solenoid cool boards are used to drive the solenoid valves. When the control module sends the signal to the cool boards, the cool boards provide full power (12 VDC) to the solenoids during the first 100 msec and then cut the power to approximately half (5 VDC) and hold it for 120 or 480 sec until the DAQ system receives the fourth output signal from INNOVA 1412 analyzer via RS232. The cool boards solve the overheating problem of the solenoid valves. Individual supply pumps with 16 L/min delivering capacity are used to continuously draw air from each of the sampling locations. The sampling train is designed such that samples are drawn from all four sampling points continuously. When a sampling point is not being analyzed, the flow is bypassed through the normally open solenoid valve (S5-S8). This arrangement is designed to minimize the residence time, and thus, greatly reducing the sample-to-sample purging time. When a sampling stream is selected, the corresponding normal close valve will open and the normal open valve will close; and the selected gas stream will flow from the sample inlet via the tubing through the manifolds (M1 and M2). The internal pump of the gas analyzers draws air from manifold M2. The gas sampling system is designed such that all solenoid valves, manifolds and associated connections are under positive pressure. Using this positive pressure approach, if a leak were to develop on the gas sampling control board at any of these components, it would not impact the integrity of the gas sample.

Two pleated paper filters enclosed in plastic, then shrouded in screen wire are used to exclude coarse debris from entering the sample lines. Additionally, a 47-mm diameter, in-line *Teflon* PFA filter holder housing a 47-mm diameter, *Teflon* PTFE-laminated polypropylene membrane filter with 20-µm pore size is installed at the sampling end of each gas sampling tube to remove airborne particulate from the sampled air (Figure 12.1). Another 5-µm pore size PTFE filter is installed after the vacuum pump to provide double protection. The in-house sample-point, intake filters are changed weekly and the in-line, 20- µm filter is changed at the midpoint and at the end of the flock growout period.

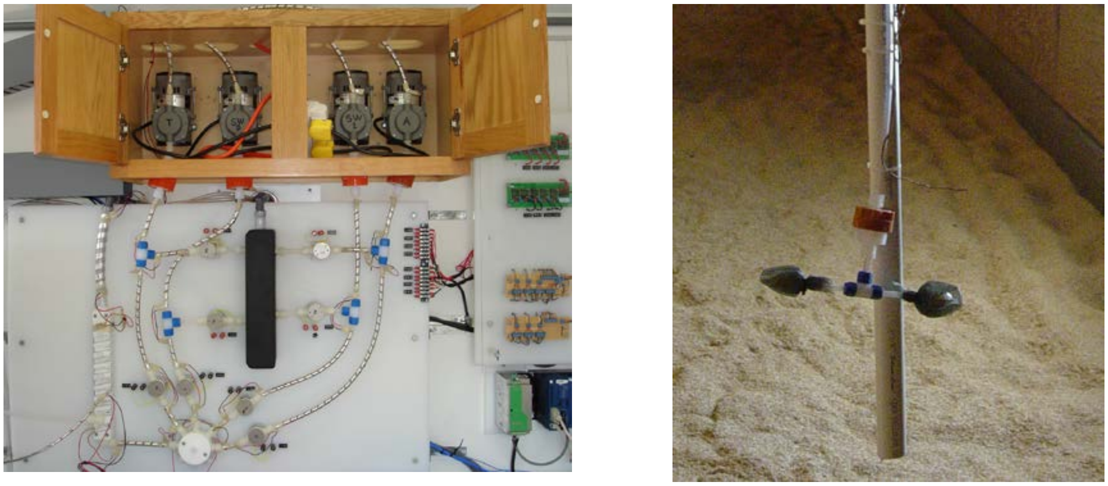


Figure 12.1. Photographical views of the air sampling system

All portions of the sample tubing that go from a warm area to, or thru, a cooler area is heat traced to a temperature of 120° F to maintain a temperature well above dew point in order to prevent in-line condensation. The GSS is heat traced and maintained at 100° F to avoid any condensation in the system. Temperature of the sampling line, and thus, the power input of the heat trace or tape is continuously monitored and regulated through the DAQ and control system.

Gas samples are analyzed using an INNOVA 1412 Photoacoustic Multi-gas monitor with RS232 output, API 101E UV Fluorescence H_2S Analyzer and Non-methane hydrocarbon using VIG200 methane/non-methane/total hydrocarbon analyzer and the INNOVA 1412 (Figure 11.3). Because the INNOVA 1412 has a separate filter for each analyzed component, it can continuously monitor five pollutants. For more details on the operation and specifics for the INNOVA 1412 (NH_3, CO_2, non-methane hydrocarbon), see Appendix D. The INNOVA 1412 is specified with 1 second sampling integration time and fixed flushing time (chamber 2 seconds and tubing 3 seconds). Using a 30-s measurement cycle, the INNOVA demonstrates a T95-97 response time of 120 s (i.e., four measurement cycles), see Appendix D. Hence, the first 2-3 readings during each sampling period are considered invalid and excluded in the determination of the emission rate. The volume of sample air is 100cm^3/sample. The INNOVA 1412 sampling flow rate is 1.8 L/min. The response time of the API 101E UV Fluorescence H_2S Analyzer to step changes in gas concentrations was tested. For more details on the operation and specifics for the API 101E UV Fluorescence H_2S Analyzer, see Appendix K. The response time of the API 101E is shorter than 100 seconds. The API 101E sampling flow rate is 0.6 L/min. The VIG model 200 methane/non-methane/total hydrocarbon analyzer uses column technology to separate methane and non-methane from total hydrocarbons and use a dual FID (flame ionization detectors) to measure each component in the air sample. The VIG model 200 sampling flow rate is 2.5-3 L/min. To obtain continuous gas data to match continuous airflow, the data in long intervals between valid readings is estimated by linear interpolation, as described in section 11.1.

The air sampling schedule from four locations is determined by the fan running status at three inside locations. Tables 12.1 summarizes the sampling methods and intervals for easy reference.

Table 12.1. Gas Sampling Locations and Sampling Methods/SOPs

		Sampling location			
		Sidewall fan 1	**Sidewall fan 3**	**Tunnel end**	**Outside**
Location ID Number		**1**	**2**	**3**	**0**
Analytical parameters		**NH_3, CO_2, H_2S, NMHC, and CH_4 (ppm)**	**NH_3, CO_2, H_2S, NMHC, and CH_4 (ppm)**	**NH_3, CO_2, H_2S, NMHC, and CH_4 (ppm)**	**NH_3, CO_2, H_2S, NMHC, and CH_4 (ppm)**
Sampling SOP		**Appendix B, D, G, K, and L**	**Appendix B, D, G, K, and L**	**Appendix B, D, G, K, and L**	**Appendix B, D, G, K, and L**
Sample flow rate		**15 L/min**	**15 L/min**	**15 L/min**	**15 L/min**
Sampling time		**120 s**	**120 s**	**120 s**	**480 s**
Exhaust Fans Running Combinations	**No Fan**	**120 s**			**2 hr**
	SW 1 or 2	**120 s**			**2 hr**
	SW 3 or 4		**120 s**		**2 hr**
	Any Tunnel Fan (TF)			**120 s**	**2 hr**
	SW 1 or 2 + SW 3 or 4	**240 s**	**240 s**		**2 hr**
	SW 1 or 2 + any TF	**240 s**		**240 s**	**2 hr**
	SW 3 or 4 + any TF		**240 s**	**240 s**	**2 hr**
	SW 1 or 2 + SW 3 or 4 + any TF	**360 s**	**360 s**	**360 s**	**2 hr**

12.4 Particulate Matter Concentration Methods

<u>TSP.</u> The TSP mass concentration of the exhaust air is measured by the Rupprecht & Patashnick TEOM series 1400a PM_{10} monitor (Appendix M) designated as Reference Method number EQPM-1090-79 as per 40 CFR Parts 58. For measuring TSP, The PM_{10} inlet will be replaced by a TSP inlet. The TEOM 1400a is a true gravimetric instrument that draws ambient air through a filter at a constant flow rate, continuously weighting the filter and calculating near real-time (2

sec) mass concentration. The mass concentration is calculated by the exponential smoothing based on the total mass loaded on the filter. The TSP TEOM is operated in the house with a flow rate of 16.7 L/min (1 L/min main flow and 15.67 L/min auxiliary flow); the total mass and mass rate/mass concentration averaging times are set at 300 seconds; the temperature of the sample stream will be set at 50^{o}C. The mass concentration unit of ug/m^3 is used. The output of the mass concentration is based on a standard temperature and pressure of 25^o C and 1 atmosphere (atm), respectively.

PM$_{10}$. The PM$_{10}$ mass concentration of the exhaust air is measured by the Rupprecht & Patashnick TEOM series 1400a PM$_{10}$ monitor (Appendix N) designated as Reference Method number EQPM-1090-79 as per 40 CFR Parts 58. The TEOM 1400a is a true gravimetric instrument that draws ambient air through a filter at a constant flow rate, continuously weighing the filter and calculating near real-time (2 sec) mass concentration. The mass concentration is calculated by the exponential smoothing based on the total mass loaded on the filter. The PM$_{10}$ TEOM is operated in the house with a flow rate of 16.7 L/min (1 L/min main flow and 15.67 L/min auxiliary flow); the total mass and mass rate/mass concentration averaging times are set at 300 seconds; the temperature of the sample stream is set at 50^o C. The mass concentration unit of ug/m^3 is used. The output of the mass concentration is based on a standard temperature and pressure of 25^o C and 1 atmosphere (atm), respectively.

PM$_{2.5}$. The PM$_{2.5}$ mass concentration of the exhaust air is measured with the Rupprecht & Patashnick TEOM series 1400a PM$_{10}$ monitor (Appendix O) with the addition of the PM$_{2.5}$ cyclone designated as Reference Method number EQPM-1090-79 as per 40 CFR Parts 58. The PM$_{2.5}$ TEOM is operated in the house with a flow rate of 16.7 L/min, with the total mass and mass rate/mass concentration averaging times set at 300 seconds. The detection limit of the TEOM is 0.01 ug/m^3. TEOM is a U.S. EPA recognized, correlated acceptable continuous monitor for continuous PM$_{2.5}$ measurements.

TSP, PM$_{10}$ and PM$_{2.5}$ TEOMs are placed in the houses at location SW1 or tunnel end (Figure 11.1 and 11.2). The analog outputs (mass concentration, pressure drop percentage and auxiliary flow rate) from TSP, PM$_{10}$ and PM$_{2.5}$ TEOMs will be connected to and recorded by compact Fieldpoint. With the fan flow rate from fan runtime monitoring and calibrated fan curve, the particulate matter emission will be calculated (see Appendix J). During the brooding period, the TEOMs are placed at SW1 sampling location. When the brood curtain is open, the TEOMs are moved to the tunnel end sampling location. Because of the intermittent fan operation in broiler houses it is critical that PM concentration be correlated to fan operational periods to avoid large over-estimation of the PM emissions. The TEOMs provide time-stamped data required for an accurate calculation of TSP, PM$_{10}$ and PM$_{2.5}$ emissions.

Table 12.2. Particulate Matter Sampling Locations and Sampling Methods/SOPs

	Sidewall fan 1 (SW1)	**Tunnel end (TE)**
Location ID number	**1**	**3**
Analytical parameters	**TSP, PM_{10}, $PM_{2.5}$**	**TSP, PM_{10}, $PM_{2.5}$**
Sampling SOP	**Appendix M, N and O**	**Appendix M, N and O**
Sample flow rate	**1 L/min**	**1 L/min**
Sampling average time	**30 s**	**30 s**
Sampling period	**Brooding**	**Full house**

12.5 Environment Conditions Sampling

Electronic transmitters (Vaisala Model HMW 61U) will be used to monitor relative humidity in the houses, while type T thermocouples will be used to monitor indoor air temperature at the air sampling locations. A 0.0 to 0.5 inch WC (0 to 125 pa) differential pressure transducer (Setra Model 264) will be used to measure house static pressure. An 800-1100 mbar barometric pressure sensor (WE100) will be used to measure atmospheric pressure. For more details on the operation and specifics for the Vaisala Model HMW 61U, type T thermocouple, Setra Model 264, and WE100, see Appendix E and F.

12.6 Ventilation Rate Sampling

A device for in-situ exhaust fan airflow capacity measurement, referred to as the Fan Assessment Numeration System (FANS) device, previously developed and constructed at the USDA-ARS Southern Poultry Research Laboratory, was refined and reconstructed by UK (Gates et al., 2004). FANS measures the total airflow rate of a ventilation fan by integrating the intake velocity field obtained from an array of five propeller anemometers used to perform a real-time traverse of the airflow entering ventilation fans of up to 122 cm (48 in) diameter. At the beginning of the project, all 14 ventilation fans in each house were calibrated by FANS and fan curves were developed. Three to four fans in each house (at least 20% of the total fans) are randomly chosen and calibrated at the beginning of each flock. The fan running status is monitored by an induction current switch (Muhlbauer et al., 2006). The voltage signal from induction current switches attached to the fan power cords are sampled every second and recorded into the compact Fieldpoint modules every 30 seconds as the average or duty cycle of the time interval (see Appendix R).

12.7 DAQ System Recording Methods

The RS232 output generated by the INNOVA 1412 analyzer, as well as the analog output signal from API 101 E, VIG Model 200, TSP PM_{10} and $PM_{2.5}$ and the analog output signal other sensors for environmental conditions and equipment operations monitoring are logged by the National Instruments (NI) compact Fieldpoint control and measurement modules. The NI compact Fieldpoint is an expandable programmable automation controller composed of rugged I/O modules and intelligent communication interfaces. The monitoring and controlling program generated from LabView 7 is downloaded to the embedded controller and temperature, RH and pressure sensors connected directly to the analog and discrete I/O modules. The I/O modules are the cFP-TC-120 8-Channel Thermocouple input module, the cFP-AI-110 8-Channel Analog Voltage and Current input module, the cFP-AI-112 16-Channel Analog Voltage, and the cFP-DO-400 8-Channel digital output module. The signals from the analyzers and sensors are sampled every second and recorded into the compact Fieldpoint modules and on-site PC every 30 seconds as average or duty cycle of the time interval, see Appendix G. The recorded data will be managed by the following procedures in Section 20. Specifics sheets for the above listed materials are provided in Appendix V.

12.8 Sampling/Measurement System Corrective Action

Corrective action measures in the gas concentration, particulate concentration, ventilation rate, environment conditions, and DAQ system recording, will be taken to ensure the data quality objectives are attained. There is the potential for many types of sampling and measurement system corrective actions. If the corrective actions involve calibration, please check corresponding instrument SOPs. Table 12.3 details the expected problems and corrective actions.

Table 12.3 Possible problems and planned corrective actions.

Item	Problem	Action	Notification
Gas Concentration	NH_3, CO_2, NMHC, or CH_4 concentration from INNOVA 1412 out of Specification (± 5% of QC standard)	1). Check sampling line connection. 2). Replace inlet filter. 3). Recalibrate	Document on field data sheet
Gas Concentration	H_2S concentration out of Specification (± 5% of QC standard)	1). Check sampling line connection. 2). Recalibrate	Document on field data sheet
Gas Concentration	NMHC or CH_4 concentration from VIG 200 out of Specification (± 5% of QC standard)	1). Check sampling line connection. 2). Recalibrate	Document on field data sheet
Gas Sampling	Low flow rate in sampling manifold	1). Check solenoid valve and pump. 2). Check in line filters. 3). If any valve or pump fails, replace it. 4). If inline filter is clogged, replace it.	Document on field data sheet
Gas Sampling	Sampling line air leakage	1). Check all tubing adaptors on the sampling line. 2). If need, change the adaptors.	Document on field data sheet
Gas Sampling	Heat traced and heat taped sampling line temperature out of control	1). Turn off all pumps and stop sampling. 2). Check program. 3). Check line voltage.	Document on field data sheet Notify ISU personnel

		4). Check control module. 5). Check control relay.	
PM Concentration	Air leak	Inspect all seals and O-rings, replace as necessary and re-perform leak test	Document on field data sheet
Environment Conditions	Temperature out of Specification (±0.5°C)	Replace thermocouple	Document on field data sheet
Environment Conditions	Relative humidity out of Specification (±5% of QC standard)	Recalibrate	Document on field data sheet
Environment Conditions	Barometric pressure out of Specification (±5% of QC standard)	Recalibrate	Document on field data sheet
Environment Conditions	Static pressure out of Specification (±5% of QC standard)	Recalibrate	Document on field data sheet
Item	Problem	Action	Notification
Power	Power Interruptions	1). Check UPS log event from computer. 2). Check line voltage	Document on field data sheet Notify field manager
DAQ	PC locked up	Reboot	Document on field data sheet Notify ISU personnel
DAQ	No internet connection	1). Check satellite modem. 2). Check satellite dish. 3). Check computer setup, open remote desktop. 4). If needed, reboot modem 5). If needed, contact with vender.	Document on field data sheet Notify ISU personnel
DAQ	No connection between compact Fieldpoint and PC	1). Check cable. 2). Check router. 3). Check PC IP address.	Document on field data sheet Notify ISU personnel
Instrument	Instrument failure	1). Contact ISU personnel. 2). Contact vender for technical support.	Document on field data sheet Notify ISU personnel
Ventilation Rate	Current Switch failure	Replace	Document on field data sheet

12.9 Litter Sampling

In House, Total Litter Sampling - The differences between brooding areas and non-brooding areas in terms of organic matter and nitrogen content and proximity of feeders and waterers to the sampling point within a broiler house make accurate sampling and nutrient testing essential if best management practices are to be followed during handling and land application of poultry litter (Singh et al., 2004). Currently, there are two preferred methods that are suitable for sampling litter, the trench and the point methods (random walking method). In the case of very dry litter (e.g., dry matter of 80% or more), it can be very difficult to dig a trench and obtain an intact sample using a shovel. Location of water lines and feeders may further complicate the process of digging trenches. It is also difficult to sample litter using the trench method when the birds are in the house. Alternatively, litter can be sampled using the point or random walking method. For this method, the number of random sampling points within each zone of a section should be proportional to the contributing area of that zone (Figure 12.3). Both the trench and point method lead to similar results but the point method has easy implementation with representative samples for analysis. The point method (or random walking method) is used for sampling broiler litter.

For the point method the broiler facility is divided in two main zones: non-brooding and brooding zone. Each zone is subdivided in three sections, for replication.
Zone: division of the facility (two zones per one facility)
Section: division of the zone (three sections per one zone)

The sampling points are distributed uniformly in each section. In order to obtain representative samples from each zone, the number of sub-samples taken from each section in areas affected by sidewall, feeders, waterers, and the central area are proportional to the areas they represented in the house. Twenty random samples are collected from each section inside of a zone, and pooled together to form one composite sample per section (three composite sub-samples per zone).

The samples are collected with a tulip bulb digger to a maximum depth of 7.6 cm. Samples from each subsection (20) are pooled together in a container and mixed thoroughly using a shovel before collecting a composite sample. About 1 kg sample from each subsection is stored in labeled plastic bags and transported in a cooler with ice packs to keep the temperature near 4°C. The excess sample left in the container is discarded. The sampling equipment is decontaminated by cleaning them with detergent, preferably anti-bacterial, after sampling each house.

Caked Litter Sampling – During the clean up between the flock, only the surface layer of litter (referred to as “cake”) is removed from the house. Shovel samples are taken from each load of removed cake and combined to form two, 20 L samples which are stored in plastic buckets. The two buckets are labeled and transported to a freezer at the UK Research and Education Center (less than an hour of transport time).

Sample Identification - The sample labels include site ID, sampling zone, sampling section and date. For example, a sample collected from site 3-3, from the brooding area and from the west side of the brooding area on Feb. 3, 2006 will be labeled as 3-3 loose B1 020306 where,

Site ID: 3-3 or 1-5
Type of litter:
Loose broiler litter: Loose Caked boiler litter: Cake
Sampling Zone:
Brood Area: B Non-Brood Area: N
Section:
West side: 1 Middle: 2 East side: 3
Date: mmddyr

The samples will be collected after the removal of each flock, and will be analyzed for pH, moisture content, ammonia, and total Kjeldahl nitrogen. Information on the analytical methods is in Section 14.

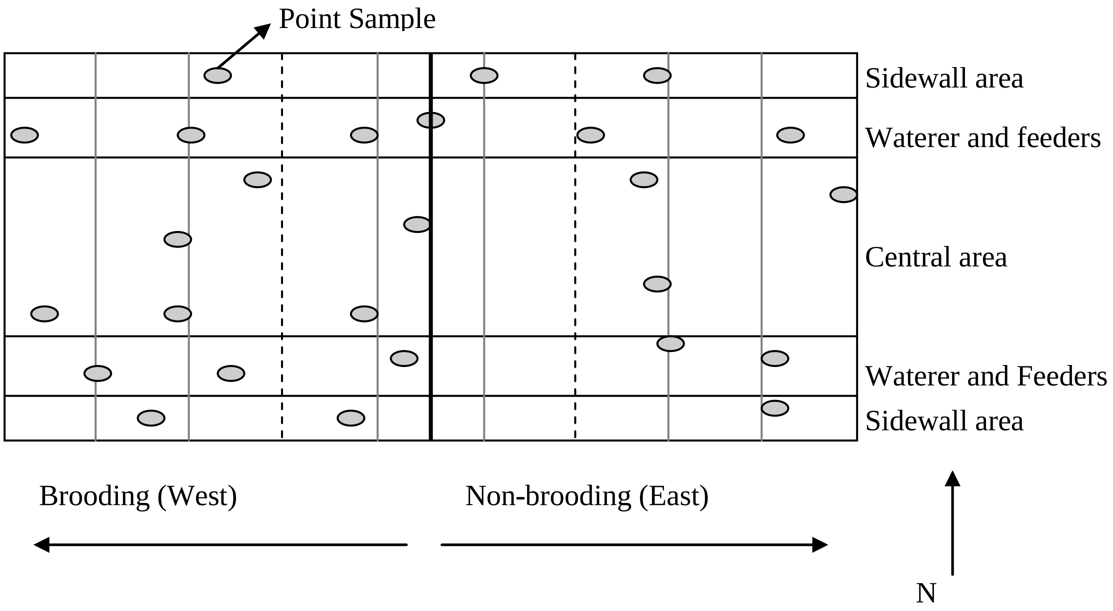


Figure 12.2. Schematic of litter sampling scheme.

13.0 Sample Handling and Custody

13.1 Gaseous and Particulate Matter Samples

Data recorded by the monitoring equipment will be available to authorized project members through remote viewing using LabView 7 over the Internet and will be handled and recorded as described in Section 20 – Data Management and in Appendix I.

13.2 Litter Samples

When litter samples are collected as described in Section 12.4 – Litter Sampling Methods, the following handling method is used. All collected samples are solid in nature. In-house, total litter samples are collected in one gallon air tight bags and cake litter samples are collected in 20 L plastic buckets. Samples are labeled by sample type, location, and date. An example of the sample label is included in Figure 13.1. Collected samples are transported to the UK Research and Education Center with a completed chain of custody form and stored in a freezer for transport to ISU for analysis. The chain of custody form is shown in Figure 13.2. The form is completed by the sampler and shipped with the samples inside of a Ziplock bag to the Agricultural Waste Management Lab at ISU. Coolers used for transport are taped closed and have a chain of custody seal placed over a location on the cooler closure. Samples are either shipped within 24 hrs via a ground transportation service or brought back by individuals returning to Iowa after working at the project site. If samples are shipped, the individual initiating the shipment contacts Lara Moody via email to notify her of the samples arrival and to provide her with a shipment tracking number. Samples are shipped to:

Lara Moody
Iowa State University
3252 NSRIC
Ames, IA 50011

Sample Date: ______________

Sample ID: ________________

Sample Type: ______________

Figure 13.1. Example litter sample label.

Upon arrival at the laboratory, a laboratory technician checks for shipment integrity and ensures the chain of custody seal is still intact on the cooler closure. The chain of custody form is retrieved from the samples. The completed chain of custody form is provided with the analysis results. Regulatory requirements indicate samples should be analyzed for ammonia and total Kjeldahl nitrogen to be analyzed within 28 days of collection. Samples are analyzed in the

Agricultural Waste Management Laboratory at ISU. Samples are analyzed for pH, moisture content, ammonia and total Kjeldahl nitrogen. Samples arriving at the Agricultural Waste Management Laboratory are logged into the laboratory's "Samples to Analyze" notebook. Information entered into the notebook for each sample set includes: date of arrival, sample sender, sample receiver, sample storage (refrigerator, freezer, freezer to freeze dry, or ambient), sample set ID and date, required analyses, and project ID. Analyzed samples are held by the laboratory until the results are reviewed. After acceptance of the litter analysis data, the project PIs give the laboratory permission to dispose of the samples. It is the responsibility of the lead PI, Robert Burns, to oversee the filing and archiving of the sample handling documents.

Sample Collection and Chain of Custody Form

(fill out one form for each shipping container used)

Sample Collector Information	**Shipping Information**	**For Lab Use Only**
Organization Name: **Address:**	**Lab Name:** Iowa State University Agricultural Waste Management Lab **Address:** 3165 NSRIC Ames, IA 50010 Ph.: (515) 294-4167 Fax: (515) 294-4250	**Date received:** **Time received:** **Sample temperature on receipt:** **Sample condition on receipt:**
Sampler Name:	**Date Shipped:** **Carrier:**	

Sample Identification and Collection Information

Facility ID:	**Sample collection point ID:**	**Sample collection date:**	**Sample volume:**	**Number of containers per sample:**	

Additional Comments:

Sampler signature:	**Date:**
Lab technician signature:	**Date:**

Figure 13.2. Litter sample chain of custody form

14.0 Analytical Methods

14.1 Litter Samples

All litter samples will be processed by the Agricultural Waste Management Laboratory in the Department of Agricultural and Biosystems Engineering at ISU. Upon arrival, samples are placed in the cooler at 4° C. Moisture Content and pH are analyzed within 7 days after arrival. Also, the samples are freeze dried and ground within 7 days after arrival. The ground samples are then placed in a freezer at -20° C until analysis. The ground samples are then analyzed for extractable ammonia and total Kjeldahl nitrogen. The methods and equipment to be used are shown in Table 14.1. Full method descriptions are included in Appendix S.

The laboratory manager is responsible for obtaining and completing the Chain of Custody form. The manager acts as the common point of reference between activities performed in the laboratory and activities required by the project PIs. The laboratory manager is responsible for result reporting and laboratory analysis quality control (QC) checks.

The laboratory currently maintains QC by performing triplicate analysis and spike matrices on methods used. For this project, triplicate analyses and spiked matrices are performed on one sample from each between-flock sampling period.

Analyzed samples are placed in a freezer at -20°C for archiving until the project PIs permit sample disposal. Samples will be disposed of in accordance with ISU Environmental Health and Safety requirements. If a failure in one of the analytical systems occurs, Lara Moody is to be contacted. She will then notify the lead project personnel. If the problem cannot be resolved in a time period sufficient to complete the analyses, the samples will be analyzed using an equivalent alternative method or instrument.

Table 14.1. Methods for litter analysis.

Parameter	**Method**	**Quantity**	**Container**	**Preservative**	**Analytical Instrument**
pH (water 1:2)	Manure pH (Combs et al., 2003)	20 g	Ziplock Bag	Cool to 4°C	Orion 4-Star pH meter
Moisture Content	Standard Method 2540 G (APHA et al., 1998)	2 g	Ziplock Bag	Cool to 4°C	Fisher Isotemp Oven
Ammonia	Standard Methods 4500-NH_3 B & C (APHA et al., 1998)	20 g	Ziplock Bag	Cool to 4°C	Labconco Rapid Still II
Total Kjeldahl Nitrogen	Standard Methods 4500-N_{org} D and C (APHA et al., 1998)	5 g	Ziplock Bag	Cool to 4°C	Labconco Block Digester and Rapid Still II

15.0 Quality Control Measures

Quality assurance and quality control include the use of properly maintained and reliable instrumentation, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, audits, and documentation. When appropriate, published EPA analytical methodologies are used. The QC measurements for all instruments are listed in the table 15.1. Logs are maintained for each instrument.

Specific quality control procedures will include the following:

1. A measurement of certified zero air is included as a field blank for gas concentration measurements once a week.
2. A replicated multipoint calibration of analyzers is performed initially and whenever the span checks are beyond the acceptable limits shown in Table 15.1.
3. Calibration checks (zero and span) of gas analyzers are conducted twice a week. Calibration records are maintained in the project logbook.
4. Thermocouples are calibrated before and after the 6-month collection period with spot checks of each sensor every flock.
5. Relative humidity probes are tested with a National Institute of Standards and Technology (NIST) transfer standard or equivalent every 6 months.
6. Calibrations of the differential pressure transmitters are conducted every 6 months. Zero checks are conducted every flock.
7. Barometric sensors are tested every 6 months and calibrated if the zero or span drift is beyond the acceptable limit shown in Table 15.1.
8. The TSP, PM_{10} and $PM_{2.5}$ TEOM analyzers are maintained weekly and calibrated yearly.
9. Online results of all the continuous measurement variables are displayed on a PC video monitor and published to the Web where continuous Internet connection is available. Project personnel check the online display at least daily by either remote or on-site access.
10. An email alarm mechanism was developed and is used when critical data is out of range, which could be caused by malfunction of instruments, over detection limit of instruments and power failures. The alarm email is generated automatically by the program and sent to all project personnel. The problems are addressed and solved the next business day.
11. Logged data files in the PC in the previous day are checked the next business day to find and correct any problems with the system.
12. Experienced analysts run all equipment.
13. An uninterruptible power supply with battery backup is used to prevent damage to sensitive equipment and data loss in case of power failure.
14. Surge suppressors are used to protect the PC and the instruments.
15. Internal performance and internal and external system audits are performed to evaluate the accuracy of field measurements of air pollutants.

Table 15.1. QC checks of the project

Category	Requirement	Frequency	Acceptance Criteria	Analyzer	Reference	Information provided
Calibration Standards	Flow rate	1/yr	±2 % of NIST-traceable standard			Certification of Traceability
Calibration Standards	Thermometer	1/yr	±0.1 ^oC resolution			Certification of Traceability
Calibration Standards	Field Barometer	1/yr	±1 mm Hg resolution			Certification of Traceability
Calibration/ Verification	NH_3	if needed	±5 % of Transfer standard	Innova 1412	Appendix D	Calibration drift/Verification to assure proper function
Calibration/ Verification	CO_2	if needed	±5 % of Transfer standard	Innova 1412	Appendix D	Calibration drift/Verification to assure proper function
Calibration/ Verification	CH_4	if needed	±5 % of Transfer standard	Innova 1412	Appendix D	Calibration drift/Verification to assure proper function
Calibration/ Verification	Non-CH_4	if needed	±5 % of Transfer standard	Innova 1412	Appendix D	Calibration drift/Verification to assure proper function
Calibration/ Verification	H_2S	if needed	±5 % of Transfer standard	API 101 E	Appendix K	Calibration drift/Verification to assure proper function
Calibration/ Verification	NMHC	if needed	±5 % of Transfer standard	VIG 200	Appendix L	Calibration drift/Verification to assure proper function
Calibration/ Verification	CH_4	if needed	±5 % of Transfer standard	VIG 200	Appendix L	Calibration drift/Verification to assure proper function
Calibration/ Verification	Temperature	if needed	±0.5 oC	Type-T Thermocouple	Appendix E	Calibration drift/Verification to assure proper function
Calibration/ Verification	Static pressure	if needed	±5 % of Transfer standard	Setra 264	Appendix F	Calibration drift/Verification to assure proper function
Calibration/ Verification	Relative humidity	if needed	±5 % of Standard	Vaisala HMW61 U	Appendix E	Calibration drift/Verification to assure proper function
Calibration/ Verification	Barometric pressure	if needed	±5 % of Transfer standard	WE100	Appendix P	Calibration drift/Verification to assure proper function
Calibration/ Verification	Flow controller (software)	1/Six month	±5 % of Transfer standard	TEOM	Appendix M, N, O	Calibration drift/Verification to assure proper function
Calibration/ Verification	Flow controller (Hardware)	1/yr	±5 % of Transfer standard	TEOM	Appendix M, N, O	Calibration drift/Verification to assure proper function
Calibration/ Verification	Analog I/O Amplifier board Ambient air temp Ambient pressure Mass transducer	1/yr	±5 % of Transfer standard	TEOM	Appendix M, N, O	Calibration drift/Verification to assure proper function
Accuracy or Bias Checks/ Audits	GSS Leak Check	1/Flock	±5 % of Transfer standard	GSS	Appendix B (Inject cal-gas from sampling port)	Measure system bias
Accuracy or Bias Checks/ Audits	GSS flow rate check	2/week	±5 % of Transfer standard	GSS	Appendix B (Check flow rate)	Measure system bias
Accuracy or Bias Checks/	NH_3	2/wk	±5 % of Transfer standard	Innova 1412	Appendix D	Instrument bias

Audits						
Accuracy or Bias Checks/ Audits	CO_2	2/wk	±5 % of Transfer standard	Innova 1412	Appendix D	Instrument bias
Accuracy or Bias Checks/ Audits	CH_4	2/wk	±5 % of Transfer standard	Innova 1412	Appendix D	Instrument bias
Accuracy or Bias Checks/ Audits	Non-CH_4	2/wk	±5 % of Transfer standard	Innova 1412	Appendix D	Instrument bias
Accuracy or Bias Checks/ Audits	H2S	2/wk	±5 % of Transfer standard	API 101 E	Appendix K	Instrument bias
Accuracy or Bias Checks/ Audits	NMHC	2/wk	±5 % of Transfer standard	VIG 200	Appendix L	Instrument bias
Accuracy or Bias Checks/ Audits	CH4	2/wk	±5 % of Transfer standard	VIG 200	Appendix L	Instrument bias
Accuracy or Bias Checks/ Audits	Static pressure (0 point)	1/Flock	±5 % of Transfer standard	Setra 264	Appendix F	Instrument bias
Accuracy or Bias Checks/ Audits	Relative humidity	1/Six months	±5 % of Standard	Vaisala HMW61 U	Appendix E	Instrument bias
Accuracy or Bias Checks/ Audits	Barometric pressure	1/Six months	±5 % of Transfer standard	WE100	Appendix P	Instrument bias
Accuracy or Bias Checks/ Audits	Leak Check	1/Flock	±5 % of Transfer standard	TEOM	Appendix M, N, O	Instrument bias
Accuracy or Bias Checks/ Audits	Change inlets	Everyday	±5 % of Transfer standard	TEOM	Appendix M, N, O	Instrument bias
Accuracy or Bias Checks/ Audits	Exhaust fan	1/flock	±10 % of Transfer standard	FANS	Appendix C	Instrument bias
Data Quality	Alarm	If needed			Appendix I	Data processing
Data Quality	Raw data check	Everyday			Appendix I	Data processing
Data Quality	Processing data	Everyday			Appendix I	Data processing

15.1 Calibration

Calibration is the comparison of a measurement standard or instrument with another standard or instrument to report, or eliminate by adjustment, any variation (deviation) in the accuracy of the item being compared. The purpose of calibration is to minimize bias.
For air and PM, calibration activities follow a two step process:

1. Certifying the calibration standard and/or transfer standard against an authoritative standard
2. Comparing the calibration standard and/or transfer standard against the routine sampling/analytical instruments

Calibration requirements for the critical field and equipment are found in Table 15.1; the details of the calibration methods are included in the calibration section (Section 17) and Appendixes for SOPs.

15.2 Accuracy or Bias Checks

Accuracy is defined as the degree of agreement between an observed value and an accepted reference value and includes a combination of random error (precision) and systematic error (bias). In this program, the following accuracy checks are implemented:

- GSS leak check and flow rate checks
- Gas analyzer checks
- TEOMs flow rate audit
- TEOMs leak checks
- Static pressure checks
- Relative humidity checks
- Barometric pressure checks
- Exhaust fans flow rate checks

GSS leak check and flow rate check

The response times of the analyzers have been tested in the lab. However, the actual on-site performance of the sampling system had to be tested also. Therefore, ammonia span gas was injected into a sampling line on-site through the longest sampling line (tunnel end) (Figure 15.1). The results of INNOVA 1412 analyzers from both houses are shown in Figures 15.2 and 15.3. For both sampling system, the fourth ammonia concentration readings (30 s X 4=120 s) reached 96% and 97% of the span concentration.

Figure 15.1. Picture of span gas injection from sampling points.

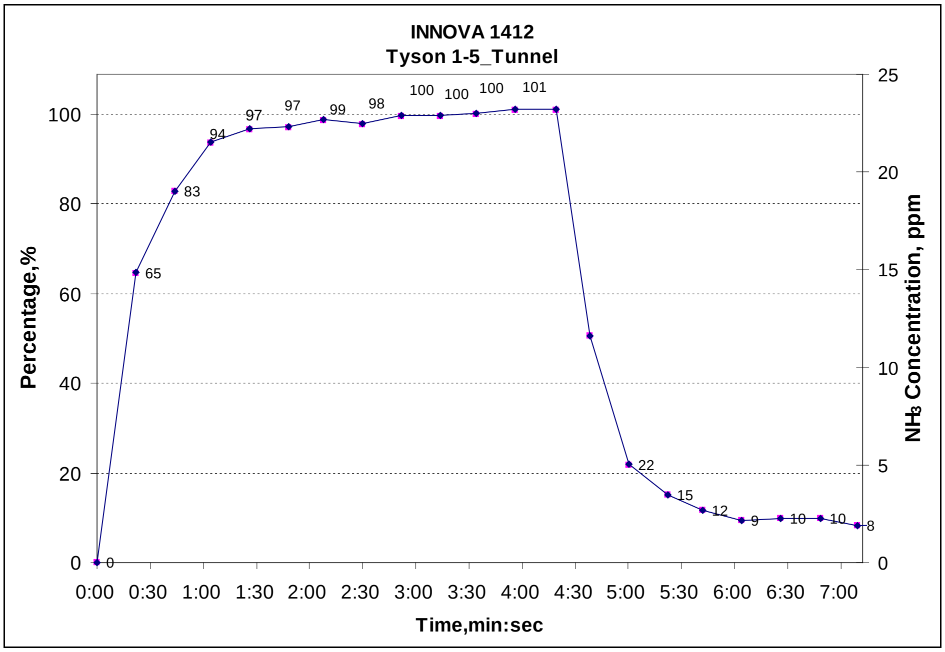


Figure 15.2. Tyson 1-5, sampling system and INNOVA analyzer response time check.

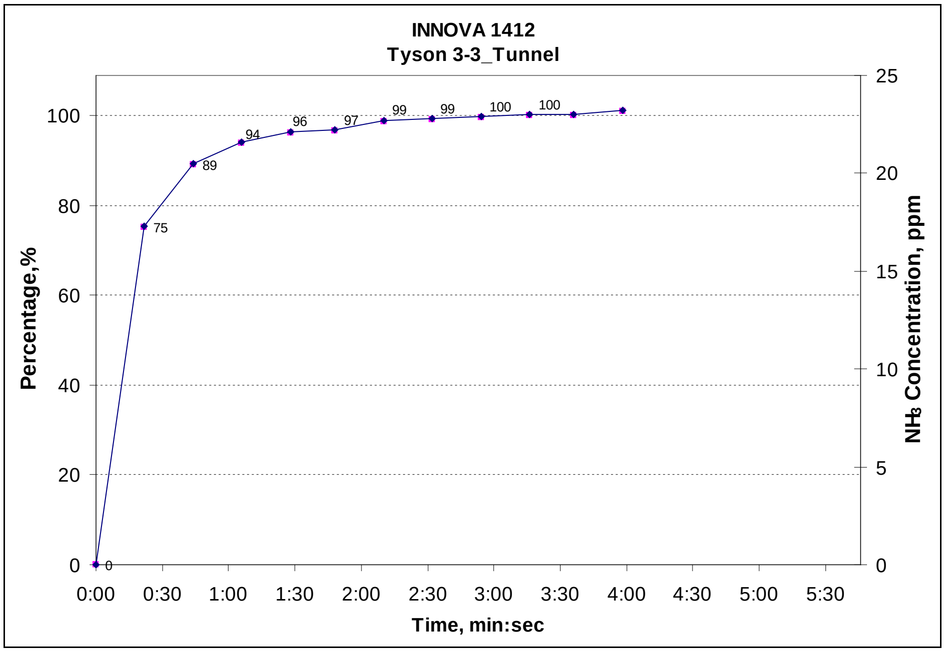


Figure 15.3. Tyson 3-3, sampling system and INNOVA analyzer response time check.

As well as using span gas to challenge the sampling system at one location, multiple point sampling system tests have been done by comparing the readings of INNOVA 1412 analyzer inside of the monitoring trailer with three INNOVA 1412 analyzers located at three sampling locations (SW1, SW3 and TE). Three INNOVA 1412 analyzers were located near the three sampling locations and continuously took samples during the whole testing period (Figure 15.4).

All INNOVA 1412 analyzers were synchronized and calibrated by the same NH_3 calibration gases before this test.

Figure 15.4. INNOVA side-by-side comparison between in-house and MAEMU NH_3 readings.

At Tyson 1-5 site, the number of sampling cycles per location of the INNOVA in the MAEMU were set to 4, 6 and 8 per location for testing the response time effect. The NH_3 readings from the INNOVA 1412 in the MAEMU were compared with the readings in three locations (Figure 15.5). Only the last readings from the MAEMU in each sampling cycle at each location were compared with the most recent readings from the INNOVAs in the houses. At the Tyson 1-5 site, five pairs of readings for each sampling number at each location were chosen. Two-way ANOVA test was used for the statistic analysis. There was neither a sampling number effect nor location effect ($P = 0.37$). Table 15.2 provides a comparison of continuous in-house NH_3 readings with those obtained from location cycling by the MAEMU INNOVA at 4, 6, or 8 sampling iterations from Tyson 1-5 (unit: ppm). It indicated that the NH_3 reading in the MAEMU matched to the reading in the house at all three locations and there was no difference for using 4, 6 and 8 sampling numbers at each location. As such, four sampling iterations were chosen to reduce the time required to cycle from each sampling location in the house. Because fan operation periods can be as short as 30 seconds in a typical broiler facility, it is very important to move between sample locations quickly to capture temporal variability due to fan operation cycles as ammonia-laden air is exhausted and fresh air is introduced through the box inlets. Because four samples were proven to provide equivalent performance as a higher sampling frequency, only a 4-cycle test was performed at Tyson 3-3. The value of this test at both Tyson 1-5 and Tyson 3-3 was to provide an indirect leak check of each sample line system and the GSS in each MAEMU. Since the NH_3 reading in the MAEMU matched the reading in the house at each location, it can be concluded that no dilution air was entering the system, thus, no leakage was occurring.

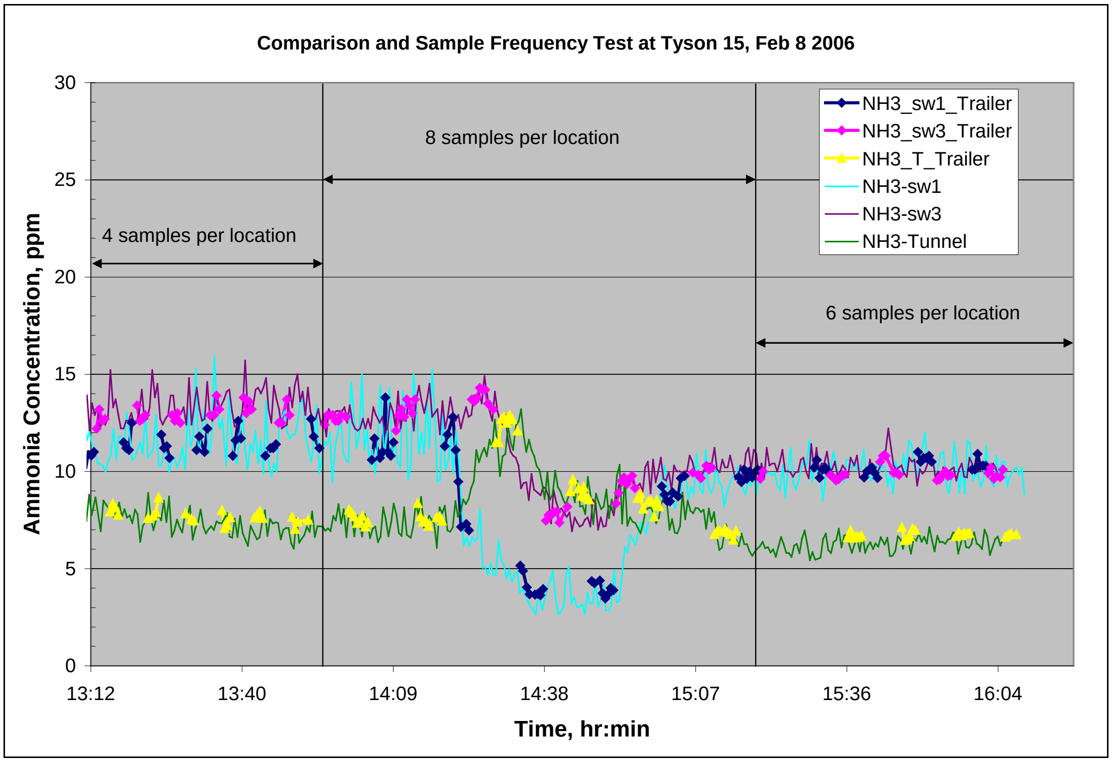


Figure 15.5. Ammonia readings from the MAEMU and in-house INNOVAs

At Tyson 3-3 site, six pairs of readings at each location with four sampling numbers were chosen. A one-way ANOVA test was used for the statistic analysis. There was no location effect for NH_3 reading in the trailer (P = 0.26). Table 15.3 provides a comparison of continuous in-house ammonia readings with those obtained from location cycling by the MAEMU INNOVA at four sampling iterations at Tyson 3-3 (unit: ppm). The mean values are $NH_{3(in\text{-}house)} - NH_{3(MAEMU)}$.

It indicated that the NH_3 reading in the trailer matched the reading in the house at all three locations.

Table 15.2. Comparison of in-house NH_3 readings with those obtained from location cycling by the MAEMU INNOVA

No. of sampling iterations	$NH_{3(in\text{-}house)} - NH_{3(MAEMU)}$ For sampling locations of			(ppm)	P=0.37
	SW1	SW3	Tunnel	Mean	SD
4	0.72	0.20	0.31	0.41^a	0.65
6	0.26	0.08	-0.19	0.05^a	0.37
8	0.18	-0.02	0.46	0.20^a	0.39
Mean	0.39^b	0.09^b	0.19^b	Total mean	0.22
SD	0.66	0.33	0.40	Total SD	0.50

*Column or row means with the same superscript letter are not significantly different (P>0.10)

Location	Mean (ppm)	SD
SW1	0.45^a	0.46
SW3	0.03^a	0.83
Tunnel	-0.27^a	0.98
Total	0.03	0.82

*Column means with the same superscript letter are not significantly different (P>0.10)

GSS flow rate check

The sampling flow rate at each sampling line is checked by monitoring the air flow rate at each sampling port through an in-line flow indicator. The flow rate change between two check points should be lower than the QC standard.

Corrective action- The whole sampling line and all connectors will be inspected and the leakage will be sealed.

Gas Analyzer Checks

The analyzers of INNOVA 1412, API 101E and VIG 200 are challenged by NIST-traceable calibration gases. The interferences of each gas are tested as well. For INNOVA 1412, the interference of gases will be compensated by the analyzer self. For API 101E and VIG 200, the interference will be recorded.

Corrective action- The analyzer will be calibrated.

TEOMs flow rate audit

This flow rate audit means the flow controller audits. Details of the audit are included in the TEOM manual and Appendixes M, N and O. The audit is made by measuring the analyzer's normal operating flow rate using a certified flow rate transfer standard.

Corrective action- The flow controller will be calibrated.

TEOMs leak checks

A leak check is performed after every movement of TEOMs and inlet change. A leak test kit will be used.

Corrective action- The whole sampling lines and all connectors will be inspected and the leakage will be sealed.

Static pressure checks
The static pressure sensors are tested under “0” differential pressure condition. Details of the audit are included in the SOP of differential static pressure sensor transmitters (Appendix F).

Corrective action- The transmitter will be calibrated.

Relative humidity checks
The relative humidity sensors are tested with multiple points. Details of the audit are included in the SOP of temperature and humidity measurement (Appendix E).

Corrective action- The transmitter will be calibrated.

Barometric pressure checks
Details of the audit are included in Appendix P. The audit is made by measuring the sensor’s normal operating pressure using a certified barometric pressure transfer standard.

Corrective action- The barometer will be calibrated.

Exhaust fans flow rate checks
Twenty percent of the total exhaust fans are calibrated and details of the checks are included in Appendix C. The audit is made by measuring the fan flow rate using the FANS system.

Corrective action- All exhaust fan will be calibrated.

15.3 Data Quality Control

Online results of all the continuous measurement variables are displayed on a PC video monitor and published to the Web where continuous Internet connection is available. Project personnel check the online display at least daily by either remote or on-site access. An email alarm mechanism was developed and is used when critical data is out of range, which could be caused by malfunction of instruments, over-detection limit of instruments and power failures. The alarm email is generated automatically by the program and sent to all project personnel. The problems are addressed and solved the next business day. Logged data files in the PC in the previous day are checked the next business day to find and correct any problems with the system. Details of data processing are included in Sections 20 and 24.

15.4 Control Charts

Control charts are used extensively by the project. They provide a graphical means of determining whether various phases of the measurement process are in statistical control. The project utilizes charts which graph single measurements of a standard or a mean of several measurements. Table 15.3 indicates which QC samples are control charted.

Table 15.3 Control charts

QC Check	Plotting technique
GSS leak check	Single values plotted
GSS flow rate check	Single values plotted
Innova check	Single values plotted
API 101 E check	Single values plotted
VIG 200 Check	Single values plotted
TEOM leak check	Single values plotted
TEOM flow controller check	Single values plotted
Static pressure sensor check	Single values plotted
Relative humidity check	Single values plotted
Barometric pressure check	Single values plotted
Exhaust fans flow check	Multiple values plotted

16.0 Instrument/Equipment Testing, Inspection, and Maintenance

The purpose of this element in the QAPP is to discuss the procedures used to verify that all instruments and equipments are maintained in sound operating condition and are capable of operating at acceptable performance levels. See Section 9 for document and record details.

16.1 Testing

All instruments and equipment are or will be purchased new with NIST-traceable or manufactory certifications. The INNOVA 1412, API 101E and VIG 200 are calibrated with NIST-traceable certification. The project personnel runs the analyzers at the laboratory. NIST-traceable calibration gases are used for the verification checks. If any of these checks are out of specification (see Table 15.1), the project personnel contacts the vendor for initial corrective action. Once installed at the sites, the field operators run the tests mentioned above. These tests are properly documented and filed as indicated in Section 9.

16.2 Inspection

Inspection of various equipment and components are provided here. Inspections are subdivided into two sections: one pertaining to online monitoring and one associated with field activities.

Online monitoring

Online monitoring is performed daily through real-time display on computers. There are several items that need daily inspection in the online monitoring. Table 16.1 details the items to inspect and how to appropriately document the inspection.

Inspection of Field Items

There are several items that need inspection in the field. Table 16.2 details the items to inspect in the field and how to appropriately document the inspection.

Table 16.1. Inspections online

Item	Inspection Frequency	Inspection Parameter	Action if Item Fails Inspection	Documentation Requirement
Innova 1412	Daily	Sampling frequency 30~32 sec	Check analyzer Call service provider that holds maintenance agreement	1). Document in logbook 2). Notify field personnel
API 101E	Daily	H_2S concentration > 0 ppb	Check analyzer Call service provider that holds maintenance agreement	1). Document in logbook 2). Notify field personnel
VIG 200	Daily	Concentration > 0 ppm	Check analyzer Call service provider that holds maintenance agreement	1). Document in logbook 2). Notify field personnel
Computer	Daily	Remote desktop	Reboot computer	1). Document in logbook 2). Notify field personnel
Internet Service	Daily	IP address	Check satellite receiver and modem Call service provider that holds maintenance agreement	1). Document in logbook 2). Notify field personnel
Heat trace temperature	Daily	Temp. > 45 ^oC	Check compact Fieldpoint Check breaker Check AC relay	1). Document in logbook 2). Notify field personnel
Heat tape temperature	Daily	Temp. > 40 ^oC	Check compact Fieldpoint Check breaker Check AC relay	1). Document in logbook 2). Notify field personnel
Static pressure	Daily	$\Delta P > 0$ when fans are on	Check compact Fieldpoint Check fuses on board Check signal wire	1). Document in logbook 2). Notify field personnel
Trailer temperature	Daily	20-30 ^oC	Check thermostat Check heater Check AC	1). Document in logbook 2). Notify field personnel
TEOM filter load	Daily	< 10%	Change filters	1). Document in logbook 2). Notify field personnel
TEOM main flow rate	Daily	1 L/min	Check pump Check in-line filter Leak check	1). Document in logbook 2). Notify field personnel
Barometric pressure check	Daily	0.97-1.0 bar	Check compact Fieldpoint Check fuses on board Check signal wire	1). Document in logbook 2). Notify field personnel
Relative humidity sensor	Daily	10-99%	Check compact Fieldpoint Check fuses on board Check signal wire	1). Document in logbook 2). Notify field personnel

Table 16.2. Inspections performed in the field before and after samples are taken.

Item	**Inspection Frequency**	**Inspection Parameter**	**Action if Item Fails Inspection**	**Documentation Requirement**
Innova 1412	Twice/wk	Self check warning message	Check analyzer Call service provider that holds maintenance agreement	Document in logbook
API 101E	Twice/wk	Warning message	Check analyzer Call service provider that holds maintenance agreement	Document in logbook
VIG 200	Twice/wk	Pressure	Check analyzer Check corresponding gas tank Call service provider that holds maintenance agreement	Document in logbook
Gas tanks	Twice/wk	Pressure > 400psi	Replace	Document in logbook
GSS Flow meter	Twice/wk	~15 LPM	Check pump Check connectors Check sampling tubing	Document in logbook
TEOM in-line filters	Twice/wk	Loaded particulate	Change filters	Document in logbook
TEOM inlet heads	Twice/wk	Loaded particulate	Change inlet	Document in logbook
Fuses	Twice/wk	Continuity	Replace	Document in logbook
UPS	Twice/wk	Warning light	Check software Check breaker	Document in logbook
Air compressor	Twice/wk	55 psi	Check pump	Document in logbook
Zero Air generator	Twice/wk	Pressure 30 PSI	Adjust regulator	Document in logbook
Current switch	Every flock	ON/OFF	Replace	Document in logbook
Power supplies	Every flock	Measure the output voltage	Check fuses Replace	Document in logbook
Thermocouples	Every flock	0 to 50 ^{0}C	Replace	Document in logbook
Solenoid valve	Every flock	ON/OFF	Replace	Document in logbook
TEOM pump	Six months	Flow drop < 90%- with kits	Rebuild pump	Document in logbook

16.3 Maintenance

All analytical equipment is properly tested (as described in Section 15.1) and maintained regularly to ensure it is functioning properly in accordance with the manufacturer’s recommended intervals and acceptance parameters. All equipment, including sampling pumps and analytical instrument, is inspected regularly during weekly site visits by the project field personnel. Equipment is repaired as soon as possible upon discovery of a problem. The manufacturer’s instructions for routine maintenance of equipment are followed. Standard operating procedures for each instrument included in the project are listed in the Appendices. Table 16.3 details the appropriate maintenance checks of the equipments and their frequency. All testing, inspection and maintenance activities are documented in the field project logbook. An example of the logbook entry forms and entries are included in Appendix T.

Table 16.3 Preventive Maintenance of Field Items

Item	**Maintenance Frequency**	**Location Maintenance Performed**
INNOVA Calibration	Twice/week	Field
VIG Calibration	Twice/week	Field
TEOM inlet heads	Twice/week	Field
TEOM filter	Weekly	Field
Poultry Scale System RSC-2	Weekly	Field
Computer Virus Check	Weekly	Field
Sampling port filter	Weekly	Field
Computer files backup	Weekly	Field
TEOM leak check	Twice/flock	Field
Polytron I	Every flock	Field
Thermocouple	Every flock	Field
Current switch	Every flock	Field
Fan	Every flock	Field
GSS sampling line	Every flock	Field
Pump	Every flock	Field
Solenoid valve	Every flock	Field
Static pressure sensor	Every flock	Field
Humidity sensor	Every flock	Field
Barometric sensor	Every flock	Field
Air compressor	Every flock	Field
HVAC	Every flock	Field
Zero Air generator	Yearly	Field
TEOM	Yearly	Field

At the end of each grow-out and prior to entry of the next flock, the following maintenance checklist (see Appendix T) is performed on the broiler houses. Another checklist for six months and annual regular maintenance are shown in Appendix T.

17.0 Instrument/Equipment Calibration and Frequency

The TSP, PM_{10} and $PM_{2.5}$ analyzers (TEOM 1400, R & P Thermo Electron, East Greenbush, NY) are maintained weekly or more often as warranted. The TEOM 1400s are calibrated yearly. See Appendix M, N and O for SOPs. TEOM filters are changed weekly and TEOM inlet heads and 2.5 micron cut cyclones are exchanged with clean units semi-weekly.

At the beginning of the project, all fans were calibrated by FANS unit and fan curves were developed. Afterward, three to four fans from each house (less than 20% of the total fans) were randomly chosen and calibrated at the beginning of each flock. If the fan flow rates differences with the pervious calibration are larger than 10%, all fans were recalibrated. See Appendix C for SOP.

Calibration records of gas analyzers, RH sensors, pressure transmitters and TEOMs are maintained weekly with the schedule specified by the manufacturer in accordance with applicable standard operating procedures. The maintenance and calibration of the instruments are recorded in the Maintenance/Calibration sheets developed in each SOP. The records are submitted to and maintained by ISU and UK personnel on a weekly basis.

All the critical spare parts for the instruments are prepared and kept in the on-site MAEMUs. An inventory list of all spare parts is provided for each site. The manufacturer contact information is provided in the SOPs.

17.1 Instrumentation Requiring Calibration

17.1.1 INNOVA 1412 Multi-gas analyzer

Initially, a multipoint calibration of the analyzers is conducted in triplicate using either a precision gas mixing or dynamic dilution system with a span gas and zero air or multiple cylinders of calibration gases that provide a series of concentrations that span the range of expected concentrations for the target analysis. Accuracy and precision of the analyzer are determined from these measurements.

17.1.2 API 101E H_2S analyzer

Initially, a multipoint calibration of the analyzers is conducted in triplicate using either a precision gas mixing or dynamic dilution system with a span gas and zero air or multiple cylinders of calibration gases that provide a series of concentrations that span the range of expected concentrations for the target analysis. Accuracy and precision of the analyzer are determined from these measurements.

17.1.3 VIG 200 non-methane hydrocarbons analyzer

The VIG 200 non-methane hydrocarbon analyzer is challenged with zero air, an EPA protocol CH_4 span gas and an EPA protocol propane span gas. The routine check is conducted semi-weekly and the calibration is conducted if it cannot meet the QC limit of ±5%. See Appendix L for SOP.

17.1.4 Temperature, Pressure and Relative Humidity sensors

A precision ASTM mercury-in-glass thermometers (-8 to 32 °C and 25 to 55 °C, 0.1 °C precision) are used for calibrating thermocouple in the field as standard. A stationary mercury manometer in the UK laboratory is used as a primary standard to calibrate the one electronic barometer that go out in the field as transfer standards. An inclined manometer is used as a standard to calibrate differential pressure sensor.

The barometric pressure transmitters (WE100, Global Water, Gold River, CA) are calibrated prior to use and recalibrated every six months. See Appendix P for SOP.

The differential pressure transmitters (Model 264, Setra, Boxborough, MA) are calibrated prior to use and recalibrated at the conclusion of the test at 0 and typical building static pressure of 20-40 Pa by direct comparison with an inclined manometer every six months. The zero is checked monthly. See Appendix F for SOP.

A salt calibrator kit (Model HMK15, Vaisala, Woburn, MA) or equivalent methods are used to calibrate the capacitance-type RH sensors (HMW 61U, Vaisala, Woburn, MA) prior to commencing the study, and every six months thereafter if it cannot meet the QC limit of 5%. See Appendix E for SOP.

17.1.5 TEOM 1400 TSP, PM_{10} and $PM_{2.5}$ Particulate Monitors

Since the TEOM monitors can be directly mass calibrated, it can be directly quality assured using a mass standard. All QA procedures are coordinated with routine maintenance procedures to minimize down time. Procedures are based on routine flow auditing, leak checking, and mass calibration verification. See Appendix M, N and O for SOPs.

17.1.6 Field

As indicated above, the following calibrations are performed in the field:

- Calibration of gas analyzers in MAEMU against the bottle calibration standard gas.
- Calibration of thermocouples and pressure sensors against the NIST-traceable standard or transfer standard.
- Calibration of TEOMs against pre-weighed filters certified by the manufactory.
- Calibration of TEOM flow controller against a calibrated flow meter, transfer standard.

17.2 Calibration Method that Will Be Used for Each Instrument

17.2.1 INNOVA 1412 Gas Concentration Calibration

The calibration and QC checks of the INNOVA 1412 are addressed in Section 17.1.1 and Section 15 and Appendix D of this QAPP. The linearity of the INNOVA 1412 was tested in the range of 0 to 80 ppm. The gas concentration selected for the multipoint calibrations is 80% of the expected concentration levels. Routine calibration checks are conducted twice per week by introducing a span gas into manifold M2 (see Figure 1 of Appendix B). In this way, the calibration gas flows through the same plumbing that the samples flow through in the trailer except for the solenoids. Every site visit, zero gas and span gases are manually introduced into the analyzer. For INNOVA 1412 analyzers, PC-based calibration software (Gas Monitoring Software 7304, INNOVA) will allow consistent calibration, thus eliminating human error.

The INNOVA 1412 analyzers are challenged with zero air, span calibration gases. Certifications for calibration gases are according to EPA protocol, where available for a given concentration. The certified calibration gases consist of zero air, NH_3 in N_2, CO_2 in N_2, Methane in N_2 and Propane in N_2. All calibration gases need to have a certificate of analysis and not be used outside there expiration date. When calibration gases expire, new cylinders are purchased.

17.2.2 API 101E H_2S Gas Concentration Calibration

The calibration and QC checks of the API 101E are addressed in Section 17.1.2 and Section 15 and Appendix K of this QAPP. The linearity of the API 101E was tested in the range of 0 to 1000 ppb. The gas concentration selected for the multipoint calibrations was 90% of the expected concentration levels. Routine calibration checks are conducted twice per week by introducing a span gas into manifold M2 (see Figure 1 of Appendix B). In this way, the calibration gas flows through the same plumbing that the samples flow through in the MAEMU except for the solenoids. Every week, zero gas and diluted span gas are manually introduced into the analyzer. Certifications for calibration gases are according to EPA protocol, where available for a given concentration. The certified calibration gases consist of zero air, H_2S in N_2. All calibration gases need to have a certificate of analysis and cannot be used outside their expiration date. When calibration gases expire, new cylinders are purchased.

17.2.3 VIG 200 Gas Concentration Calibration

The calibration and QC checks of the VIG 200 are addressed in Section 17.1.3 and Section 15 and Appendix L of this QAPP. The VIG 200 non-methane hydrocarbon analyzer is challenged with zero air, an EPA protocol methane span gas and an EPA protocol propane span gas. The routine check is conducted semi-weekly and the calibration is conducted if it cannot meet the QC limit of ±5%. See Appendix L for SOP. All calibration gases need to have a certificate of analysis and cannot be used outside their expiration date. When calibration gases expire, new cylinders are purchased.

17.2.4 Thermocouple Temperature Calibration Procedure

All thermocouples for sampling ports are calibrated once per flock. A three-point verification/calibration is conducted at the field site. Several steps to follow in calibrating ambient air temperature are given in the following summary:

- Remove the ambient temperature thermocouple from the sampling pipe. Prepare a convenient container (an insulated vacuum/wide mouth thermos bottle) for the ambient temperature water bath and the ice slurry bath. Wrap the sensor(s) and a thermometer together with rubber band; ensure that all the probes are at the same level. Prepare the ambient or ice slurry solution. Immerse the sensor(s) and the attached thermometer in the ambient temperature bath. Wait at least 5 minutes for the ambient thermal mass and the sensor/thermometer to equilibrate. Wait at least 15 minutes for equilibration with the ice slurry before taking comparative readings.

- For each thermal mass, in the order of Ambient, Cold, Ambient, Hot, Ambient, make a series of five measurements, taken about 1 minute apart. If the measurements indicate equilibrium, average the five readings and record the result as the sensor temperature relative to the thermometer.

17.2.5 Pressure Calibration Procedure

A barometer can be calibrated by comparing it with a secondary standard traceable to a NIST primary standard. Protect all barometers from violent mechanical shock and sudden changes in pressure. A barometer subjected to either of these events must be recalibrated. Locate the instrument so as to avoid direct sunlight, drafts, and vibration.

A Fortin mercury type of barometer is used in the laboratory to calibrate and verify the aneroid barometer used in the field to verify the barometric sensors in field. Details are provided in Appendix P.

17.2.6 Relative Humidity Calibration Procedure

The functioning of the relative humidity calibration is based on the fact that certain salt solutions generate a certain relative humidity in the air above them. The salt solutions suitable for the calibration are lithium chloride LiCl (11% RH) and sodium chloride NaCl (75% RH). For calibration, the sensor head is inserted into a salt chamber containing a saturated salt solution. The probe/transmitter reading is then adjusted to the correct value. Calibration is usually performed at least at two different humidities to ensure the sensor accuracy over the entire humidity range (0-100 % RH). A relative humidity transmitter will be calibrated in the laboratory as a transfer standard for field calibration. Details of the calibration are provided in Appendix E.

17.2.7 TEOM 1400 TSP, PM_{10} and $PM_{2.5}$ Particulate Monitors Calibration Procedures

Procedures are based on routine flow auditing, leak checking, and mass calibration verification. Since the TEOM monitor can be directly mass calibrated, it can be directly quality assured using a mass standard. All QA procedures should be coordinated with routine maintenance procedures to minimize down time.

- Flow Audit: A flow audit adapter is provided and the procedures are outlined in the operating manual. Both the sample flow rate and total flow rate may be checked using the flow audit adapter with a capped nut for closing the flow splitter bypass line port. It is recommended that the volumetric flow rates be within ±7% of the set points. The U.S. EPA requires a tolerance of ±10% for the total flow through the inlet. If measured flows differ by more than the stated tolerances, recheck all settings, and perform the test again. Large errors in the flow may indicate other sources of error, such as a malfunctioning flow controller, a system leak, or improper temperature and pressure settings. The flow controllers of a TEOM are verified and calibrated by a certified calibrated flow meter. The details of the flow controller calibration are in the TEOM service manure Section 3.5.

- Leak Check: The leak check procedures are included in the operating manual (Section 7.6). The leak check is performed with NO sample filter attached to the mass transducer, which prevents accidental damage from occurring to the sample filter cartridge when exposed to the high pressure drop (vacuum) in the sample line that the leak check creates. Flow rates should indicate less than 0.15 L/min for the main flow and less than 0.65 L/min for the auxiliary flow with the end of the sample line closed, if not, systematically check plumbing for connector leaks.
- Mass Calibration Verification: The mass transducer is permanently calibrated and never requires recalibration under normal use. However, the mass measurement accuracy of the instrument may be verified following procedures in the operating manual. R&P offers a mass calibration verification kit to help perform this procedure. A detailed explanation of how the calibration is performed can be found in Appendix M, N, and O and TEOM service manure Section 3.2.5.

17.3 Calibration Standards

Flow Rate

The flow rate standard apparatus used for flow-rate calibration (field-NIST-traceable, piston-type volumetric flow rate meter; laboratory-NIST-traceable manual soap bubble flow meter and time monitor) has its own certification and is traceable to other standards for volume or flow rate that are themselves NIST-traceable. A calibration relationship for the flow-rate standard, such as an equation, curve, or family of curves, is established by the manufacturer (and verified if needed) that is accurate to within 2% over the expected range of ambient temperatures and pressures at which the flow rate standard is used. The flow rate standard will be recalibrated and recertified at least annually.

The actual frequency with which this recertification process must be completed depends on the type of flow rate standard; some are much more likely to be stable than others. The project team will maintain a control chart (a running plot of the difference or percentage difference between the flow rate standard and the NIST-traceable primary flow rate or volume standard) for all comparisons.

In addition to providing excellent documentation of the certification of the standard, a control chart also gives a good indication of the stability of the standard. If the two standard-deviation control limits are close together, the chart indicates that the standard is very stable and could be certified less frequently. The minimum recertification frequency is one year. On the other hand, if the limits are wide, the chart indicates a less stable standard that will be recertified more often.

Temperature

The EPA Quality Assurance Handbook, Volume IV (EPA 1995), Section 4.3.5.1, gives information on calibration equipment and methods for assessing response characteristics of temperature sensors.

The temperature standard used for temperature calibration has its own certification and is traceable to a NIST primary standard. A calibration relationship to the temperature standard (an equation or a curve) is established that is accurate to within 2% over the expected range of ambient temperatures at which the temperature standard is to be used. The temperature standard must be reverified and recertified at least annually. The actual frequency of recertification depends on the type of temperature standard; some are much more stable than others. The best way to determine recertification requirements is to keep a control chart. The project team will use an ASTM- or NIST-traceable mercury in glass thermometer, for laboratory calibration.

Pressure

The Fortin mercurial type of barometer works on fundamental principles of length and mass and is therefore more accurate but more difficult to read and correct than other types. By comparison, the precision aneroid barometer is an evacuated capsule with a flexible bellows coupled through mechanical, electrical, or optical linkage to an indicator. It is potentially less accurate than the Fortin type but can be transported with less risk to the reliability of its measurements and presents no damage from mercury spills. The Fortin type of barometer is best employed as a higher quality laboratory standard which is used to adjust and certify an aneroid barometer in the laboratory.

17.4 Document Calibration Frequency

See Table 15.1 for a summary of QC checks that includes frequency and acceptance criteria and references for calibration and verification. All of these events, as well as calibration equipment maintenance are documented in field data records and notebooks and annotated with the flags required in the manufacturer's operating instruction manual and any others indicated in Section 23 of this document. Laboratory and field activities associated with equipment used by the respective technical staff are kept in record notebooks as well. The records are normally controlled by the Managers, and located in the labs or field sites when in use or at the manager's offices when being reviewed or used for data validation.

18.0 Inspection/Acceptance of Supplies and Consumables

18.1 Purpose

The purpose of this element is to establish and document a system for inspecting and accepting all supplies and consumables that may directly or indirectly affect the quality of the project. The MAEMU relies on various supplies and consumables that are critical to its operation. By having documented inspection and acceptance criteria, consistency of the supplies can be assured. This section details the supplies/consumables, their acceptance criteria, and the required documentation for tracking this process.

18.2 Critical Supplies and Consumables

Each MAEMU is equipped with a certain amount of spare parts and consumables (Table 18.1).

18.3 Acceptance Criteria

If a spare is used to replace an existing part (pump, solenoid valve) or a consumable is used at the correct replacement interval (filters) the person doing the replacement must follow the correct inspection criteria outlined in Table 18.1. The same applies to usage of calibration equipment. Supplies are inspected immediately upon receipt, and returned to the vendor if found to be unusable. A supply of spare parts in working condition is maintained whenever possible in order to ensure continuous data collection.

18.4 Tracking and Quality Verification of Supplies and Consumables

Tracking and quality verification of supplies and consumables have two main components. The first is the need of the end user of the supply or consumable to have an item of the required quality. The second need is for the purchasing department to accurately track goods received so that payment or credit of invoices can be approved. In order to address these two issues, the following procedures outline the proper tracking and documentation procedures:

1. Receiving personnel perform a rudimentary inspection of the packages as they are received from the courier or shipping company. Note any obvious problems with a receiving shipment such as crushed box or wet cardboard.
2. The package is opened, inspected and contents compared against the packing slip.
3. Supply/consumable is compared to the acceptance criteria in Table 17.2.
4. If there is a problem with the equipment/supply, note it on the packing list, notify the supervisor of the receiving area and immediately call the vendor.
5. If the equipment/supplies appear to be complete and in good condition, sign and date the packing list and send it to accounts payable so that payment can be made in a timely manner.
6. Notify appropriate personnel that equipment/supplies are available.
7. Stock equipment/supplies in appropriate pre-determined area.
8. For supplies, consumables, and equipment used throughout the project, document when these items are changed out. If available, include all relevant information such as model number, lot number, and serial number.

Table 18.1. Supplies at Tyson 3-3 MAEMU and Tyson 1-5 MAEMU

Qty.	Description	Company Contact	Inspection Criteria
2	pump, 115 VAC, 16.4L/min, 1/4" NPT ports, teflon diaphram, Thomas	Combined Fluid Products (847-540-0054)	Visual Inspection--no dents or cracks Operational Check before data collection
8	pump diaphram rebuild w/ teflon liner	Combined Fluid Products (847-540-0054)	Visual Inspection--no dents or cracks
4	valve, teflon, solenoid operated, 12V, 1/8" NPT ports, normally closed (648T011)	Neptune Research (973-808-8811)	Visual Inspection--no dents or cracks Operational Check before data collection
4	valve, teflon, solenoid operated, 12V, 1/8" NPT ports, normally open (648T021)	Neptune Research (973-808-8811)	Visual Inspection--no dents or cracks Operational Check before data collection
2	Cool Drive Board, voltage reducing (648D5X12)	Neptune Research (973-808-8811)	Visual Inspection--no dents or cracks Operational Check before data collection
4	PFA-220-1-2, 1/8"NPT-1/8" OD	Swaglok (402-733-7636)	Visual Inspection--no dents or cracks
4	PFA-620-1-4, 1/4" NPT - 3/8" OD	Swaglok (402-733-7636)	Visual Inspection--no dents or cracks
4	PFA-620-2-4, 1/4" NPT - 3/8" OD elbow	Swaglok (402-733-7636)	Visual Inspection--no dents or cracks
4	PFA 620-9, 3/8" OD elbow	Swaglok (402-733-7636)	Visual Inspection--no dents or cracks
4	NY 600-2-1, 1/8" NPT - 3/8" OD elbow	Swaglok (402-733-7636)	Visual Inspection--no dents or cracks
10	fitting, 1/8" NPT - 3/8" OD, Nylon (NY-600-1-2)	Swaglok (402-733-7636)	Visual Inspection--no dents or cracks
2	Power supply, 5V, 15W, 2A, switching (Z1151-ND)	Digikey (800-344-4539)	Visual Inspection--no dents or cracks Operational Check before data collection
2	Power supply, 12V, 100W, 8.6A, switching (602-1045-ND)	Digikey (800-344-4539)	Visual Inspection--no dents or cracks Operational Check before data collection
10	Induction style current switch, (CR9321-PNP)	CR Magnetics (636-343-8518)	Visual Inspection--no dents or cracks Operational Check before data collection
6	6-47-6 teflon filter holder	Savilex (954-936-2295)	Visual Inspection--no dents or cracks
15	filter (30-60 micron) (pkg. 10)	Savilex (954-936-2295)	Visual Inspection--no dents or cracks
1	N_2 zero gas (99.999%)	Matheson (800-416-2505)	Visually Inspect Bottle for cracks or dents
1	NH_3 span gas (2ppm)	Matheson (800-416-2505)	Visually Inspect Bottle for cracks or dents
1	CO_2 span gas (2000ppm)	Matheson (800-416-2505)	Visually Inspect Bottle for cracks or dents
1	CH_4 span gas (3ppm)	Matheson (800-416-2505)	Visually Inspect Bottle for cracks or dents
1	Propane span gas (3ppm)	Matheson (800-416-2505)	Visually Inspect Bottle for cracks or dents
1	H_2S span gas (10ppm)	Matheson (800-416-2505)	Visually Inspect Bottle for cracks or dents
1	Cablibration equipment, hoses, glass impinger, flowmeter	NA	Visual Inspection--no dents or cracks Operational Check before data collection

19.0 Data Acquisition Requirements (Non-Direct Measurement)

Not applicable.

20.0 Data Management

All original and final data is reviewed and/or validated by technically qualified staff, and so documented in the program records. The documentation includes the dates the work was performed, the name of the reviewer(s), and the items reviewed or validated.
Corrections and additions to original data must be made as follows:

1. After correction, original entries must remain legible (for manual corrections) or intact (for computerized corrections).
2. The correction or addition must be readily traceable to the date and the staff who performed the correction or addition.
3. Corrections must be explained.

20.1 Background and Overview

This section describes the data management operations pertaining to air emission measurements for the MAEMU stations operated by ISU and UK personnel. This includes an overview of the mathematical operations and analyses performed on raw (“as-collected”) data. These operations include data recording, validation, transformation, transmittal, reduction, analysis, management, storage, and retrieval.

Data processing for air emissions data is summarized in Figure 20.1. Originally, all electronic data is collected automatically using a set of programs written in LabView 7, which resides on a machine running the Windows XP operating system. And, the data, which resides on a machine running the Windows XP operating system, is processed using a set of programs written in Windows Excel 2003. This machine is shown in the upper left of Figure 20.1.

Each MAEMU has a compact Fieldpoint DAQ system. These DAQ systems continuously provide data collection at each site. The collected data is remotely acquired through a high speed satellite internet system.

Data tracking and chain of custody information is entered into the DAQ system at four main stages as shown in Figure 20.2. Project personnel are able to remotely view the real-time system display on status of site, fan status, sampling location and results of analyzer, etc. using the DAQ system. All users must be authorized by the QA Manager to log on to the DAQ system.

Different privileges are given to each authorized user depending on that person's need. The following privilege levels are defined:
Data Entry Privilege - The individual may see and modify only data that he or she has personally entered. After a data set has been "committed" to the system by the data entry operator, all further changes generate entries in the system audit trail.

Reporting Privilege - This privilege permits generation of data summary reports available under DAQ system. No data changes are allowed without additional privileges.

Data Administration Privilege - Data Administrators for the DAQ system are allowed to change data as a result of QA screening and related reasons. All operations resulting in changes to data values are logged to the audit trail. The Data Administrator is responsible for performing the following tasks on a regular basis merging/correcting the duplicate data entry files

- running verification and validation routines and correcting data as necessary
- generating summary data reports
- uploading verified/validated data to EPA

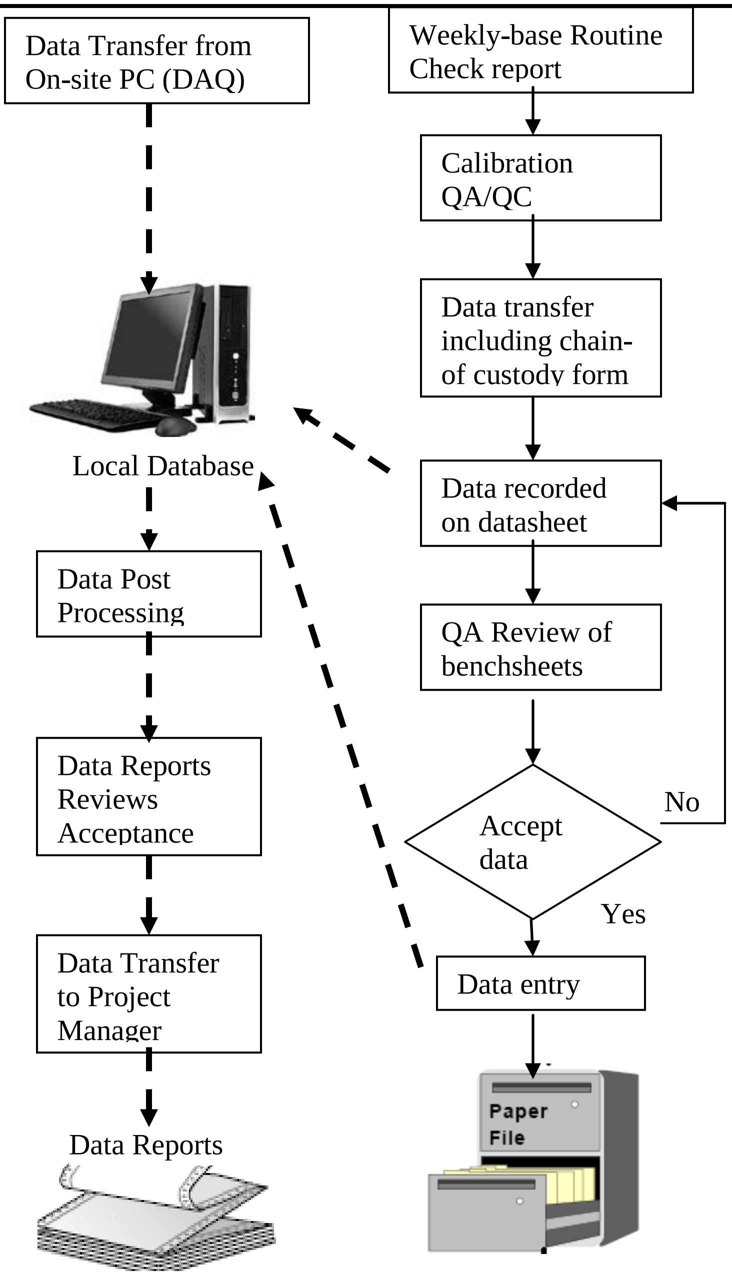


Figure 20.1 Data tracking and chain of custody information

20.2 Data Recording

Any internal checks (including verification and validation checks) that are used to ensure data quality during data encoding in the data entry process, are identified together with the mechanism for detailing and correcting recording errors. Examples of data entry forms and checklists should be included.

Data entry, validation, and verification functions are all integrated in the routine report, DAQ system and Post Process. Bench sheets shown in Figure 20.1 are entered by laboratory personnel. Procedures for data recording and subsequent data entry are provided in SOPs listed in Table 20.1 and included in the corresponding Appendix.

Table 20.1. List of SOPs for data processing

SOP	**Title**	**Description**
Appendix I	Data Management	Describes the data processing operations, validation, and reduction.
Appendix J	Reporting and Calculation of Contaminant Concentrations, Ventilation and Emissions	Describes the procedures for data reporting and processing,

20.3 Data Validation

The details of the process of data validation and pre-specified criteria are documented in this element of the QAPP. This element addresses how the method, instrument, or system performs the function it is intended to consistently, reliably, and accurately in generating the data.

Data validation is a combination of checking that data processing operations have been carried out correctly and monitoring the quality of the field operations. Data validation can identify problems in either of these areas. Once problems are identified, the data can be corrected or invalidated, and corrective actions can be taken for field or laboratory operations. Numerical data stored in the DAQ system are never internally overwritten by condition flags. Flags denoting error conditions or QA status are saved as separate fields in the database, so that it is possible to recover the original data.

The following validation functions are incorporated into the DAQ system to ensure quality of data entry and data processing operations:

Range Checks - almost all monitored parameters have simple range checks programmed in. For example, valid times must be between 00:00 and 23:59, summer temperatures must be between 10 and 50 degrees Celsius, etc. The data operator is notified immediately when data are out of range. The operator has the option of correcting the entry or overriding the range limit. The specific values used for range checks may vary depending on season and other factors. The currently used range values for data acceptance are provided in SOPs. Since these range limits for data input are not regulatory requirements, the data operators may adjust them from time to time to better meet quality goals.

Completeness Checks - When the data is processed, certain completeness criteria must be met. For example, each air sample must have a start time, end time, average flow rate, temperature, relative humidity, and operator and technician names. The data entry operator is notified if an incomplete record has been entered before the record can be closed.

Data Retention - Raw data sheets are retained on file at ISU for a minimum of five years, and are readily available for audits and data verification activities. After five years, hardcopy records and computer backup media are cataloged and boxed for storage at ISU. Physical samples, such as litter samples, shall be discarded with appropriate attention to proper disposal of potentially hazardous materials.

Statistical Data Checks - Errors found during statistical screening are traced back to original data entry files and to the raw data sheets, if necessary. These checks are run on a monthly schedule and prior to any data submission to the project manager. Data validation is the process by which raw data is screened and assessed before it can be included in the main database.

Data Validation – Data validation, which is discussed in Section 24, associates flags that are generated by QC values outside of acceptance criteria. Data containing too many flags is rerun and or invalidated.

20.4 Data Transmittal

Data transmittal occurs when data is transferred from one person or location to another, or when data is copied from one form to another. Some examples of data transmittal are copying raw data from a notebook onto a data entry form for keying into a computer file and electronic transfer of data over a telephone or computer network. The QAPP describes each data transfer step and the procedures used to characterize data transmittal error rates and to minimize information loss in the transmittal. Table 20.2 summarizes data transfer operations.

Table 20.2. Data Transfer Operations

Description of Data Transfer	**Originator**	**Recipient**	**QA Measures Applied**
Calibration and Audit Data	Auditor or field supervisor	Data base Computer	Entries are checked by QA Manager
Electronic data transfer	(Between computers or over network)		Parity checking; transmission protocols
Data summaries	Data processing operators	Air Quality Supervisor	Entries are checked by QA Manager

20.5 Data Reduction

Data reduction includes all processes that change the number of data items. This process is distinct from data transformation in that it entails an irreversible reduction in the size of the data set and an associated loss of detail. For manual calculations, the QAPP includes an example in which typical raw data is reduced. For automated data processing, the QAPP clearly indicates how the raw data is to be reduced with a well-defined audit trail, and reference to the specific software documentation is provided.

Data reduction processes involve aggregating and summarizing results so that they can be understood and interpreted in different ways. The monitoring regulations require certain summary data to be computed and reported regularly to U.S. EPA. Other data is reduced and reported for other purposes such as station maintenance. Examples of data summaries include:

- average air concentration and emissions for a station or set of stations for a specific time period
- accuracy, bias, and precision statistics based on accumulated data
- data completeness reports based on numbers of valid samples collected during a specified period

The post process is another important concept associated with data transformations and reductions. Post process is a data structure that provides documentation for changes made to a data set during processing. Typical reasons for data changes that would be recorded include the following:

- corrections of data input due to human error
- application of revised calibration factors
- addition of new or supplementary data
- flagging of data as invalid or suspect
- logging of the date and times when automated data validation programs are run

The DAQ post process is implemented as a separate table in the Microsoft Excel database. Post process records will include the following fields:

- operator's identity (ID code)
- date and time of the change
- table and field names for the changed data item
- reason for the change
- full identifying information for the item changed (date, time, site location, parameter, etc.)
- value of the item before and after the change

When routine data screening programs are run, the following additional data is recorded in the audit trail:

- version number of the screening program
- values of screening limits (e.g., upper and lower acceptance limits for each parameter)
- numerical value of each data item flagged and the flag applied

The post process is produced automatically and can only document changes; there is no "undo" capability for reversing changes after they have been made. Available reports based on the Post Process include:

- log of routine data validation, screening, and reporting program runs
- report of data changes by site for a specified time period
- report of data changes for a specified purpose
- report of data changes made by a specified person

Because of storage requirements, the System Administrator must periodically move old Post Process records to backup media.

20.6 Data Analysis

Data analysis sometimes involves comparing analyzer readings with standard calibration gas. It frequently includes computation of summary statistics, standard errors, confidence intervals, and goodness-of-fit tests. This element briefly outlines the proposed methodology for data analysis and a more detailed discussion will be included in the final report.

ISU is currently implementing the data summary and analysis requirements, see Appendix A. It is anticipated that as the monitoring program develops, additional data analysis procedures will be developed. The following specific summary statistics will be tracked and reported for the network:

- Analyzer bias or accuracy (based on cal-gas routine check, flow rate performance audits, and sensor performance evaluations)
- Analyzer precision
- Data completeness

Equations used for these reports are given in Table 20.3.

Table 20.3 Report Equations

Criteria	Equation	Reference
Accuracy of analyzer-single gas Check (d_i) X_i is reference flow; Y_i is measured	$d_i = \frac{Y_i - X_i}{X_i} \times 100$	40 CFR 58 Appendix A, Section 5.5.1.1
Bias of a single check - Annual Basis (D_i)- average of individual percent differences between sampler and reference value; n_j is the number of measurements over the period	$D_j = \frac{1}{n_i} \times \sum_{i=1}^{n_j} d_i$	5.5.1.2
Percent Difference for a Single Check (d_i) - X_i and Y_i are concentrations from the primary and duplicate samplers, respectively.	$d_i = \frac{Y_i - X_i}{(Y_i + X_i)/2} \times 100$	5.5.2.1
Coefficient of Variation (CV) for a single Check	$CV_{j,q} = \sqrt{\sum_{i=1}^{n_j} \frac{CV_i^2}{n_{j,q}}}$	5.5.2.2
Completeness	$\text{Completeness} = \frac{N_{valid}}{N_{theoretical}} * 100$	

20.7 Data Flagging

A sample qualifier or a result qualifier consists of three alphanumeric characters, which act as indicators of the fact and the reason that the data value (a) did not produce a numeric result, (b) produced a numeric result, but it is qualified in some respect relating to the type or validity of the result or (c) produced a numeric result, but for administrative reasons is not to be reported outside the laboratory. Qualifiers are used both in the field and in the laboratory to signify data that may be suspect due to contamination, special events, or failure of QC limits. Some flags are generated by the sampling instrument. Appendix I contains a complete list of the data qualifiers for the field and laboratory activities. Qualifiers will be placed on field and bench sheets with additional explanations in free form notes areas. When the validation process runs (see Section 24), flags are generated. During the sample validation process, the flags are used to decide on validating or invalidating individual samples or batches of data. Section 24 discusses this process.

20.8 Data Tracking

Data management includes tracking the status of data as it is collected, transmitted, and processed. The QAPP describes the established procedures for tracking the flow of data through the data processing system.

The DAQ contains the necessary input functions and reports necessary to track and account for the whereabouts of calibration and the status of data processing operations for specific data. Information about analyzer calibration is updated at distributed data entry terminals at the points of significant operations. The following input locations are used to track calibration location and status:

- Mobile Laboratory
    - Calibration gas checking on analyzers
    - Calibration data for analyzers
    - Fan calibrations
- Emailing and Shipping (calibration data is entered for both sending and receiving)
- Laboratory
    - Data entering
    - Post processing

In most cases, the tracking database and the monitoring database are updated simultaneously. For example, when the calibration checking and calibrating data is entered into the monitoring database and the calibration time and location are entered into the tracking database.

20.9 Data Storage and Retrieval

The QAPP should discuss data storage and retrieval including security and time of retention, and it should document the complete control system. The QAPP should also discuss the performance requirements of the data processing system, including provisions for the batch-processing schedule and the data storage facilities.

The DAQ system consists of a PC and compact Fieldpoint (National Instruments Corporation, Austin, TX) which is a data acquisition and automation controller composed of rugged I/O modules and intelligent communication interfaces. Real-time DAQ program developed using LabView 7 software (National Instruments, Corporation, Austin, TX) is used to acquire data, automate sampling location control, display real-time data, and deliver data and system operation status. The DAQ program consists of two sub-programs: an embedded program running in the CFP-2020 network module for collecting raw signals and controlling sampling location and a PC-based program running in the on-site project computer for data post-processing and data publishing on the webpage. The embedded program can stand-alone run and send out data and alarm email. All the real-time readings of the instruments are recorded and displayed on the front panel of the program. Using LabView 7, the front panel can be published as a web page, and viewed in real-time and controlled from a remote location, through Internet. The recorded data are stored daily to the on-site PC and backed up by a remote computer via a satellite high-speed internet connection. The stored data are also automatically transmitted through an email sever on a daily basis to provide redundant data transfer.

Electronic data will be recorded and stored on the on-site computer and downloaded daily with a scheduled time via a high-speed internet connection to a dedicated project computer at ISU. The data is backed-up weekly to CDs onsite by the UK personnel and to an external hard drive at ISU. As the data redundant system, the compact Fieldpoint stand-alone controller records the electronic raw data in a compact flash memory and sends the data out by email via a high-speed Internet connection (see Appendix G). For the precise data post process in the dedicated project computer, all the processed data will be stored in the computer and backed-up to the external hard drive. In addition to computer storage, raw tables or graphs are printed out and stored in loose-leaf notebooks.

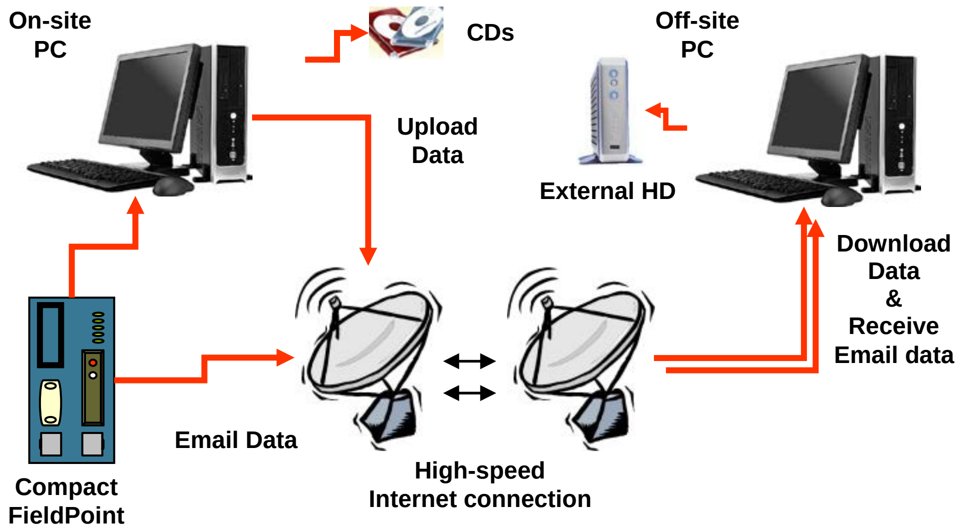


Figure 20.2. Flowchart of electronic data back-up and storage

Field test documentation and electronic data storage are maintained in accordance with standard operating procedures (see Appendix H) including storage of all raw electronic data in ASCII file format for later analysis using commercially-available spreadsheet and statistical programs (Appendix I). A large portion of the data is be maintained electronically in the form of spreadsheets. All pollutants, temperature, pressure, RH and fan ON/OFF data is electronically stored and compiled in a manner that will facilitate computation of hourly and daily averages.

Accurate working files of all documentation, including logbook entries, original data, calculations, deviations from approved procedures, data uncertainties, assumptions, QA/QC results and external performance data, audits, and review, inspection, and validation are maintained by the principal investigators as appropriate until archived after the completion of the project. Project records are maintained in a systematic and logical form and adequately filed for rapid retrieval, accounted for and appropriately indexed.

Data archival policies for the air emission data are shown in Table 20.4.

Table 20.4 Data Archive Policies

Data Type	Medium	Location	Retention Time	Final Disposition
Laboratory Notebooks	Hardcopy	Laboratory	3 years	Discarded
Database	Electronic	Laboratory	Indefinite (may be moved to backup media after 5 years)	Backup
Audit trail	Electronic	Laboratory	3 years	Discarded
Samples		Laboratory	1 year	Discarded

The air emission data resides on an IBM-PC compatible computer at ISU. This computer has the following specifications:

- Processor: Pentium 2.8 GHZ
- Operating System: Windows XP
- Memory: 1 GB
- Storage: 200 GB
- Backup: Incremental backups daily; full backups weekly (750 MB CD-ROM)
- Network: Windows XP, 100 Mbps Ethernet network (Satellite internet connection via 196 kbps modem)
- Database Software: Microsoft Excel, Labview 7.0
- Security: Password protection on all PCs and internet connection; Additional password
- Protection applied by application software, internet connection with firewall.

Security of data in the air emission database is ensured by the following controls:

- Password protection on the data base that defines three levels of access to the data
- Regular password changes
- Independent password protection on internet connection
- Logging of all incoming communication sessions
- Storage of media including backup tapes in locked, restricted access areas

21.0 Assessments and Response Actions

The principal investigators (PIs) are responsible for the initial assessment and evaluation of data in accordance with the validation procedures. Internal QA/QC audits of data collection and validation are conducted by the project QA Manager. The project PIs are responsible for initiating necessary response actions in response to data assessment or internal audit findings. In the event that work must be stopped in order to conduct any response action required to comply with QAPP requirements or for other necessary reasons, the following project personnel have the authority to stop work: Kevin Igli and Steve Patrick with Tyson Foods (Funding Agency), Robert Burns and Hongwei Xin with ISU, Rich Gates with UK (Primary Project PIs) and Lara Moody (Project QA Manager). The following assessment mechanisms, shown in Table 21.1, are implemented as part of the project quality assurance. As indicated Lara Moody will serve as the Project Quality Assurance Manager. While Moody is an employee of ISU she will not be under the supervision of any of the project PIs in regards to this project. Raj Raman is serving as Moody’s direct supervisor in regards to her duties as Quality Assurance Manager for this project. Moody will report the results of her QA/QC activities on the project directly to Raman. Raman will review her findings and communicate the results and required actions to the project PIs.

Table 21.1. Quality assurance assessments and implementation frequency

Assessment Type	Daily	Twice Weekly	Weekly	Every Flock	Once
Remote System Observance	X				
On-site System Inspection		X			
Internal Technical System Audits				X	
External Technical System Audits					X
Data Completeness and Out of Range Data Flagging / Review	X		X		
Flock Data Completeness & Emissions				X	

21.1 Remote System Observance

Remote observation of the monitoring system performance is a normal part of daily project activities and is conducted on a daily basis by ISU personnel (Hong Li) via a high-speed Internet connection to each MAEMU. Using a web-based remote interface all pollutant monitoring readings are viewed daily in real-time, as well as individual fan operational status, pressure differential, and temperature, relative humidity and dew point conditions at all four sampling points. The sample line heat trace temperatures are reviewed, as well as the GSS heat tape temperatures, GSS exhaust air flow and the temperature inside each MAEMU.

21.2 On-site System Inspection

A complete on-site inspection of the monitoring system is conducted twice per week by UK personnel (John Earnest and Doug Overhults) who are located 30 minutes from each monitoring site. During a twice-weekly visit to each site, project personnel conduct a visual check on all system components including in-house sampling points, TEOMs and fans, the ambient monitoring point, and all instruments and components located inside the MAEMU at each location. During one visit per week the paper element filters and the 20 micron *Teflon* filters are replaced. The TSP, PM_{10} and $PM_{2.5}$ TEOM heads are also exchanged for clean heads during this visit (TEOM heads are exchanged twice per week due to the high dust conditions encountered in the broiler houses). A report detailing assessment observations and any required response actions is prepared by John Earnest following each visit and emailed to all team members the next business day following the site visit.

21.3 Internal Technical System Audits

The broiler houses are empty for approximately ten days following the removal of each flock of birds (each flock is in the house for ~ 52 days). During this ten day period between each flock ISU and UK project personnel (Robert Burns, Hongwei Xin, Rich Gates, Doug Overhults, John Earnest and Hong Li) conduct an Internal Technical Systems Audit at both Tyson 1-5 and Tyson 3-3. This audit includes a visual inspection of all system components, and a flow check at each of the four sample points to confirm pump flows are maintaining a 15 L/min flow rate. A flow-audit is conducted on each TEOM during the audit. Leak checks of the GSS and supply lines are conducted by calibrating an additional INNOVA 1412 with the INNOVA 1412 located in the MAEMU, and then placing the second INNOVA 1412 at each sample point inside the broiler house and confirming matching ammonia readings. This provides a confirmation that no dilution air is entering the system, and that no leaks are present. The results of each Internal Technical System Audit are documented and provided to the Quality Assurance Manager for review. During a minimum of two Internal Technical System Audits the Project QA Manager (Lara Moody) will conduct a field oversight of sampling and analysis activities at each site, during which performance audit samples will be analyzed During field oversight, the Project QA Manager will visually observe sample collection and analysis to verify that the procedures outlined in this QAPP are being followed and that any corrective action initiated previously is being continued. Field documentation of samples, calibration, QC measures, and corrective action will also be reviewed. In addition, the Project QA Manager will conduct a review of data and record management systems during the field monitoring period. During this review, the Project QA Manager will verify that the data management procedures are being followed. Reports from these two field assessments that document all issues identified during these reviews will be provided to Raj Raman and copied to Kevin Igli and Steve Patrick with Tyson Foods (Funding Agency), Robert Burns and Hongwei Xin with ISU, Rich Gates with the UK (Primary Project PIs) and the EPA Project Manager and the EPA Quality Officer. The project PIs will prepare an action plan that identifies how all items will be addressed and the schedule that the responses will be implemented in.

21.4 External Technical System Audits

An external technical systems audit team has been established and will conduct an audit following acceptance of the project QAPP. The audit team members are Drs. Larry Jacobson and David Parker. Both are national recognized experts in AFO air emissions monitoring. Dr. Larry D. Jacobson is a Professor of Biosystems and Agricultural Engineering at the University of Minnesota located in St. Paul, MN. Dr. David B. Parker is an Associate Professor of Environmental Science and Engineering in the Division of Agriculture at West Texas A&M University located in Canyon, Texas USA.

1. Dr. David Parker, Associate Professor
   West Texas A&M University
   dparker@mail.wtamu.edu
   806-655-6499

2. Dr. Larry Jacobson, Professor
   University of Minnesota
   jacob007@tc.umn.edu
   612-625-8288

An external technical system audit will be conducted in the 4th quarter of 2006. External auditors and EPA personnel will be asked to provide a field review of all monitoring system and data acquisition components to confirm that they have been installed in accordance with the QAPP. The project records including the notebooks that log all site visits and system calibrations, the twice-weekly On-site Visit Reports, the Internal Technical System Audit reports, the daily Data Completeness and Out of Range Data Flagging/Review reports, and the Flock Data Completeness and Emissions reports will be made available to the external auditors. The external audit team will be asked to review the above mentioned reports and emissions data to determine if the project data collection and management has been conducted in accordance with the project QAPP. The external auditors will provide a report that details their findings and any suggested changes in project execution as needed per their findings. This report will be distributed to EPA, Tyson Foods, ISU and UK project personnel. Following the distribution and review of the report the project PIs will develop a plan to implement any required changes to data collection, management or analysis that are required as a result of the external audit findings. The project PIs will meet with the Project QA Manager, the EPA Project Manager, the EPA QA Officer and

Tyson management to propose an implementation schedule that outlines each identified deficiency, the planned action and the schedule for implementation.

21.5 Data Completeness and Quality Reviews

As described in Section 24, a data processing program is run daily to process data collected on the previous day. This program calculates data completeness and automatically flags out of range data. ISU project personnel will review flagged data within two working days to confirm that the data is either invalid and cannot be used or valid and can be used. Only project PIs have the authority to validate flagged data following a review of the data. Flagged data that has not been validated will not be used in emissions calculations. A record of data review and any removal of data flags following review will be maintained. The response action to data flagged as out of range will be to investigate and document the reason that the data was flagged and to follow-up with a site visit if any data flags were the result of equipment malfunction and correct the problem.

22.0 Reports to Management

During the project, the following reports will be prepared; Quarterly QA/QC Review Reports, On-Site System Inspection Reports, Internal System Audit Reports, External System Audit Reports, Daily Data Completeness and Validity Posting, Flock Data Completeness and Emissions Postings, Field Oversight Assessment Reports, Mid-Term Project Report and a Final Emissions Report. Table 22.1 provides the frequency, content, distribution and individuals responsible for the generation of each report.

Table 22.1. Reports to Management

Report Type	Content	Frequency	Distribution	Responsible Person
Quarterly QA/QC Review	Results of QA Managers review of project data management	Quarterly	Dr. Raj Raman	Mrs. Lara Moody
On-site System Inspection Reports	Description of on-site visit & any identified issues	Twice - Weekly	All ISU and UK project personnel	Mr. John Earnest
Internal Technical System Audit Reports	Confirmation and results of each system check performed in audits	At the end of each flock (~ 52 days)	Mrs. Lara Moody Dr. R.T. Burns Dr. Hongwei Xin Dr. Rich Gates Dr. Steve Hoff Dr. Doug Overhults Mr. John Earnest	Dr. Hong Li
External Technical System Audit Reports	Results of External Audit Findings	Once during 4th Quarter of 2006	Mrs. Lara Moody Ms. Sharon Nizich Mr. Joe Elkins Dr. R.T. Burns Dr. Hongwei Xin Dr. Rich Gates Dr. Steve Hoff Dr. Doug Overhults Mr. John Earnest	Dr. David Parker Dr. L. Jacobson

Data Completeness and Validity Posting	Data completeness & validity determination for daily environmental & emissions data	Daily	All ISU and UK project personnel via web	Dr. Hong Li
Flock Data Completeness & Emissions	Data completeness & validity determination for flock emissions data	Each flock (~ 52 days)	All ISU and UK project personnel via web	Dr. Hong Li
Field Oversite Assessment Reports	Assessments of Internal Technical System Audits Execution	Twice during project	Dr. Raj Raman	Mrs. Lara Moody
Mid-Term Project Report	Project and milestone completion status	3rd Quarter 2006	Mr. Kevin Igli Mr. Steve Patrick Ms. Sharon Nizich	Dr. Robert Burns
Final Emissions Report	Emissions results	3rd Quarter 2007	Mr. Kevin Igli Mr. Steve Patrick Ms. Sharon Nizich Mr. Joe Elkins	Dr. R.T. Burns Dr. Hongwei Xin Dr. Rich Gates Dr. Steve Hoff

23.0 Data Review, Verification, and Validation Requirements

For this project, data review is the examination of data to ensure that the information has been recorded, transmitted, and processed correctly; including checking for errors pertaining to data entry, transcription, calculation, reduction and transformation. Data review for the gaseous and particulate matter sampling includes 1) quality control information as described in Section 15 – Quality Control Measures (i.e., instrument set-up, calibration, and accuracy and bias check data), 2) instrument testing and maintenance information as described in Section 16 – Instrument/Equipment Testing, Inspection and Maintenance (i.e., online and on-site inspection and maintenance data), 3) instrument calibration and frequency records and described in Section 17 – Instrument/Equipment Calibration and Frequency (i.e., calibration dates, instrument calibration offsets from standards, and corrective measures), and 4) generated gaseous, particulate matter, fan flow and environmental condition data used for emission rate calculations. Data review for the litter analysis includes 1) quality control information as described in Section 14 – Analytical Methods (i.e., spiked matrices and triplicate analyses), 2) records verifying litter sample collection and handling methods as described in Sections 12 and 13 describing Sampling Methods, Handling and Custody, and 3) nutrient concentration data generated through litter sample analysis.

Data verification is the process for evaluating the completeness, correctness and conformance of a data set against the collection methods specifications. For the gaseous and particulate matter sampling, this means insuring the data sets are 75% complete and that daily emission rates meet the Measurement Performance Criterion of less than 10% uncertainty as per the DQO stated in Section 7 – Quality Objectives and Criteria for Measurement Data, and insuring that individual concentration and fan flow data falls within the ranges specified for the equipment and the project as described in Section 7 – Quality Objectives and Criteria for Measurement Data. For the litter analyses, data verification means insuring the standard deviations between replicated samples and generated data are acceptable for the methods described in Section 14 – Analytical Methods. Data validation extends beyond data verification and is to determine the quality of the data for end use. Data validation for both gaseous and particulate matter sampling and litter sampling will occur throughout the project. Data is compared to other data already available in the literature to determine if it is within the expected range. Data verification and validation are described below in additional detail.

All UK and ISU project personnel who perform work on-site have a responsibility to report any deviation from the SOPs established for the project. Any deviations from the SOPs that occur during twice-weekly on-site visits conducted by UK personnel will be recorded in the On-Site System Inspection Reports. Any deviations from standard SOPs that occur during the Internal System Audits will be documented and explained in the Internal System Audit Report generated following the audit visit.

23.1 Gas and Particulate Matter Sampling System

Section 11 – Sampling Process Design describes the sampling system design for this project; including, emission rate calculations, sampling equipment selection, in-house sample locations, and data collection frequency. The objective of the sampling design is to determine air emissions representative of broiler houses and to ensure adequate levels of spatial and temporal resolution. It is the responsibility of the project PIs to ensure that the sampling systems function properly and the responsibility of the Project Quality Assurance Manager to confirm that appropriate data quality checks and documentation is implemented to confirm the final quality of collected data. During twice weekly on-site inspections UK project personnel confirm through visual inspection that the sampling system conforms to the sampling system design specifications. The actual performance of the sampling system is confirmed during Internal Technical System Audits conducted between each flock of birds (approximately every 52 days).

<u>Verification.</u> Verification of individual fan flow rates will occur at the end of each flock removal from the broiler houses. Following bird removal from the houses and prior to fan calibration each fan is visually inspected to confirm that it has been pressure washed and that belts (on belt driven fans) are adjusted to the correct tension. During the between flock checks, all aspects and parts of the fan calibration will be checked and verified by following the QC.

<u>Verification.</u> Verification of the sampling system occurs through routine twice-weekly and between flock checks. The twice-weekly check inspects the functioning of sampling instruments. The sample lines and data lines are visually checked. (The output from all instruments and operation of the sampling system components are checked daily). During the between flock checks, all aspects and parts of the sampling system are checked and verified by following the QC.

<u>Sampling System Validation.</u> The data from routine visit and between flock audits will be used to validate the sampling system and to ensure that the sampling system meets the objective of the project as described in Section 6 – Project Task Description.

23.2 Analytical Procedures

Section 15 details the requirements for the analytical methods. The methods include acceptance criteria (Sections 15 and 16) for important components of the procedures, along with suitable codes for characterizing each sample's deviation from the procedure.

<u>Verification.</u> The Quality Assurance Manager conducts audits to ensure the analytical method specifications mentioned in the QAPP are being followed. The audits will include checks on the identity of litter samples collected between flocks. Deviations from the analytical procedures will be noted in audit finding forms and corrected using the procedures described in Section 21.

<u>Validation.</u> Similar to the validation of sampling activities, the review of data from lab blanks, calibration checks, laboratory duplicates and other laboratory QC that are described in Sections

15 and 16 can be used to validate the analytical procedures. Acceptable precision and bias in these samples indicate that the analytical procedures are adequate. Any data that indicates unacceptable levels of bias or precision or a tendency (trend on a control chart) will be flagged and investigated as described in Section 21. Any discovery of inappropriate analytical procedures will trigger corrective action.

23.3 Quality Control

Sections 15 and 16 detail the requirements for the QC during sampling collection, handling, and analysis, which include analyses of check standards, calibration and accuracy check. For each specified QC check, the procedure, acceptance criteria, and corrective action are specified.

Verification. As mentioned in the above sections, both internal and external audits will be performed to ensure the QC method specifications mentioned in the QAPP are being followed.

Validation. Validation activities of many of the other data collection phases mentioned in this subsection use the quality control data to validate the proper and adequate implementation of that phase. Therefore, validation of QC procedures will require a review of the documentation of the corrective actions that will be taken when QC samples failed to meet the acceptance criteria, and the potential effect of the corrective actions on the validity of the routine data.

23.4 Calibration

When calibration problems are identified, any data produced between the suspect calibration event and any subsequent recalibration will be flagged to alert data users. Sections 16 and 17 detail the calibration activities and requirements for the critical pieces of equipment for the air emission monitoring.

Verification.

As mentioned in the above sections, both internal and external technical systems audits will be performed to ensure the calibration specifications and corrective actions mentioned in the QAPP are being followed. Deviations from the calibration procedures will be noted in audit finding forms and corrected using the procedures described in Section 21.

Validation.

Similar to the validation of sampling activities, the review of calibration data that are described in Sections 15 and 16, can be used to validate calibration procedures. Calibration data within the acceptance requirements would lead one to believe that the sample collection measurement devices are operating properly. Any data that indicates unacceptable levels of bias or precision or a tendency (trend on a control chart) will be flagged and investigated. Validation would include the review of the documentation to ensure corrective action will be taken as prescribed in the QAPP.

23.5 Data Reduction and Processing

When calibration problems are identified, any data produced between the suspect calibration event and any subsequent recalibration will be flagged to alert data users. Sections 16 and 17 detail the calibration activities and requirements for the critical pieces of equipment for the air emission monitoring.

Verification. As mentioned in the above sections, both internal and external technical systems audits will be performed to ensure the data reduction and processing activities mentioned in the QAPP are being followed.

Validation. As part of the audits of data quality, discussed in Section 20, a number of sample IDs, chosen at random will be identified. All raw data files, including the following will be selected:

- Electronic data (recorded by DAQ system and computer)
- Routine check
- Calibration -the calibration information represented from that sampling period
- Sample handling/custody
- Corrective action

Data post processing

24.0 Verification and Validation Methods

Many of the processes for verifying and validating the measurement phases of the emission data collection have been discussed in Section 23. If these processes, as written in the QAPP, are followed, the DQOs should be achieved. However, exceptional field events may occur, and it is expected that some of the QC checks will fail to meet the acceptance criteria.

Information on problems that could affect the integrity of data is identified in the form of flags (Appendix I). It is important to determine what caused these out of range indications in the data. In some cases there may be a unique event occurring and the data may truly represent measures parameters and simply be outside of the expected range. In other cases out of range data may be due to equipment that is out of calibration or that has failed. The review of this raw data and their associated QC data will be verified and validated in a routine report on the basis of calibration data. The routine report and calibration data is the most efficient entity for verification/validation activities. It is assumed that if measurement uncertainty can be controlled within acceptance criteria, at calibration level, then the overall measurement uncertainty will be maintained within the precision and bias DQOs.

24.1 Verification

After a one-day data set is downloaded to the ISU computer, a review will be conducted for completeness, correctness, conformance/compliance of the environmental and concentration data against the QC standard, instrument operational conditions and broiler house normal operating conditions. All data is evaluated using a program specifically developed for this task (MAEMU v1.2, developed by using Visual Basic), running on an ISU computer for this project. The program reviews the data for data outliers and data outside of acceptance criteria. These data are flagged appropriately. The acceptance criteria, listed in Table 24.1, is set up in the program and is used to determine if individual data or data from a particular instrument has been flagged. These flagging criteria can be varied due variations in expected data ranges due to seasonal differences and bird growth. Verification of measurement data is conducted in three parts, one for the environmental condition measurement value, the second for the air sample measurements and the third for fan operational parameters.

Temperature, relative humidity, barometric pressure and static pressure readings are inspected first. Any reading out of the normal operation range is flagged appropriately and UK field personnel are notified and asked to make an on-site inspection to determine the reason for out of range data (e.g., malfunction of sensors or true out of range reading). The following correction actions are performed if the on-site visit determines that are required to address the issue.

- The gas analyzers, INNOVA, API 101E, and VIG, are routinely challenged (weekly) with calibration gases. If the recent reading of one gas does not meet the QC standard, the data collected between current site visit and the last site visit where the unit met the QC criteria will be flagged. For example, the NMHC reading is 2.8 ppm when 3 ppm propane cal-gas is injected, the difference, 0.2 ppm is larger than 5% of cal-gas concentration (0.15 ppm). In this case all NMHC readings since the last calibration will be flagged with “CVN”. In addition, the gas-concentration will be flagged if the reading is out of the analyzer operation range. For instance all NMHC data would be flagged with “OVN” if the NMHC reading exceeds 10 ppm.

- The TSP, PM_{10} and $PM_{2.5}$ operational readings from TEOMs are reviewed based on the routine leak test and operation range. If the main flow rate of TEOM with a TSP head is not in the range, 0.98 to 1.02 L/min, a flag “OTF” will be recorded.

A separate flag data set will be created and flags of individual data will be filed. Based on the data flags, the daily completeness of each variable will be derived by using following equation:

$$\text{Completeness} = \frac{N_{total} - N_{flag}}{N_{total}} \times 100$$

After calculating completeness and data flagging, the program will create a daily verification form to summarize the flags and completeness for environment variables, air pollutants and fan operation data. The flagged data will not be used for daily air emission calculation.

Daily emissions for each pollutant are calculated based upon the data flag status (i.e. only data that has not been flagged is used) and a daily emission report is generated, which includes a summary table for individual gas emission, flags and completeness of the pollutant. If any flag is detected by the program, a flag notification email will be sent to all PIs for addressing and solving the problem(s). This daily report will be posted on a secured web-site and PIs (Burns, Xin, Gates or Hoff) will review it within 2 working days. All the data points with flags is inspected and the reason addressed. Also, the verified daily emission data is summarized on a flock basis.

24.2 Validation

Data is internally validated by the Quality Assurance Manager (Lara Moody), data processing operators (Hong Li) and all PIs. The daily air emission reports are reviewed as well as the other routine reports, field calibration data and lab record.

The data validation includes the following four steps:

- Review all the routine field visit reports and calibration report to ensure QC standard is met, if not the corresponding data will be invalidated.

- Review data verification records, including data flags, daily emission reports; if the flagged data meets the QC standard, these data points will revalidated and the data processing program will be rerun.
- Summarize data and QC deficiencies if the data quality was not met and evaluate the impact on overall data quality
- Develops data validation reports quarterly.

A checklist of criteria and items to evaluate during each stage of data review is listed in Table 24.1. In cases where any of the criteria and checks can be automated using the post processing program, random checks should still be done to ensure that the auto-check is working properly. If errors or problems are identified through any of the following checks, corrective action, appropriate to the problem, should be taken (e.g., reanalysis, data qualification, troubleshooting, or documentation).

Table 24.1 Verification and Validation data flags and action

Requirement	**Data Range**	**Acceptance criteria**	**Flag**	**Action**
Temperature	32°F ~ 105 °F	> 105 °F < 32°F	OET	Reanalysis/ Confirmation by on-site visit / calibrate / replace Thermocouple/document
Relative humidity	0~100 %	>100% < 0	OEH	Reanalysis/ Confirmation by on-site visit / calibrate / replace RH Sensor/document
Barometric pressure	900~1050 kpa	>1050 < 900	OEB	Reanalysis/Confirmation by on-site visit / calibrate / replace Barometric pressure sensor/document
Static pressure	-0.05 ~ 0.5 inch Water	>0.25 < -0.02	OEP	Reanalysis/Confirmation by on-site visit / calibrate / replace Static pressure sensor/document
Fan current switch	ON/OFF	OFF (all the time)	FCS	Reanalysis/Confirmation by on-site visit / replace Fan Current Switch/document
Temperature	<±1°F (Checking)	>±1°F	OCT	Reanalysis/Confirmation by on-site visit / replace Thermocouple/document
Relative humidity	<±5 % of Standard (Checking)	>±5 %	OCH	Reanalysis/Confirmation by on-site visit / Calibration/document
Barometric pressure	<±5 % of Standard (Checking)	>±5 %	OCB	Reanalysis/Confirmation by on-site visit/ Calibration/document
Static pressure	<±5 % of Standard	>±5 %	OCP	Reanalysis/Confirmation by on-

	(Checking)			site visit / Calibration/document
NH_3	<±5 % of Standard	>±5 %	CIA	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
CO_2	<±5 % of Standard	>±5 %	CIC	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
H_2S	<±5 % of Standard	>±5 %	CHS	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
Non-Methane Hydrocarbon (NMHC)	<±5 % of Standard	>±5 %	CVN	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
Methane	<±5 % of Standard	>±5 %	CVM	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
Total Hydrocarbon (THC)	<±5 % of Standard	>±5 %	CVT	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
H_2S measurement range	0~100 ppb	> 100 < 0	OHS	Reanalysis/Confirmation by on-site visit / Calibration/document
NMHC measurement range	0-10 ppm	> 10 < 0	OVN	Reanalysis/Confirmation by on-site visit / Calibration/document
Methane measurement range	0-100 ppm	> 100 < 0	OVM	Reanalysis/Confirmation by on-site visit / Calibration/document
THC measurement range	0-100 ppm	> 100 < 0	OVY	Reanalysis/Confirmation by on-site visit / Calibration/document
TSP flow	0.98~1.02 LPM (<0.15 leak check)	> 1.02 < 0.98 (>0.15 leak)	OTF	Data qualification Reanalysis/Confirmation by on-site visit / Leak check & correction/document
TSP measurement range	0~100 mg/m^3	> 100 < 0	OTR	Reanalysis/Confirmation by on-site visit / Instrument Inspection
PM10 flow	0.98~1.02 LPM (<0.15 leak check)	> 1.02 < 0.98 (>0.15 leak)	OPF	Data qualification Reanalysis/Confirmation by on-site visit / Leak check & correction/document
PM10 measurement range	0~50 mg/m^3	> 50 < 0	OPR	Reanalysis/Confirmation by on-site visit / Instrument Inspection/document
PM2.5 flow	0.98~1.02 LPM (<0.15 leak check)	> 1.02 < 0.98 (>0.15 leak)	OMF	Data qualification Reanalysis/Confirmation by on-site visit / Leak check & correction/document
PM2.5 measurement range	0~20 mg/m^3	> 20 < 0	OMR	Reanalysis/Confirmation by on-site visit / Instrument Inspection/document

25.0 Reconciliation with User Requirements

Section 7 – Quality Objectives and Criteria for Measurement Data describes the DQOs set forth for this project to assure data representativeness, completeness, comparability, and accuracy. Section 23 – Data Review, Verification, and Validation Requirements and Section 24 – Verification and Validation Methods describe the requirements and methods used in this project to determine the data representativeness, completeness, comparability, and accuracy that will aid in meeting the DQOs. The DQO for data completeness is to obtain valid emissions data for no less then 75% of the scheduled sampling for each pollutant. The DQO sets the Measurement Performance Criterion for daily emission rates at an uncertainty of less than 10%. The emission rate uncertainty for each pollutant is calculated as per section 7.4 at the end of each flock. Uncertainties for fan flow can be calculated at the end of each flock by comparing fan calibrations from the beginning and end of the flock cycle. Pollutant measurement uncertainties can be calculated on a weekly basis based on the calibration gas challenge that is completed for each instrument on a weekly basis. This allows an emissions rate uncertainty to be calculated for each pollutant by week at the end of each flock following the post flock calibration of fans.

The steps to perform the Data Quality Assessment are provided below:

1. Review the DQOs provided in Section 7 and the sample design process detailed in Section 11 – Sample Process Design
2. Conduct a preliminary review of the data
    a. Uncover potential limitations to using the data, to reveal outliers, and to explore the basic structure of the data (processing, reviewing, and sharing the preliminary data included in Section 24)
    b. Look for anomalies in recorded data, missing values, and any deviation from standard operating procedure
3. Perform statistical analysis of the preliminarily accepted data
    a. Base statistical test selection on the primary objective (to determine representative broiler house gaseous and particulate emission rates (kg bird^{-1} day^{-1}))
4. Verify assumptions of the statistical tests
    a. Assumptions include those associated with the development of the DQOs
        i. DQO is based on performance criteria and component error analysis
        ii. Data used for the statistical computation of an emission rate must meet the 75% completeness standard defined in the DQOs (Section 7)
5. Draw conclusions from the data
    a. Determine if an statistical assumptions were violated
    b. Use the statistical analysis to determine representative emission rates

Data is provided to the end users (Tyson and EPA decision makers) in the Final Emissions Report delivered in the 4th quarter of 2007. The report will include a section describing the steps taken to meet the DQOs and descriptions of the data provided. Data provided will include all acceptable raw data (acceptable as determined by the validation and verification methods in

Section 24) and the statistical analysis used to draw conclusions about the results. Possible limitations to the data will be described in the report. The report will also provide a description of the facilities where the data was collected to describe for end users what systems this data is representative of.

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Appendix A: SOP of Information Required from Tyson and Information for the Producer

Measurements to be Taken

1. Inside and outside temperature and relative humidity.
2. Fan status (on/off) and airflow rate.
3. Operation of lights, feeders.
4. Static pressure difference between inside and outside the barn.
5. Inside and outside ammonia and carbon dioxide concentrations.

Measurement Duration

Continuous monitoring of two barns for 12 months, beginning January 2006.

Measurement Logistics

Gas samples are collected using flexible FEP tubes, at three locations in each barn. All gas samples and instrumentation equipment are housed in an 8 ft x 14 ft MAEMU positioned adjacent to the barn. This MAEMU will serve as a shelter for measurement instruments.

Project staff visits the site once a week, or more often as needed. This is required to check equipment status, calibrate sensors, and to make sure everything is working as planned. Most of this time is spent in the instrumentation trailer and not the barns, although some time needs to be spent in the barns to change sample line filters, TEOM filters, exchange TEOM inlet heads, and to check sensors. Strict adherence to biosecurity as per Section 1.7 will be followed.

Barn Modifications

In order to introduce the sensor wires and gas sampling lines into the barns, two 4-in PVC pipes connect the MAEMU to each barn. These pipes house data lines and air sample lines, and are buried.

Requirements for Tyson and Collaborating Producer

Tyson is required to provide the university the following information about each barn:

1. Animal diet, feed consumption, inventory and body weight
2. Production outputs, marketed birds and birds mortality
3. Record of litter removals
4. Record of cleaning operations
5. Record of animal movements in and out of the barn
6. Record of water consumption
7. Advance notification of any alteration in production schedules and methods.
8. Record of equipment failures, (e.g., ventilation fans, inlet control)
9. Power failures
10. Temperature set points
11. Operation of lights

Appendix B: SOP of Gas Sampling System

Vacuum pumps (P1-P4) with *Teflon* wetted parts are used to deliver air from the sampling locations via solenoids and a manifold (M1), and transport the air stream to another manifold (M2), which connects to the gas analyzer. Teflon or Teflon coating is used in all wetted parts of the sampling system (pump, solenoid valves, manifold, and tubing). Four pairs of 2-way solenoid valves (S1-S8) in the air sampling system located in sampling lines are controlled by the DAQ system and control unit to allow measurements of gas concentrations by automatic gas sampling from four locations (figure 1). To avoid the malfunction of solenoid valves due to overheating, solenoid cool boards are used to drive these solenoid valves. When the control module sends the signal to the cool boards, the cool boards will provide full power (12 VDC) on the solenoids during the first 100 ms and then cut the power to approximately half (5 VDC) and hold it. The cool boards solve the overheating problem of the solenoid valves (Figure 2). Individual supply pumps with 16 L/min delivering capacity are used to continuously draw air from each of the sampling locations. The sampling train is designed such that a sample will be drawn from all four sampling points continuously unless a sampling point is note being analyzed. When this occurs, the flow will be bypassed through the normally open solenoid valve (P5-P8). This arrangement is designed to minimize the residence time and thus greatly reduce sample-to-sample purging time. When a sampling stream is selected, the corresponding normal close valve will open and the normal open valve will close; and the selected gas stream will flow from the sample inlet via the tubing through the manifolds (M1 and M2). The internal pump of the gas analyzers draws air from manifold M2. The gas sampling system is designed such that all solenoid valves, manifolds and associated connections are under positive pressure. Using this positive pressure approach if a leak were to develop on the gas sampling control board at any of these components, it would not impact the integrity of the gas sample.

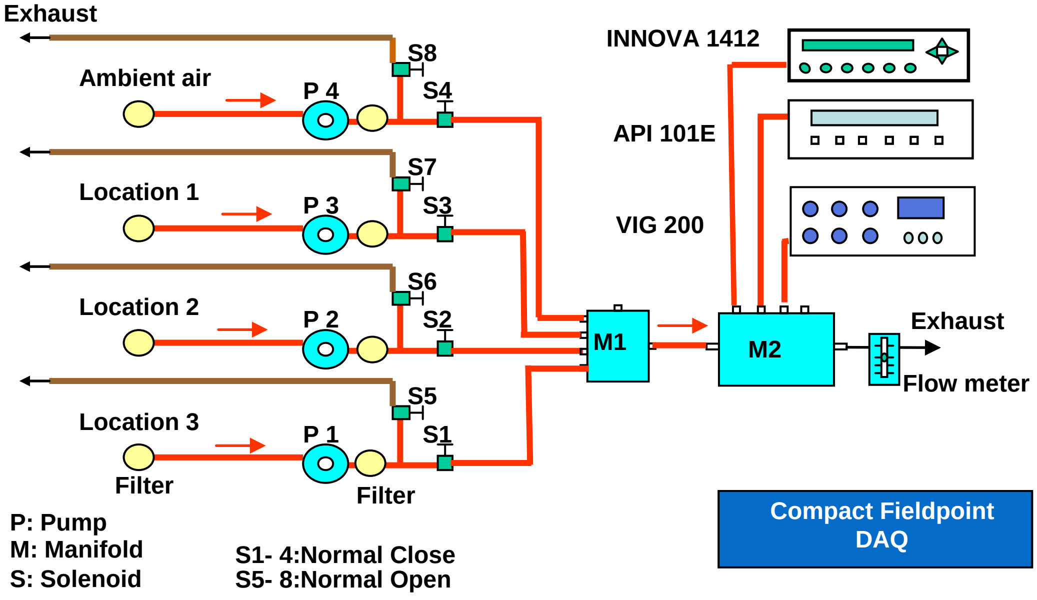

Figure 1. Schematic of sampling system configuration. (The analyzers have internal pumps.)

When needed sampling lines are heated with heat trace or heat tape to prevent in-line condensation, temperature of the sampling line and thus, power input of the heat trace or tape, is continuously monitored and regulated through the DAQ and control system.

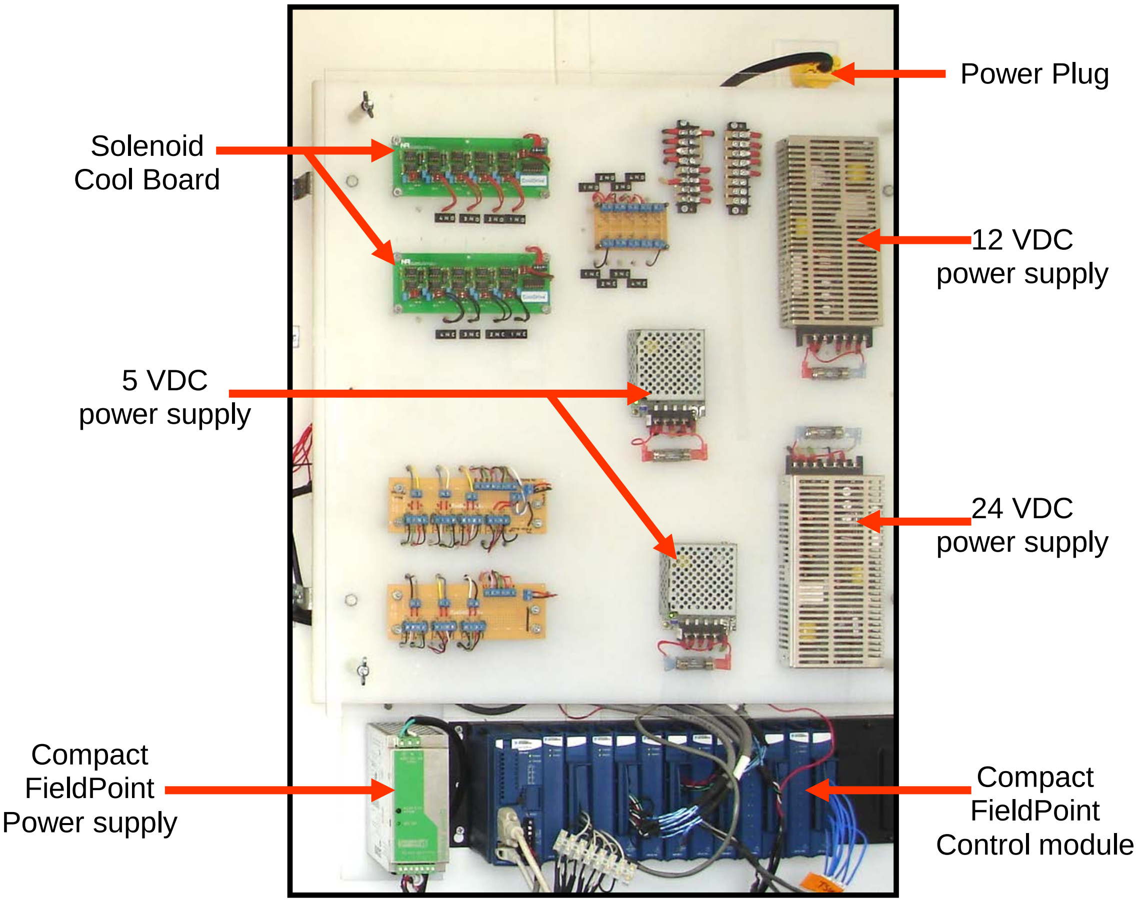

Figure 2. Electronic board and control modules for the sampling system

Two pleated paper filters are used to exclude insects and other coarse particulates, as well as a 47-mm diameter, in-line *Teflon* PFA filter holder housing a 47-mm diameter, *Teflon* PTFE-laminated polypropylene membrane filter with 20-µm pore size, is installed at the sampling end of each gas sampling tube to remove airborne particulate from the sampled air. Another 5-µm pore size PTFE filter is installed right after the vacuum pump to provide double protection. Both in-house sample filters are changed weekly (Figure 3).

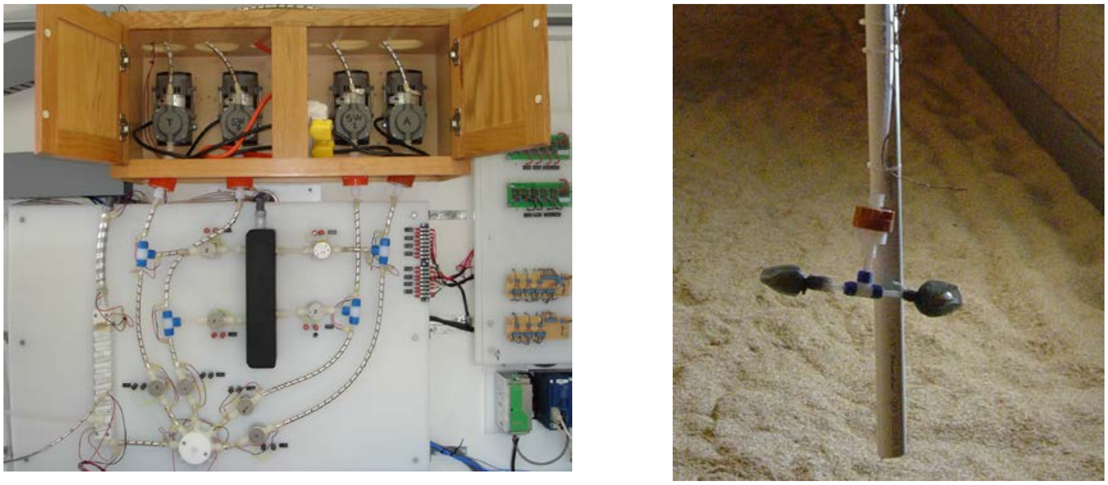

Figure 3. Photographical views of the air sampling system

Appendix C: SOP of Field Estimation of Ventilation Capacity Using FANS

Field Estimation of Ventilation Capacity Using FANS

Introduction

A device for in-situ exhaust fan airflow capacity measurement, referred to as the Fan Assessment Numeration System (FANS) device, previously developed and constructed at the USDA-ARS Southern Poultry Research Laboratory, was refined and constructed by University of Kentucky (Gates et al., 2004[1]). FANS measures the total airflow rate of a ventilation fan by integrating the velocity field obtained from an array of five propeller anemometers used to perform a real-time traverse of the airflow entering ventilation fans of up to 122-cm (48-in) diameter. This SOP provides instructions on installation of the program and operation of the FANS analyzer, and helps in producing high quality measurements.

Data Acquisition Computer

Before using the FANS analyzer, it is necessary to prepare a computer with the necessary hardware to link with the FANS analyzer and software to control and record data. For this, a Keithley DriverLINX card, and the WildCat Anemometer Program (Anemometer2.exe) is needed. *The installation procedures that follow were provided by Ken Casey of the University of Kentucky, and distributed with each FANS unit manufactured.*

Installing Keithley DriverLINX and Anemometer Program

1. Close down all background applications of the computer to be installed.
2. Insert Keithley Card into PCMCIA.
3. Insert the Keithley DriverLINX CD and run the autostart program with command “setup.exe”
4. After the installation window appears, click *“Install DriverLINX”*
5. Click *“Install Drivers”* – c:\Program Files\DrvLINX4
6. and follow directions for registration, use defaults
7. Click “Install Interfaces” – same procedures as step a
8. Be sure to select all options (three of them)
9. Use default folder
10. Click *“Install Documentation”* – use default folder
11. Click *“Back”*, *“Exit”*, and *“Done”*
12. Your computer will be restarted
13. Once restarted, a screen should come up for hardware configuration
14. Follow step 2. Plug & Play should install drivers

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[1] Gates, R.S., K.D. Casey, H. Xin, E.F. Wheeler and J.D. Simmons. 2004. Fan Assessment Numeration System (FANS) design and calibration specifications. Transactions of the ASAE, 47(5):1709-1715.

15. Wait some time for response
16. Afterwards – click *"continue"*, follow directions
17. Probably, click *"configure"*
18. Under hardware configuration
19. Assign logical device number (the default – probably 0)
20. Leave all other values at default, click *"OK"*, and close window
21. Remove Keithley Card, wait about 10 seconds
22. Reinsert card, click "*Start*", "*Programs*", "*DriverLINX*", "*Test Panels*"
23. Run the AIO Panel
24. If it says "No Driver loaded" – reboot, ignore the rest of installer and restart AIO Panel.
25. You should be ready to run
26. You may need to tweak in "*DriverLINX Configuration Panel"*
27. Copy *Anememeter2.exe* and *Anememeter2.mdb* from floppy disc supplied into your directory

FANS Analyzer Unit

In order to ensure the FANS analyzer is operating properly, test both manual and software control as follows:

1. Supply the FANS analyzer with power.
2. The right-most toggle switch should be in up position.
3. Toggle left-most switch up and down, holding for a few seconds at a time to ensure that the motor is moving the anemometers properly.
4. After successful manual operation, test the "motor up" and "motor down" functions on the computer screen to determine if software has functional control.

If all is working properly, initiate a data collection traverse with no airflow and without anemometer propellers installed to establish the zero offset airflow correction. Then place the individual propellers onto the unit. The propellers cannot be installed at the traverse end positions due to limited space; therefore the traverse bar must be moved at least six inches from the top or bottom. Make sure that the number of the propeller and of the open-vane anemometer match (there are five in all – numbers are marked on both).

Operation. The fan to be tested should be turned on and warmed up for at least 10 minutes. A fan is tested over the normal operating range of building static pressure (SP) difference. At least four SPs are tested covering a range from slightly below to slightly above the normal building operating range. After the FANS is positioned at a chosen fan, a static pressure (SP) is set. Once SP has stabilized, two FANS traverses are run in quick succession. If the two runs differ by more than 2%, another traverse is performed. For lower range airflows, a 3% difference between traverses is acceptable. All tests are done when the house has no birds present so that any ventilation condition could be evaluated without jeopardizing bird comfort and well-being.

Moving and Positioning. A cart is helpful to aid in moving the FANS unit down the length of a long poultry house and positioning it in front of a fan. A hydraulic lift can be added to provide easy height adjustment of the 80-pound FANS unit to match the test fan height. Moving and positioning is best done with two workers. Complications with FANS setup include the need to move knee braces, water lines and electrical outlets in certain facilities. Each of these situations and other anomalies require special attention and can add substantial time to each setup.

Sealing FANS to Fan Housing. Sealing the FANS to the wall and/or fan housing is critical to accurate measurement, and can take the bulk of the setup time in moving the FANS from one fan to the next. A special gasket created from open-cell pipe insulation placed over ½-in PVC pipe and positioned between the FANS frame and the wall has been successfully used to provide a tight seal and reduce the need for extensive taping. The FANS is positioned against this gasket and two ratchet straps are used to draw the FANS unit tightly against the gasket and wall. Duct tape is used to seal any remaining gaps or cracks.

Fan housings that project through the wall into the interior space can prevent the FANS unit from being placed against the wall and thus present special challenges. For these situations, a 6-inch extension of the FANS frame, constructed of polystyrene and the same dimensions as the FANS frame, has been used to seal against the above mentioned pipe insulation gasket.

Duct Transition to Smaller Fan. Measurement accuracy is not affected by use of a transition to measure smaller diameter fans. A lightweight collapsible duct (blue polystyrene R-3) can be used to connect the FANS unit, with square opening of about 52 in, to 36 in or smaller fans. Gaps are sealed with duct tape. The duct is 48 inches long, which is about 1.3 fan diameters of the smaller fan, with one to two diameters length considered acceptable. Setup time for the duct is even longer than for the sealing method descried in the previous section for testing larger fans. Wherever possible, the FANS unit should be used directly without a transition, simply to save time.

Measuring Larger Ventilation Fans. Measurement accuracy is affected by use of a transition to measure larger diameter fans. Available literature (Gates et al., 2004) suggests that there is a penalty associated with forcing airflow through the FANS unit and into a fan whose approach aperture exceeds that of the FANS. It is recommended that each model of fan be independently tested in a certified fan test facility, with and without the FANS unit, to assess the degree of penalty. Ventilation fans of 48 inches or smaller have not been shown to be affected by this issue.

Streamlining Data Collection. Once the crew is practiced at setting up and operating the FANS at different static pressures, a complete setup and test for 4 or 5 static pressures can be accomplished in 1 to 1 ½ hours per fan in a broiler barn. The approximate time required for each fan test is as follows. About 7 minutes is needed for two consecutive FANS traverses plus data notation time, although more than 2 traverses are sometimes required. Changing and stabilizing each static pressure setting requires less than 5 minutes, but with even minor complications this can exceed ten minutes. For example, end doors and all inlets need to be opened to get a zero SP reading and then closed again to get the other SP settings. These FANS traverses are preceded by 10 to 20 minutes of FANS positioning and about 10 minutes of sealing the FANS to the fan housing. If a transition duct is used for a 36-inch fan, then 40 to 50 minutes is needed to assemble and seal a pre-cut duct between the FANS and the fan housing. More time is needed if the duct is fabricated from scratch.

Walkie-talkie radios are used so that the person adjusting static pressure in the control room can communicate with the person(s) running the FANS unit. Often these two people are out of sight of each other. The radios eliminate disruptive yelling and miscommunications. The FANS unit operator can tell the SP control person when tests are completed. Likewise, the SP control person can indicate when the test SP is adjusted and steady in order to start the test.

Appendix D: SOP of INNOVA 1412 Photoacoustic Multi-gas Monitor

INNOVA 1412 Photoacoustic Multi-gas Monitor

Description and Principle of Operation

The photoacoustic multi-gas monitor (INNOVA 1412, Innova AirTech Instruments, Denmark) is a highly accurate, reliable and stable quantitative gas monitoring system. It uses a measurement system based on the photoacoustic infra-red detection method, and is capable of measuring almost any gas that absorbs infra-red light. Gas selectivity is achieved through the use of optical filters. By installing up to five of these filters in the 1412, it can measure the concentration of up to 5 component gases and water vapour in any air sample. Although the detection limit is gas dependent, it is typically in the ppb region. The accuracy of these measurements is ensured by the 1412's ability to compensate for temperature and pressure fluctuations, water vapour interference and interference from other gases known to be present. Reliability of measurement results can be ensured by regular self-tests, which the 1412 performs.

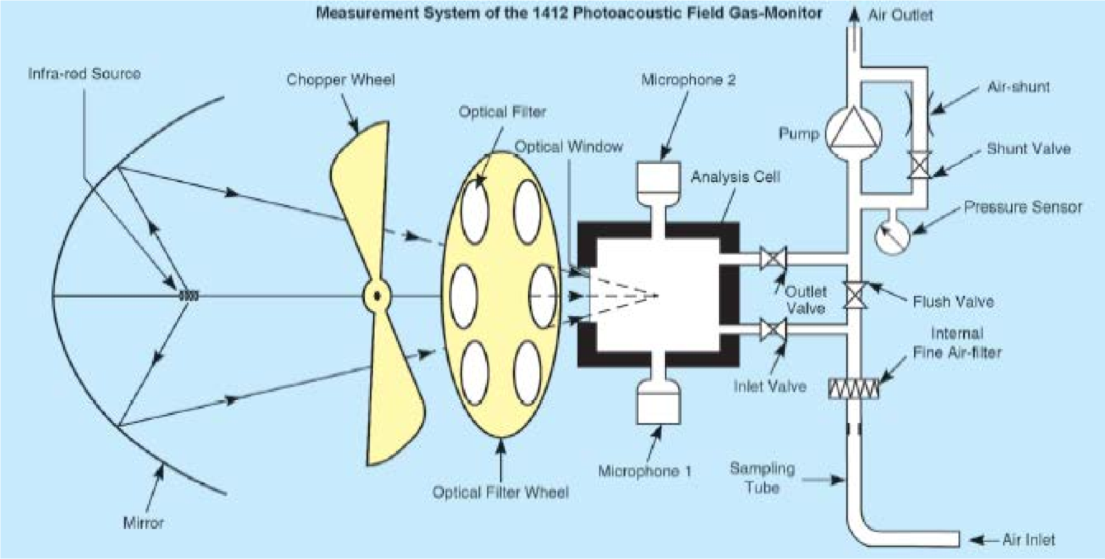


Figure 1. Measurement System of the 1412

An interior pump draws air from the sampling point through the air-filter to flush out the "old" air in the measurement system and replace it with a "new" air sample. The "new" air sample is hermetically sealed in the analysis cell by closing the inlet and outlet valves (Figure 1). Light from an infra-red light source is reflected off a mirror, passed through a mechanical chopper, which pulsates it, and then through one of the optical filters in the filter wheel. The gas being monitored, causes the temperature of the gas to increase selectively absorbs the light transmitted by the optical filter. Because the light is pulsating, the gas temperature increases and decreases, causing an equivalent increase and decrease in the pressure of the gas (an acoustic signal) in the closed cell. Two microphones mounted in the cell wall measure this acoustic signal, which is directly proportional to the concentration of the monitored gas present in the cell. The filter wheel turns so that light is transmitted through the next optical filter, and the new signal is measured. The number of times this is repeated is dependent upon the number of gases being measured. The response time is down to approximately 13 s for one gas or water vapour, or approximately 40 s if five gases and water vapour are measured. The NH_3's full scale is adjustable up to 2000 ppm. It has a lower detectable limit of 60 ppb.

The INNOVA 1412 multi-gas analyzer is specified with 1-second sampling integration time and fixed flushing time: 2 seconds for the chamber and 3 seconds for the tubing; and the response time for one single sampling cycle with NH_3, carbon dioxide and dew-point temperature measurements is approximately 22 sec. The response time of the analyzer to step changes in gas concentrations was tested (figure 2). The analyzer was challenged with two NH_3 calibration span gases, 22.8 ppm and 60.8 NH_3 respectively in a N_2 balance (±2% accuracy) (Matheson Gas Products, Inc., Montgomeryville, PA) at flow rates of 8 L/min through two 80 ft long individual sampling lines. At the beginning of the test, the two sampling lines were full of N_2 gas. During the first two sampling cycles, the time taken for the readings to change from 0 ppm (N_2 gas) to 22.8 ppm was 10 cycles (220 s), and the time taken for the readings to change from 22.8 ppm (span gas) to 60.8 ppm was also 10 cycles (220 s). After the first two span gas changes, the time taken for the readings to change from 22.8 to 66.8 ppm or from 60.8 to 22.8 ppm within ± 2% difference was 4 cycles (88 sec).The reason of 10 cycles required for the initial two changes was to purge the N_2 gas in the sampling lines. Once the sampling lines were full of the span gases, the NH_3 analyzer had a faster response time. It implied that separate sampling line should be used for each sampling location and air sample should be drawn continuously. Similarly, the time taken for the readings to change from 22.8 ppm to zero air was greater than 10 cycles when sampling lines were purged by zero gas. Thus, the results indicated that an 88-s sampling time (4 cycles) for the NH_3 analyzer would be sufficient to achieve 97% or better of the concentration value.

INNOVA 1412 setup: 22 sec/sample (Chamber flush: 2 s; Tube flush: 3s; S.I.T.: 1 s)

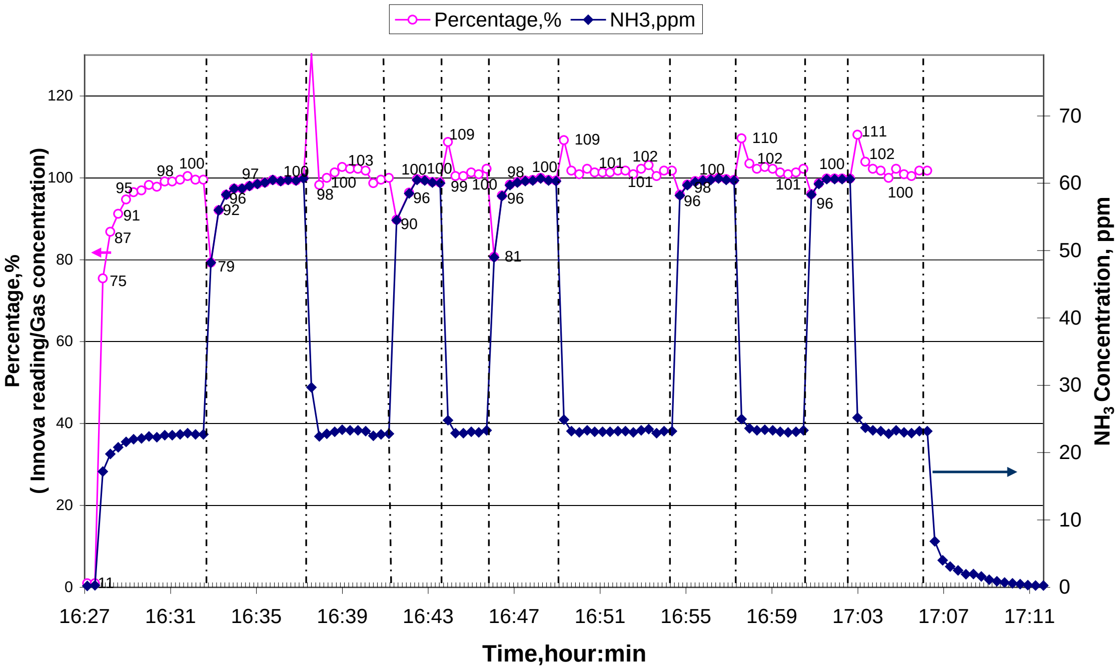


Figure 2 . Response of INNOVA 1412 intermittent exposure of 22.8, 60.8 ppm NH_3 (N_2 balance) and ambient air.

Warming Up the Monitor

The infra-red light source is very hot and the temperature in the analysis cell thus increases as calibration measurements procedure. Conditions within the cell tend to stabilize more quickly once the temperature inside the analysis cell is 15°C above the ambient room temperature. A period of 30 – 40 min is suggested to warm up the analysis cell before a calibration task is started. This will reduce the time required for calibration.

The Basic Calibration Set-up

The general equipment required to perform the calibration is shown in Figure 3. The sampling tubing to the VIG 200 will be disconnected and plugged. All the solenoid valves around the manifold (M1) will be close by using the manual control in the LabView 7 program. The tubing from the gal-gas cylinder will be connected to the flow meter which is mounted on the side of the instrument rack and connected to the sampling manifold (M2).

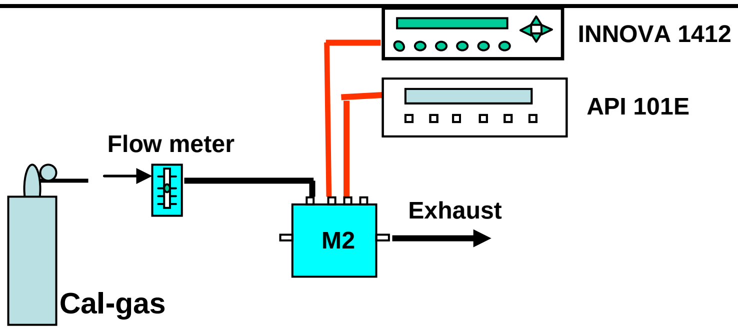


Figure 3. General equipment required for a calibration task

Calibration

Producing a Supply of Clean, Wet Air

Bubble zero-gas through a thermostatically controlled water-bath to produce a supply of clean, wet air to the Monitor during humidity interference calibration of the filters (see Figure 4).
The temperature of the water bath should be at least 2°C **below** the ambient temperature of the room where calibration is to be performed.

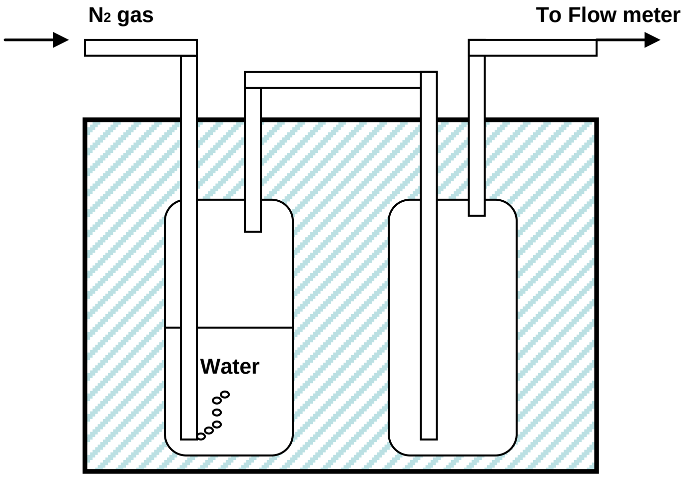


Figure 4. Schematic diagram of the equipment necessary to produce a supply of clean, wet air.

Setting the communication parameters

The communication parameters necessary for the monitor to communicate with the Gas Monitoring Software 7304 are shown below:

Baud rate	9600
Stop bits	1
data bits	7
Parity	Even
Hardwire mode	leased line
Handshake type	Hardwire

To prevent communication errors, the text line terminator, print data log and print error log must be set as shown below:

Text line Terminator	CR-LF

Print Data Log	**NO**
Print Error Log	NO

Setup→ CONFIGURATION→System→General→Test→ Self test→Yes→Print Data Log→NO→Print Error Log→NO

Calibration Gases

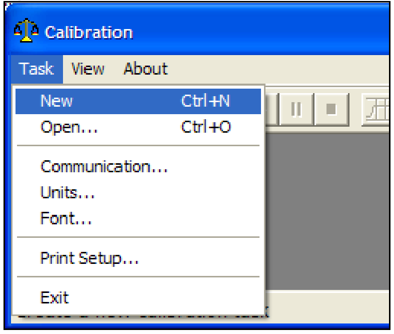
Zero air, CO_2 in N_2 and NH_3 in N_2 are used to calibrate the instrument. The certified calibration gases will consist of zero air (Acid Rain CEM zero), CH_4 in N_2 (EPA Protocol, ±2 % accuracy), Propane in N_2 (EPA Protocol, ±2 % accuracy), CO_2 in N_2 (EPA Protocol, ±2 % accuracy), NH_3 in nitrogen (Title 5 ammonia per EPA Conditional Method 27E, ±2% accuracy).

Zero and Span Calibration Procedure for Analyzer Only

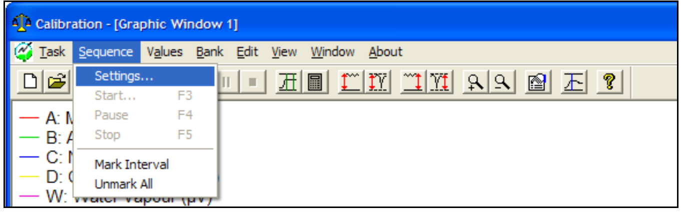
- Change the setting of 1412 communication parameters.
- Turn off the 1412 and disconnect 1412 with the Compact Fieldpoint module.
- Reconnect the 1412 to the COM1 port of the PC.
- Turn on the 1412.
- Open the Calibration program and create a new calibration task.
- Detach the air inlet tube from the existing sampling manifold. Close the pipe adapter of the sampling manifold with a cap or plug.
- Attach the 1412 to a calibration manifold.

<u>Zero (N_2) Gas Calibration</u>

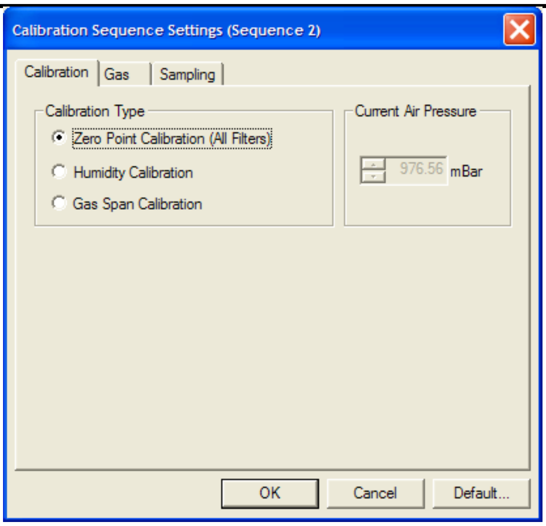
1. Open the Calibration program and create a **New** task.



2. Type in the desired task name (TYSON ##_MMDDYYYY) and click **OK**.
3. Pull down the **Sequence** menu. Click **Settings**.



4. Click on the Calibration index-card, if it is not already at the front.

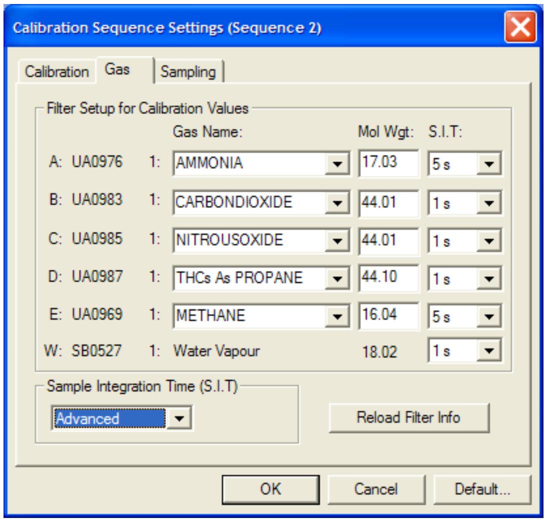


Calibration Sequence Settings (Sequence 2)

Calibration Type
● Zero Point Calibration (All Filters)
○ Humidity Calibration
○ Gas Span Calibration

Current Air Pressure
976.56 mBar

5. Click to select **Zero point** radio-button.
6. Click on the Gas index-card and click in the Sample Integration Time field, and select the desired time: 5 s for Ammonia, 1s for CO_2, 1s for Nitrous oxide (N_2O), 1s for propane and 5s for CH_4.



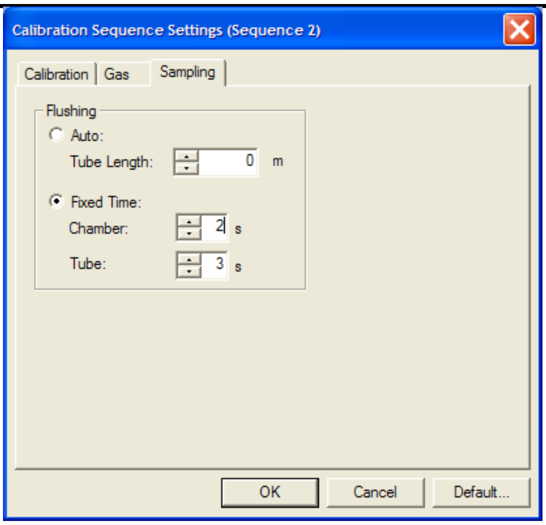
Calibration Sequence Settings (Sequence 2)

Filter Setup for Calibration Values

		Gas Name:	Mol Wgt:	S.I.T:
A: UA0976	1:	AMMONIA	17.03	5 s
B: UA0983	1:	CARBONDIOXIDE	44.01	1 s
C: UA0985	1:	NITROUSOXIDE	44.01	1 s
D: UA0987	1:	THCs As PROPANE	44.10	1 s
E: UA0969	1:	METHANE	16.04	5 s
W: SB0527	1:	Water Vapour	18.02	1 s

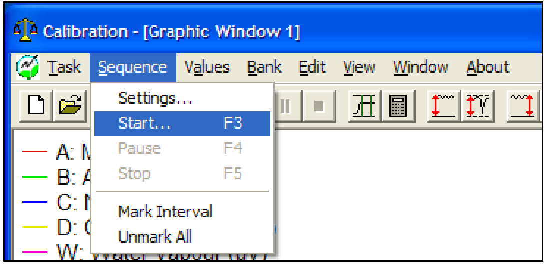
Sample Integration Time (S.I.T)
Advanced

7. Click on the Sampling index-card and set the flushing time to desired time: Fixed time, 2 s for Chamber and 3 s for Tube.

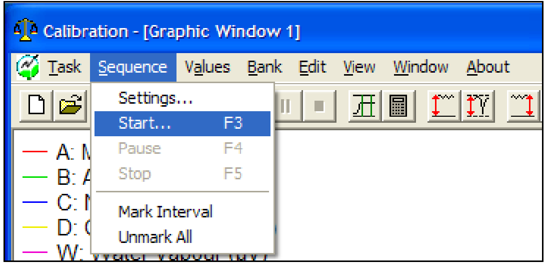


Flushing
○ Auto:
Tube Length: 0 m
● Fixed Time:
Chamber: 2 s
Tube: 3 s

8. When all the settings are correct, click on **OK**.
9. Pull down the **Sequence** menu and click on **Start.**

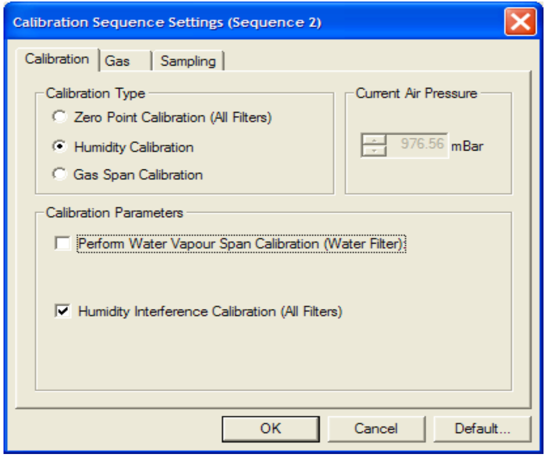


10. Insert the 1/4” ID tubing (from N_2 gas regulator) to the flow meter mounted on the side of the instrument rack; then open the regulator valve to allow gas flow. Zero gas is now flowing from the cylinder to the 1412.
11. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra zero air to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
12. Record time and analyzer display in lab notebook.
13. Close regulator and remove Zero gas tubing.
14. Pull down the **Sequence** menu and click on **Stop** after display is stabilized (typically 10 to 15 minutes).



Humidity Calibration

1. Pull down the **Sequence** menu. Click **Settings**.
2. Click on the Calibration index-card, if it is not already at the front.
3. Click to select **Humidity Calibration**.



Calibration Type
○ Zero Point Calibration (All Filters)
● Humidity Calibration
○ Gas Span Calibration

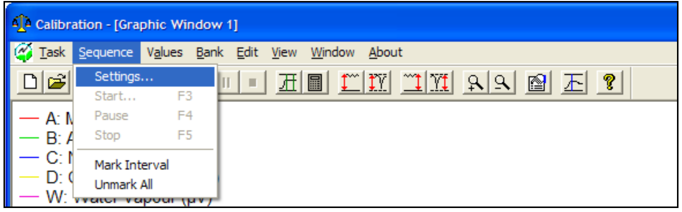
Current Air Pressure
976.56 mBar

Calibration Parameters
☐ Perform Water Vapour Span Calibration (Water Filter)
☑ Humidity Interference Calibration (All Filters)

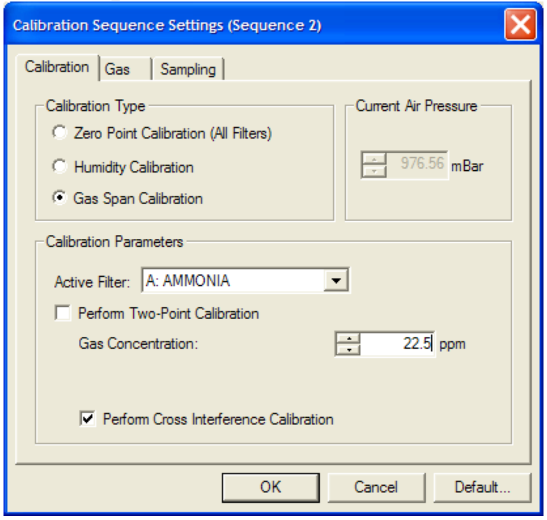
4. Only Select "**Humidity Interference Calibration (All Filters)**". **Do not** select "Perform Water Vapor Span Calibration".
5. Click on the Gas index-card and click in the Sample Integration Time field, and select the desired time as above.
6. When all the settings are correct, click on **OK**.
7. Pull down the **Sequence** menu and click on **Start**.
8. Connect a water bath device between the zero gas regulator and the flow meter mounted on the side of the instrument rack; then open the regulator valve to allow gas flow. Zero gas is now flowing from the cylinder to the 1412.
9. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra zero air to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
10. Record time and analyzer display in lab notebook.
11. Close regulator and main valve and remove zero gas tubing.
12. Pull down the **Sequence** menu and click on **Stop** after display is stabilized (typically 10 to 15 minutes).

Span Gas Calibration (NH_3)

1. Pull down the **Sequence** menu. Click **Settings**.



2. Click on the Calibration index-card, if it is not already at the front.
3. Click to select **Gas Span Calibration** radio-button.



Calibration Type
○ Zero Point Calibration (All Filters)
○ Humidity Calibration
● Gas Span Calibration

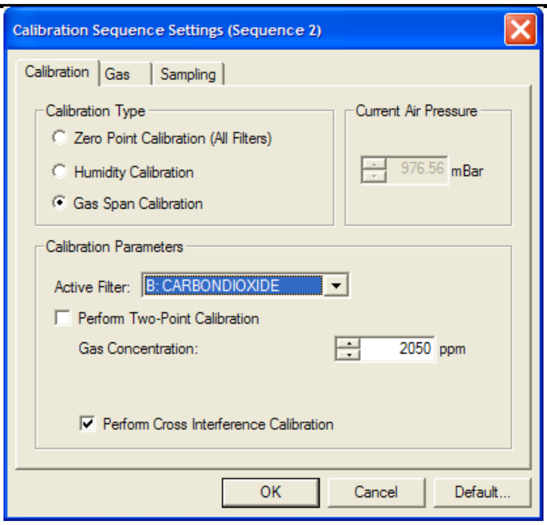
Current Air Pressure
976.56 mBar

Calibration Parameters
Active Filter: A: AMMONIA
☐ Perform Two-Point Calibration
Gas Concentration: 22.5 ppm
☑ Perform Cross Interference Calibration

4. Click in the Active filter field Ammonia and select the **Ammonia**, and check **Perform Cross Interference Calibration** and input the concentration of NH_3 gas.
5. Click on the Gas index-card and click in the Sample Integration Time field, and select the desired time as above.
6. When all the settings are correct, click on **OK**.
7. Pull down the **Sequence** menu and click on **Start**.
8. Insert the 1/4” ID tubing (from the NH_3 gas cylinder) to the flow meter mounted on the side of the instrument rack; then open the regulator valve to allow gas flow. NH_3 gas is now flowing from the cylinder to the 1412.
9. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
10. Record time and analyzer display in lab notebook.
11. Close regulator and main valve and remove tubing from the NH_3 gas cylinder.
12. Pull down the **Sequence** menu and click on **Stop** after display is stabilized (typically 10 to 15 minutes).

Span Gas Calibration (CO_2)

1. Pull down the **Sequence** menu. Click **Settings**.
2. Click on the Calibration index-card, if it is not already at the front.
3. Click to select **Gas Span Calibration** radio-button.
4. Click in the Active filter field Ammonia and select the **Carbon Dioxide**, and check **Perform Cross Interference Calibration** and input the concentration of CO_2 gas.



Calibration Type
○ Zero Point Calibration (All Filters)
○ Humidity Calibration
● Gas Span Calibration

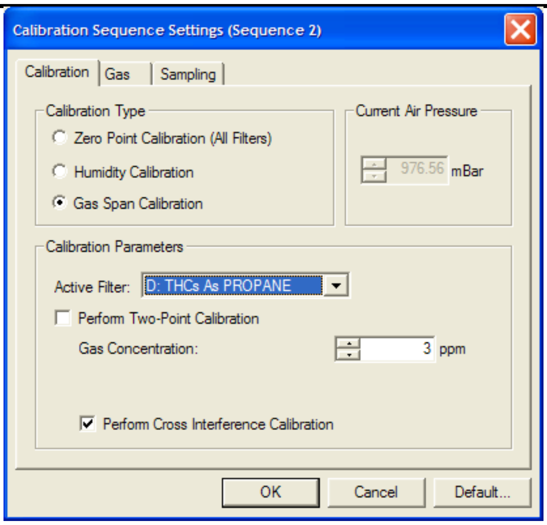
Current Air Pressure
976.56 mBar

Calibration Parameters
Active Filter: B: CARBONDIOXIDE
☐ Perform Two-Point Calibration
Gas Concentration: 2050 ppm
☑ Perform Cross Interference Calibration

5. Click on the Gas index-card and click in the Sample Integration Time field, and select the desired time.
6. When all the settings are correct, click on **OK**.
7. Pull down the **Sequence** menu and click on **Start**.
8. Connect the 1/4” ID tubing (from the CO_2 gas cylinder) with a Nafion tubing, and then connect to the manifold; then open the regulator valve to allow gas flow. CO_2 gas is now flowing from the cylinder to the 1412.
9. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
10. Record time and analyzer display in lab notebook.
11. Close regulator and main valve and remove tubing from the CO_2 gas cylinder.
12. Pull down the **Sequence** menu and click on **Stop** after display is stabilized (typically 10 to 15 minutes).

Span Gas Calibration (Propane)

13. Pull down the **Sequence** menu. Click **Settings**.
14. Click on the Calibration index-card, if it is not already at the front.
15. Click to select Gas Span Calibration radio-button.
16. Click in the Active filter field Ammonia and select the **THC (propane)**, and check **Perform Cross Interference Calibration** and input the concentration of Propane gas.



Calibration Type
○ Zero Point Calibration (All Filters)
○ Humidity Calibration
● Gas Span Calibration

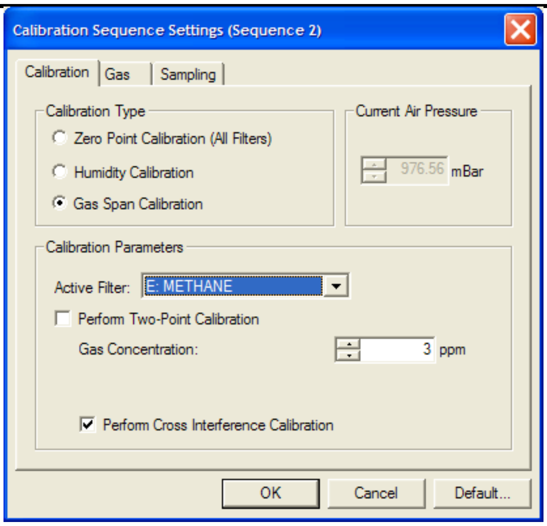
Current Air Pressure: 976.56 mBar

Calibration Parameters
Active Filter: D: THCs As PROPANE
☐ Perform Two-Point Calibration
Gas Concentration: 3 ppm
☑ Perform Cross Interference Calibration

17. Click on the Gas index-card and click in the Sample Integration Time field, and select the desired time.
18. When all the settings are correct, click on **OK**.
19. Pull down the **Sequence** menu and click on **Start**.
20. Connect the 1/4” ID tubing (from the Propane gas cylinder) to the flow meter mounted on the side of the instrument rack; then open the regulator valve to allow gas flow. Propane gas is now flowing from the cylinder to the 1412.
21. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
22. Record time and analyzer display in lab notebook.
23. Close regulator and main valve and remove tubing from the Propane gas cylinder.
24. Pull down the **Sequence** menu and click on **Stop** after display is stabilized (typically 10 to 15 minutes).

Span Gas Calibration (CH_4)

25. Pull down the **Sequence** menu. Click **Settings**.
26. Click on the Calibration index-card, if it is not already at the front.
27. Click to select Gas Span Calibration radio-button.
28. Click in the Active filter field Ammonia and select the **CH_4 (Methane)**, and check **Perform Cross Interference Calibration** and input the concentration of methane gas.



Calibration Sequence Settings (Sequence 2)

Calibration Type
○ Zero Point Calibration (All Filters)
○ Humidity Calibration
● Gas Span Calibration

Current Air Pressure: 976.56 mBar

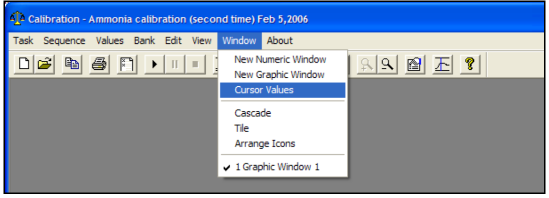
Calibration Parameters
Active Filter: E: METHANE
☐ Perform Two-Point Calibration
Gas Concentration: 3 ppm
☑ Perform Cross Interference Calibration

29. Click on the Gas index-card and click in the Sample Integration Time field, and select the desired time.
30. When all the settings are correct, click on **OK**.
31. Pull down the **Sequence** menu and click on **Start**.
32. Connect the 1/4” ID tubing (from the Methane gas cylinder) to the flow meter mounted on the side of the instrument rack; then open the regulator valve to allow gas flow. Propane gas is now flowing from the cylinder to the 1412.
33. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
34. Record time and analyzer display in lab notebook.
35. Close regulator and main valve and remove tubing from the Methane gas cylinder.
36. Pull down the **Sequence** menu and click on **Stop** after display is stabilized (typically 10 to 15 minutes).

Calculating Calibration Factors

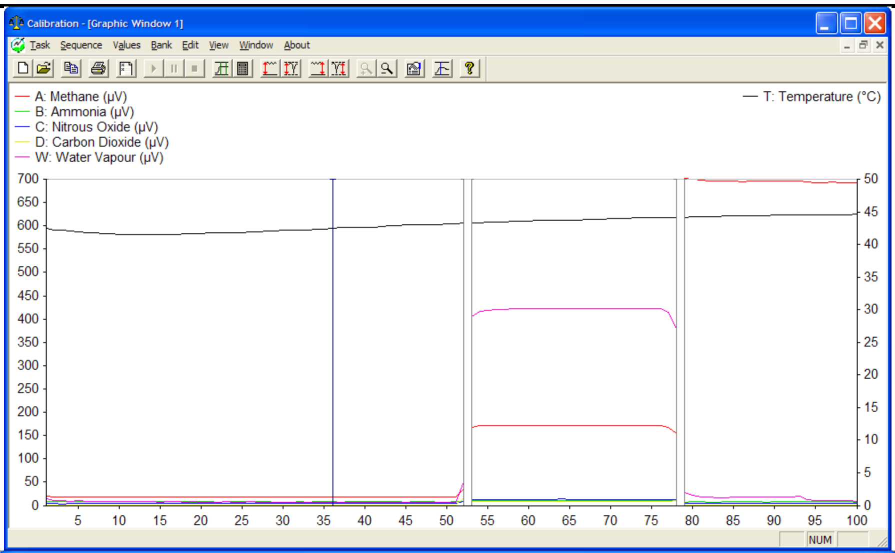
With the raw measurement data displayed on screen:

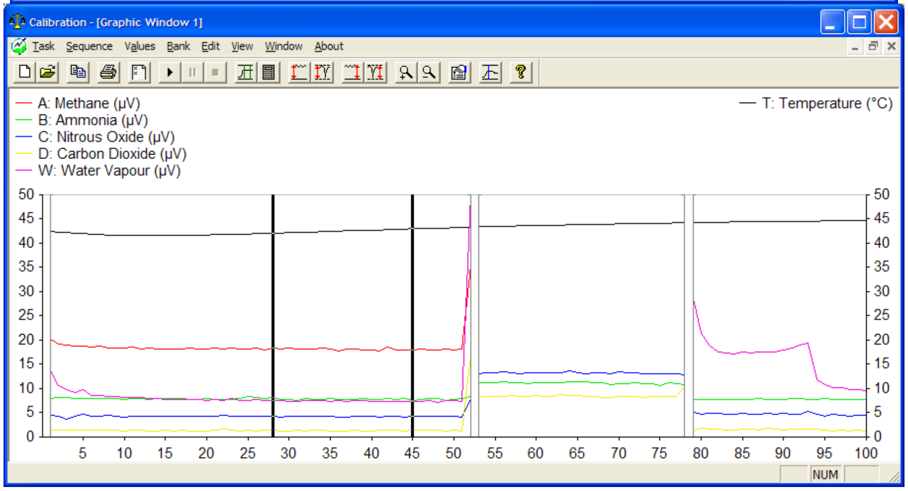
1. Open the Cursor Values dialogue.



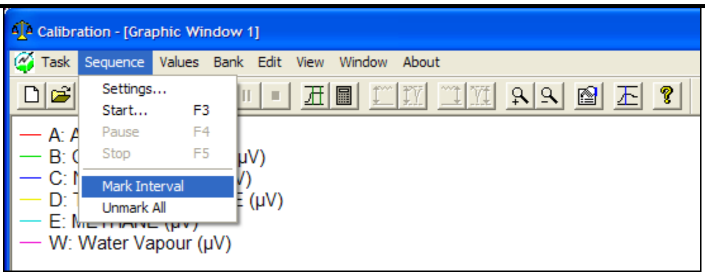
Calibration - Ammonia calibration (second time) Feb 5,2006

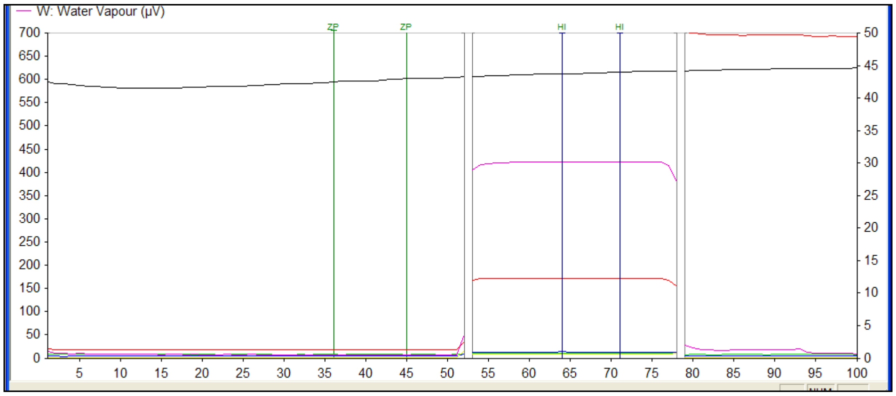
2. Use two cursors and the statistical data are displayed in the Cursor Values dialogue to locate a suitable range of data. All values in the select interval should be very stable and the temperature should be above 40 ^{o}C.



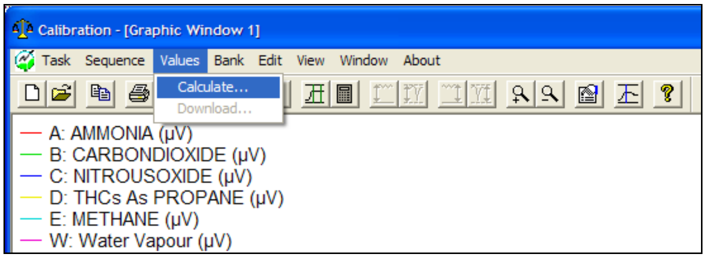


3. When you have the desired region between the cursors, pull down the **Sequence** menu and click on **Mark Interval**. The two cursors are replaced by a pair of green lines. These lines have markings at the end of them, which show the type of calibration data lying between the lines. The markings are:
   ZP: shows a zero point calibration
   HI: shows a humidity interference calibration
   SHA: shows a span calibration (filter A)
   SHB: shows a span calibration (filter B)
   SHC: shows a span calibration (filter C)
   SHD: shows a span calibration (filter D)
   SHE: shows a span calibration (filter E)





4. Select and mark all the intervals for every calibration.
5. Pull down the **values** menu and click on **calculate.**



6. When the calculation(s) is complete a Calculation Finished dialogue is displayed.

To download the calculated values

1. Pull down the **Values** menu. Click on **Download** and the Download dialogue is displayed.
2. Select the **Zero Point** index card
3. Set ticks in the NH_3, CO_2, Propane and Methane and Water Vapor check boxes.
4. Repeat steps 2 and 3 in the **Humidity** and **Gas** index cards.
5. Click on **OK**. The calibration factors are now downloaded to the monitor.

Post Calibration

a. Check and close main valves on all cylinders
b. Calibration of the 1412 monitor is complete
c. Turn off the 1412 and disconnect 1412 with the PC.
d. Reconnect the 1412 with compact Fieldpoint and turn on the 1412.
e. Set the filter sampling integration time back to original setup: 1 s for each filter.

Setup→Configuration→Filters→Filter A→YES→1s S.I.T→Filter B→YES→1s S.I.T→Filter C→YES→1s S.I.T→Filter D→YES→1s S.I.T→Filter E→YES→Water Filter→ YES→1s

6. The communication parameters necessary for the monitor to communicate with the compact Fieldpoint are shown below:

Baud rate	9600
Stop bits	2
data bits	7
Parity	Even
Hardwire mode	Leased line
Handshake type	Hard wired

Print data log and print error log must be set as shown below:

Text line Terminator	CR-LF
Print Data Log	**Yes**
Print Error Log	No

Setup→ CONFIGURATION→System→General→Test→ Self test→Yes→Print Data Log→Yes→Print Error Log→NO

Routine Checking

Zero and Span Check Procedure for Analyzer Only

- Detach the air inlet tube from the existing sampling manifold. Close the pipe adapter of the sampling manifold with a cap or plug.
- Attach the 1412 to a calibration manifold.

Zero Gas Check

a. Insert the 1/4” ID tubing (from the NH_3 gas cylinder) into the manifold connected to the valve; then open the regulator valve to allow gas flow. Zero gas is now flowing from the cylinder to the 1412.
b. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra zero air to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
c. Close regulator and remove tubing from the zero gas cylinder after display is stabilized (typically 5 to 10 minutes).

Span Gas Check (NH_3)

1. Insert the 1/4” ID tubing (from the NH_3 gas cylinder) into the manifold connected to the valve; then open the regulator valve to allow gas flow. NH_3 gas is now flowing from the cylinder to the 1412.
2. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold).

This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.

3. Close regulator and main valve and remove tubing from the NH3 gas cylinder after display is stabilized (typically 5 to 10 minutes).

Span Gas Check (CO_2)

1. Connect the 1/4” ID tubing (from the CO_2 gas cylinder) with a Nafion tubing, and then connect to the manifold; then open the regulator valve to allow gas flow. CO_2 gas is now flowing from the cylinder to the 1412.
2. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
3. Close regulator and main valve and remove tubing from the CO2 gas cylinder after display is stabilized (typically 5 to 10 minutes).
4. Reattach the filters to the existing gas sampling system.
5. Check and close main valves on all cylinders.

Span Gas Check (CH_4)

1. Insert the 1/4” ID tubing (from the CH_4 gas cylinder) into the manifold connected to the valve; then open the regulator valve to allow gas flow. CH_4 gas is now flowing from the cylinder to the 1412.
2. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
3. Close regulator and main valve and remove tubing from the CH_4 gas cylinder after display is stabilized (typically 5 to 10 minutes).
4. Reattach the filters to the existing gas sampling system.
5. Check and close main valves on all cylinders.

Span Gas Check (N_2O)

1. Connect the 1/4” ID tubing (from the N_2O gas cylinder) with a Nafion tubing, and then connect to the manifold; then open the regulator valve to allow gas flow. N_2O gas is now flowing from the cylinder to the 1412.
2. Adjust regulator valve until vent airflow is about 2.5 L/min (read from bottom of ball of the vent monitoring flow meter installed in outlet of calibration manifold). This provides a little extra gas to the 1412 and keeps the pressure inside the manifold close to the atmospheric pressure.
3. Close regulator and main valve and remove tubing from the N_2O gas cylinder after display is stabilized (typically 5 to 10 minutes).
4. Reattach the filters to the existing gas sampling system.
5. Check and close main valves on all cylinders.

Manufacturer Contact Information

Innova AirTech Instruments (www.innova.dk)
Energivej 30 Tel.: (+45) 44 20 01 00 innova@innova.dk

DK-2750 Ballerup, Denmark   Fax: (+45) 44 20 01 01

Reference:

1412 Photoacoustic Field Gas-Monitor Technical Document, INNOVA Air Tech Instruments.

Maintenance/Calibration Record Sheet for INNOVA 1412 Multi-gas Monitor

Date of Calibration: __________________ Calibrated by: __________________

Time	Items	Unit =	Notes
: :	Ambient pressure, (mm Hg)		
	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	NH_3 Reading		
: :	CO_2 Reading		
	N_2O Reading		
	CH_4 Reading		
	Propane Reading		
: :	CO_2 (______ ppm) applied (With Nafion Tubing)	---	Cylinder P: ___ psi
: :	CO_2 Reading		
: :	NH_3 (______ ppm) applied	---	Cylinder P: ___ psi
: :	NH_3 Reading		
: :	CH_4 (______ ppm) applied	---	Cylinder P: ___ psi
	CH_4 Reading		
: :	Propane (______ ppm) applied	---	Cylinder P: ___ psi
	Propane Reading		
: :	N_2O (______ ppm) applied	---	Cylinder P: ___ psi
	N_2O Reading		
: :	New Calibration	$^{Yes}/_{No}$	
: :	Zero air applied		
: :	Zero humidity air applied		
: :	NH_3 applied		
: :	CO_2 applied (With Nafion Tubing)		
: :	Propane applied		
: :	CH_4 applied		
: :	N_2O applied		
: :	Download to Bank	$^{Yes}/_{No}$	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

Appendix E: SOP of Temperature and Humidity Measurement

Temperature Measurements

Type T thermocouple is used to measure house temperature by compact Fieldpoint thermocouple module:
Maximum Temperature Range:
Thermocouple Grade
– 200 to 350°C.
Extension Grade
– 60 to 100°C.
Limits of Error
Standard: 1.0°C or 0.75% Above 0°C.
Special: 0.5°C or 0.4%.
A water bath and two precision ASTM mercury-in-glass thermometers (-8 to 32 °C and 25 to 55 °C, 0.1 °C precision) are used for calibration.

Humidity Measurements

HMW61U Humidity Transmitter

Electrical Cable Connection

+RH	-RH	
○	○	○
Red	White	Black

Measurement Instructions

The probe of the transmitter should always point downwards when installed.

Supply voltage:	10 … 35 VDC (RL = 0 Ω)
	20 … 35 VDC (RL = 500 Ω)
RH range:	0 …100% (Output 4…20mA)

Two-point humidity calibration

Two-point calibration can be performed using saturated salt solutions in controlled conditions (HMK15 or HMK13B). Please, refer also to the calibrator manual.

Greenspan's calibration table with output values according to the scale

Temperature	C	15	20	25	30	35
	F	59	68	77	86	95
LiCl	%RH	*)	11.3	11.3	11.3	11.3
4...20mA	mA		5.81	5.81	5.81	5.81
NaCl	%RH	75.6	75.5	75.3	75.1	74.9
4...20 mA	mA	16.1	16.08	16.05	16.02	15.98

1. Leave the calibrator and the probe for at least 1 hour in the same space so that their temperatures have time to equalize.
2. Open the transmitter cover, and loosen the tightening screw of the probe. Then, pull out the probe (Figure 3).
3. Unscrew the plastic probe cover and the filter.
4. Insert the probe into the measurement hole of the LiCl salt chamber.
5. Wait for 10-20 minutes.
6. Check the temperature and read the closest corresponding RH value in the calibration table (Table 1).
7. Adjust the output signal with calibration trimmer (RH OFFS ET, Figure 2) to the value given in the calibration table (Table 1).
8. Insert the probe into the measurement hole of the NaCl chamber.
9. Wait for 10 - 20 minutes.
10. Check that the reading corresponds within the desired accuracy to the reading given in the calibration table. If not, adjust the reading with the calibration trimmer (RH GAIN, Figure 2).
11. Check again the reading at the first point and repeat the procedure if necessary.
12. After completing the calibration, screw the probe cover and the filter on.

Manufacturer Contact Information

Bruce E. McDuffee
Vaisala Regional Engineer
Colorado Office
dir. 303-262-4044
toll free. 888-824-7252 x1054
fax 781-933-8029
www.vaisala.com

Reference

HMW61U/Y Humidity Transmitter Operating Manual, March 2000.

HMK15 Humidity Calibrator

Introduction

The functioning of the HMK15 is based on the fact that certain salt solutions generate a certain relative humidity in the air above them. The salt solutions suitable for the HMK15 calibrator are lithium chloride LiCl (11% RH), magnesium chloride $MgCl_2$ (33% RH), sodium chloride NaCl (75% RH) and potassium sulphate K_2SO_4 (97% RH). For calibration, the sensor head is inserted into a salt chamber containing a saturated salt solution. The probe/transmitter reading is then adjusted to the correct value. Calibration is usually performed at least at two different humidities to ensure the sensor accuracy over the entire humidity range (0-100 % RH).

Description of the solutions

Salt Name	RH	Usage
LiCl	11%	Used as the dry end reference
$MgCl_2$	33%	Used as a check point if calibration is performed at more than two points.
NaCl	75%	Used as the wet end reference for probes measuring in applications with normal humidities.
K_2SO_4	97%	Used as the wet end reference for probes measuring in applications with very high humidities.

NOTE: **Never add water to dry LiCl salt.**
LiCl is harmful when swallowed; the solution is also corrosive.
If the LiCl solution is used or stored in temperatures below +18 C, its equilibrium humidity changes permanently.

Solution Preparation Procedure

1. Take the calibrator out of the box. Open the transit cover of the chamber. Remove the measurement cover from the chamber holder and press the transit cover on the holder.
2. Pour ion exchanged water into the chamber; the required amounts are given below.

LiCl	14 ml of water
$MgCl_2$	3 ml of water
NaCl	10 ml of water
K_2SO_4	10 ml of water

3. Sprinkle the contents of a salt package in small quantities into the chamber, stirring constantly. When measuring with the measurement cup, make sure that the cup is clean and dry. Rinse and dry the cup after every use.

LiCl	15 g or 18 ml
$MgCl_2$	30 g or 30 ml
NaCl	20 g or 15 ml
K_2SO_4	30 g or 20 ml

4. When all salt has been sprinkled into the chamber, the saturated salt solution should have the ratio of 60-90% undissolved salt to 10-40% liquid.
5. Close the chamber with the chamber cover. Fasten the salt chamber on the base plate and close the measurement holes with rubber plugs. Make sure that chamber covers and plugs are carefully closed.
6. Write the preparation date on a sticker and mark the chamber with it.
7. Allow approximately 24 hours for stabilization before use.

Notices for Avoiding Errors Introduced by Temperature Difference

Usually, the errors during humidity calibration are due to temperature differences. In the laboratory, the calibrator should be stored in the part of the room where the temperature is most stable and the calibrator must be kept out of direct sunlight and away from localized heat sources.

Handle the probe as little as possible. Do not hold the salt chamber or other parts of the calibrator in your hand during calibration as they warm up and cause errors in the readings.

During calibration, the thermometer is inserted into the 13.5 mm hole of a salt chamber. Press it downwards until it passes the O-rings. The thermometer is correctly in place when you can feel a resistance while pressing it downwards.

When the thermometers are not in use or the calibrator is transformed from one place to another, place the thermometer in holders.

Calibration procedure

(If the probe/transmitter is checked against several humidity references, the checking must first be made at the dry end.)

1. Leave the HMK15 calibrator and the probe at the calibration site for at least 30 minutes before starting the calibration in order to let the probe temperature stabilize to the room temperature.
2. In the temperature range of 25-30 °C, lithium chloride humidity changes only very slightly, thus it is not necessary to use the thermometer. However, we may use it to ensure that the sleeve is in the correct place.
3. Take off the grid or filter protecting the sensor. Insert the probe into a suitable hole of the LiCl salt chamber. Press it downwards till it passes through the O-rings. Wait until the humidity reading stabilizes; this will take about 10-30 minutes. The shorter the time the hole stays open before inserting the probe; the shorter the stabilization time required.
4. Read the salt chamber temperature from the thermometer; then read the closest humidity value from the Greenspan's calibration table. Adjust the dry end to the correspond value given in the table.
5. Then use the NaCl as the wet reference. If calibrating probes that are being used for a long time in high humidities (90-100RH). Use the K_2SO_4 as the wet reference.
6. Then repeat steps 4-6 for the wet reference. Note that in high humidities the risk for errors increases and the stabilization time should be longer (about 20-40 min).

Greenspan's calibration table

°C	LiCl	$MgCl_2$	NaCl	K_2SO_4
0	*	33.7±0.3	75.5±0.3	98.8±1.1
5	*	33.6±0.3	75.7±0.3	98.5±0.9
10	*	33.5±0.2	75.7±0.2	98.2±0.8
15	*	33.3±0.2	75.6±0.2	97.9±0.6
20	11.3±0.3	33.1±0.2	75.5±0.1	97.6±0.5
25	11.3±0.3	32.8±0.2	75.3±0.1	97.3±0.5
30	11.3±0.2	32.4±0.1	75.1±0.1	97.0±0.4
35	11.3±0.2	32.1±0.1	74.9±0.1	96.7±0.4
40	11.2±0.2	31.6±0.1	74.7±0.1	96.4±0.4
45	11.2±0.2	31.1±0.1	74.5±0.2	96.1±0.4
50	11.1±0.2	30.5±0.1	74.4±0.2	95.8±0.5

Transportation Instructions

1. Turn the protective sleeve on the thermometer and place the thermometer in the holder.
2. Replace chamber covers with transit covers. Press the chamber covers on vacant chamber holders for transportation.
3. During transportation, keep the chamber as upright as possible.
4. The closer the transportation temperature is to the temperature of the calibration site, the shorter the stabilization time will be. If the transportation is below 18°C, the LiCl should transport separately to keep the solution warm.
5. When the calibrator is at the calibration site, remove the transit covers and fasten the chamber covers on salt chambers.
6. Clean the transit covers with a damp cloth and press them on vacant chamber holders.
7. Repeat the calibration procedures.

Quality control

Depending on the frequency of use and the general operating conditions, the salt solutions should be replaced after about 6-12 months. A visual check should be performed at intervals of 2-3 months. There must be a minimum of approximately 10% of undissolved salt at the bottom of the chamber and the salt must be clean.

Note: LiCl may crystallize on the surface. But it may still have solution under the surface. In such case, stir the solution and check the next day.

For correct calibration, it is essential that salt chambers are tightly closed. Check the O-rings at each salt replacement. If they are damaged, replace with new ones.

Operating temperature range is 0-50°C.

Accuracy of salt solution humidities

Lithium chloride LiCl	±1.0%RH + Greenspan's uncertainty
Magnesium chloride $MgCl_2$	±1.0%RH + Greenspan's uncertainty
Sodium chloride NaCl	±1.4%RH + Greenspan's uncertainty
Potassium sulphate K_2SO_4	±1.5%RH + Greenspan's uncertainty

Accuracy of the thermometer

With mercury	±0.3°C
With red capillary liquid	±1°C

Manufacturer Contact Information

Bruce E. McDuffee
Vaisala Regional Engineer
Colorado Office
dir. 303-262-4044
toll free. 888-824-7252 x1054
fax 781-933-8029
www.vaisala.com

Reference

HMK15 Humidity Calibrator Operating Manual, June 1998.

Table 1. Maintenance log

Data	Operator	Sensor SN#	Reason (salt replacement or other maintenance)

Table 2. Salt solution checks

Data	Operator	Sensor SN#	LiCl	$MgCl_2$	NaCl	K_2SO_4

Appendix F: SOP of Differential static pressure transmitters

Differential static pressure transmitters

The purpose of differential pressure measurements is to monitor operation of the ventilation system and to aid in the calculation of fan airflow. Barn static pressure is monitored continuously in the barns near the exhaust fans using a differential pressure transmitter (Setra Part No. 264) with a range of 0-125 Pa and an accuracy of ±1 Pa.

GENERAL INFORMATION

Setra Systems 264 pressure transducers sense differential or gauge (static) pressure and convert this pressure difference to a proportional high level analog output for both unidirectional and bidirectional pressure ranges. Two standard output versions are offered: A voltage output of 0 to 5 VDC or a current output of 4 to 20 mA.

MECHANICAL INSTALLATION

1. **Media Compatibility**

Model 264 transducers are designed to be used with air or non-conducting gases. Use with liquids or corrosive gases will damage the unit.

2. **Environment**

The operating temperature limits of the 264 are 0°F to +175°F (-18°C to +79°C).
The compensated temperature range is 0°F to +150°F (-18°C to +65°C).

3. **Pressure Fittings**

The Model 264 is designed to be used with 3/16” I.D. push-on tubing. Both the positive (high) pressure port and the reference (low) pressure port are located on the front of the unit, labeled “HIGH” and “LOW” respectively. For best results (shortest response times), 3/16” I.D. tubing is suggested for tubing lengths up to 100 feet long, 1/4” I.D. for tubing lengths up to 300 feet, and 3/8” I.D. for tubing lengths up to 900 feet.

ELECTRICAL INSTALLATION

If the Model 264 is supplied with the optional Conduit Enclosure, access the electrical terminations by removing the cover. The Model 264 is a two-wire loop-powered 4 to 20mA current output unit and delivers rated current into any external load of 0 to 800 ohms. These terminals have the designation of + and - The current flows into the + terminal and returns back to the power supply through the - terminal. The power supply must be a DC voltage source with a voltage range between 9 and 30 measured between the + and - terminals. The unit is calibrated at the factory with a 24 VDC loop supply voltage and a 250 ohm load.

CALIBRATION

The 264 transducer is factory calibrated and should require no field adjustment. Generally, the mounting position will have a zero shift effect on ranges below 1” WC. Whenever possible, any zero and/or span offsets should be corrected by software adjustment in the user’s control system. However, both zero and span adjustments are accessible either on the front of the unit or by removing the optional conduit enclosure. The 264 transducer is calibrated in the vertical position at the factory.

1. **Current Output Zero Adjustment**

   While monitoring the current output between the + and - terminals, and with both pressure ports open to atmosphere, the zero may be adjusted by turning the zero adjustment screw. The factory settings are 4mA (0.16mA) for unidirectional pressure ranges and 12mA (0.16mA) for bidirectional ranges.

2. **Current Output Span Adjustment**

   Span or full scale output adjustments should only be performed by using an accurate pressure standard (electronic manometer, digital pressure gauge, etc.) with at least comparable accuracy to the 264 transducer (1% FS). With full range pressure applied to the high pressure port (reference port open to atmosphere), the span may be adjusted by turning the SPAN adjustment screw. The factory settings are 20mA (0.16mA) for unidirectional and bidirectional pressure ranges.

The pressure sensor will be shunted to calibrate zero and compared with an inclined manometer at various span pressures. Static pressure taps will be constructed to minimize effects of air movement from wind on the measurement.

Model 264 low differential pressure transducer specifications

Electrical Output Current	4 to 20 mA
Accuracy	±1% FS
Type of Pressure	Very Low Differential
Pressure Ranges	0 to 0.5 in. WC (0-150 pa)
Media	Typically air or similar non-conducting gases

Manufacturer Contact Information

Setra Systems, Inc.
159 Swanson Road
Boxborough, MA 01719-1304
Tel (978) 263-1400
Toll Free (800) 257-3872

Maintenance/Calibration Sheet for Setra 264

Site________

Data	**Operator**	**Location**	**Sensor SN#**	**Note**

Appendix G: SOP of Compact Fieldpoint Modules and LabView Programs

Compact Fieldpoint Modules

Compact Fieldpoint network controller and Compact Fieldpoint A/O modules (National Instruments Corporation) are used as the data acquisition system (table 1):

Table1. Descriptions of compact Fieldpoint modules

Serial NO.	Description	Qty
cFP-2020	LabView 7 Real-Time/Ethernet Network Module	1
cFP-DO-400	8- channel Digital Output Module	1
cFP-AI-110	8- channel 16 Bit Analog Input Module (mA, mV, V)	4
cFP-AI-112	16- channel 16 Bit Analog Input Module (V)	1
cFP-CTR-500	8-channel Counter Input Module	1
cFP-TC-120	8-channel 16 Bit Thermocouple Input Module (TC, mV)	1

All the data signals from the instruments will be connected to and recorded by the compact Fieldpoint controller and modules. Data columns and their corresponding sensor connections will be arranged as shown in Table 2.

Table 2. Data file and sensor arrangement.

Data Col	File heading	Sensor/controller	Range	DAC hardware	Ch#	Signal or EV
1	Date & Time	---		---	---	PC clock
2	Smpl loc#	---		---	---	LabVIEW
3	NH_3,ppm	INNOVA 1412		cFP-2020		ASCII
4	CO_2,ppm	INNOVA 1412		cFP-2020		ASCII
5	dP, ºC	INNOVA 1412		cFP-2020		ASCII
6	SP1, Pa	Setra P sensor	0-125 pa	cFP-AI-110-1	0	4-20 mA
7	SP2, Pa	Setra P sensor	0-125 pa	cFP-AI-110-1	1	4-20 mA
8	RH1, %	HMW61U #1	0-100 %	cFP-AI-110-1	2	4-20 mA
9	RH2, °C	HMW61U #2	0-100 %	cFP-AI-110-1	3	4-20 mA
10	RHo, °C	HMW61U #2	0-100 %	cFP-AI-110-1	4	4-20 mA
11	Flow, L/min	Flow meter	0-10 L/min	cFP-AI-110-1	5	0-5V
12	Baro, bar	Barometric pressure sensor	800-1100 mbar	cFP-AI-110-1	6	4-20 mA
13	H_2S,ppb	API 101E	1000 ppb	cFP-AI-110-1	7	0-10 VDC
14	SW1, VDC	Side wall fan #1	0-3.8VDC	cFP-AI-110-2	0	0-10VDC
15	SW2, VDC	Side wall fan #2	0-3.8VDC	cFP-AI-110-2	1	0-10 VDC
16	SW3, VDC	Side wall fan #3	0-3.8VDC	cFP-AI-110-2	2	0-10 VDC

17	SW4, VDC	Side wall fan #4	0-3.8VDC	cFP-AI-110-2	3	0-10 VDC
18	Tunnel1, VDC	Tunnel fan #1	0-3.8VDC	cFP-AI-110-2	4	0-10 VDC
19	Tunnel2, VDC	Tunnel fan #2	0-3.8VDC	cFP-AI-110-2	5	0-10 VDC
20	Tunnel3, VDC	Tunnel fan #3	0-3.8VDC	cFP-AI-110-2	6	0-10 VDC
21	Tunnel4, VDC	Tunnel fan #4	0-3.8VDC	cFP-AI-110-2	7	0-10 VDC
22	Tunnel5, VDC	Tunnel fan #5	0-3.8VDC	cFP-AI-110-3	0	0-10 VDC
23	Tunnel6, VDC	Tunnel fan #6	0-3.8VDC	cFP-AI-110-3	1	0-10 VDC
24	Tunnel7, VDC	Tunnel fan #7	0-3.8VDC	cFP-AI-110-3	2	0-10 VDC
25	Tunnel8, VDC	Tunnel fan #8	0-3.8VDC	cFP-AI-110-3	3	0-10 VDC
26	Tunnel9, VDC	Tunnel fan #9	0-3.8VDC	cFP-AI-110-3	4	0-10 VDC
27	Tunnel10, VDC	Tunnel fan #10	0-3.8VDC	cFP-AI-110-3	5	0-10 VDC
28	Poly1, ppm	Polytron I_1 NH$_3$ sensor	0-100ppm	cFP-AI-110-3	6	4-20 mA
29	Poly2, ppm	Polytron I_2 NH$_3$ sensor	0-100ppm	cFP-AI-110-3	7	4-20 mA
30	T1, °C	Thermocouple #1		cFP-TC-120-1	0	
31	T2, °C	Thermocouple #2		cFP-TC-120-1	1	
32	T3, °C	Thermocouple #3		cFP-TC-120-1	2	
33	To, °C	Thermocouple outside		cFP-TC-120-1	3	
34	Tl, °C	Thermocouple_sample line		cFP-TC-120-1	4	
35	T6, °C	Thermocouple #6		cFP-TC-120-1	5	
36	T7, °C	Thermocouple #7		cFP-TC-120-2	6	
37	T8, °C	Thermocouple #8		cFP-TC-120-3	7	
38	TSP MC	TEOM	0-100 mg/m^3	cFP-AI-112	0	0-10 VDC
39	TSP Filer load	TEOM	0-100%	cFP-AI-112	1	0-10 VDC
40	TSP Main flow	TEOM	0-1L/min	cFP-AI-112	2	0-10 VDC
41	PM10 MC	TEOM	0-50 mg/m^3	cFP-AI-112	3	0-10 VDC
42	PM10 Filter load	TEOM	0-100%	cFP-AI-112	4	0-10 VDC
43	PM10 Main flow	TEOM	0-1L/min	cFP-AI-112	5	0-10 VDC
44	PM2.5 MC	TEOM	0-20 mg/m^3	cFP-AI-112	6	0-10 VDC
45	PM2.5 Filer load	TEOM	0-100%	cFP-AI-112	7	0-10 VDC
46	PM2.5 Main flow	TEOM	0-1L/min	cFP-AI-112	8	0-10 VDC
47	Total HC	VIG200	0-100 ppm	cFP-AI-112	9	0-10 VDC
48	Methane	VIG200	0-100 ppm	cFP-AI-112	10	0-10 VDC
49	Non-Methane	VIG200	0-10 ppm	cFP-AI-112	11	0-10 VDC
50	GC status	VIG200	ON/OFF	cFP-AI-112	12	0-10 VDC
51	Reserved			cFP-AI-112	13	0-10 VDC
52	Water flow	AMCO	0-65355	cFP-CTR-500	1	Pulse
53	Non-CH$_4$,ppm	INNOVA 1412		cFP-2020		ASCII
54	CH$_4$,ppm	INNOVA 1412		cFP-2020		ASCII
55	N$_2$O,ppm	INNOVA 1412		cFP-2020		ASCII
		Solenoid 1		cFP-DO-400-1	0	12 VDC
		Solenoid 2		cFP-DO-400-1	1	12 VDC
		Solenoid 3		cFP-DO-400-1	2	12 VDC

Solenoid 4	cFP-DO-400-1	3	12 VDC
Solenoid 5	cFP-DO-400-1	0	12 VDC
Solenoid 6	cFP-DO-400-1	1	12 VDC
Solenoid 7	cFP-DO-400-1	2	12 VDC
Solenoid 8	cFP-DO-400-1	3	12 VDC

The above A/O module will be connected to or controlled by an embedded DAQ program running in the cFP-2020 stand alone controller.

1. Data Acquisition and Control System

The data acquisition system consists of a PC and Compact Fieldpoint (National Instruments Corporation (NI), Austin, TX) which is a data acquisition and automation controller composed of rugged I/O modules and intelligent communication interfaces. A real-time DAQ program developed using LabVIEW 7 software (National Instruments, Corporation, Austin, TX) is used to acquire data, automate sampling location control, display real-time data, and deliver data and system operation status (figure 1). The DAQ program consists of two sub-programs: an embedded program running in the CFP-2020 network module for collecting raw signals and controlling sampling location; a PC-based program running in the on-site project computer for data post-processing and data publishing on the webpage. The embedded program can stand-alone run and send out data and alarm email.

Electronic relative humidity transmitters (Vaisala Model HMW 61U) with a measurement range of 0.8 -100% and corresponding analog output of 4-20 mA are used to monitor RH in the houses. Type T thermocouples are used to monitor indoor and outdoor air temperature at the air sampling locations. Two 0 to 125 pa (0 to 0.5 inch WC) differential pressure transducers (Setra Model 264, Boxborough, MA) with analog output of 4-20 mA are used to measure building static pressure in both brooding and non-brooding portions of the production houses. Barometric pressure sensors (WE100, Global Water Instrumentation, Inc., Gold River, CA) with analog output of 4-20 mA are used for measuring atmospheric pressure. All the sensors with 4-20 mA analog output are powered by a 24 VDC power supply (100W) and connected directly to the analog input modules (cFP-AI-110, NI). The type T thermocouples are attached to a cFP-TC-120 thermocouple input module. The 14 fan current switches are individually connected to a 150 Ω resistor and powered by a 5 VDC power supply. The voltage signals across the resistors are connected to the analog input modules (cFP-AI-110, NI). The voltage signals from the API 101E and VIG 200 are connected to the analog input modules (cFP-AI-112, NI). Air sampling solenoid valves are controlled through cFP-DO-400 (NI) digital output module (Figure 2).

The INNOVA 1412 is connected to the Compact FieldPoint via a RS232 cable. At the end of every sampling cycle, the INNOVA 1412 communicates with the Compact FieldPoint and sends the results in ASCII code and starts the next sampling cycle. The Compact FieldPoint records each the start time of each sampling cycle and counts the number of sampling cycles at each sampling location. Data for fan operation status and other environment variables are collected by the Compact FieldPoint controller and measurement I/O modules at 1- or 2-s intervals, and processed to 30-sec averages. Real-time ventilation rates are calculated based on the real-time fan operation status and building static pressure. All the real-time readings of the instruments are recorded and displayed on the front panel of the program. Using Labview 7, the front panel can be published as a web page, and viewed in real-time and controlled from a remote location, through internet. The recorded data are stored daily to the on-site PC and backed up by a remote computer via a satellite high-speed internet connection. The stored data are also automatically transmitted through an email sever on a daily basis to provide redundant data transfer. Figure 3 shows the flow of the DAQ system.

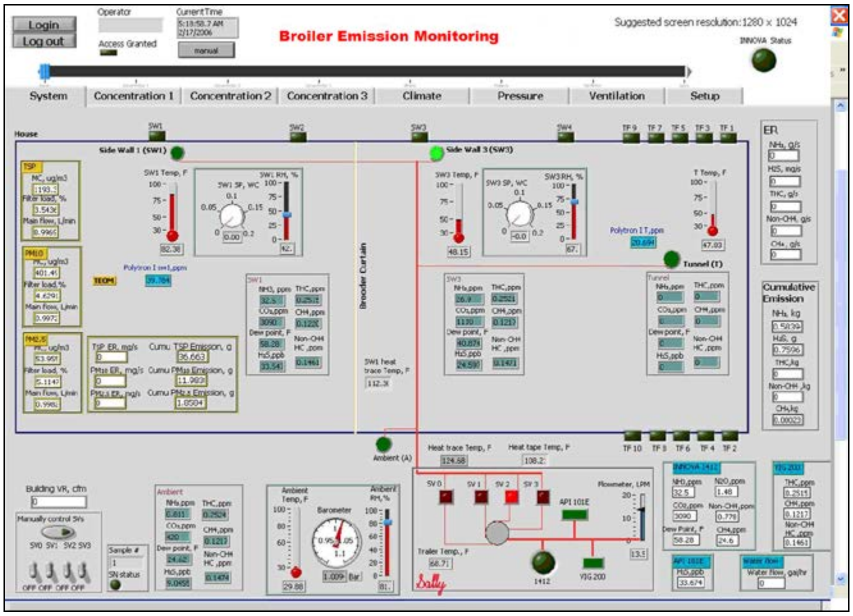


Figure 1. A snapshot of the DAQ software front panel for real-time monitoring of air emissions from animal houses

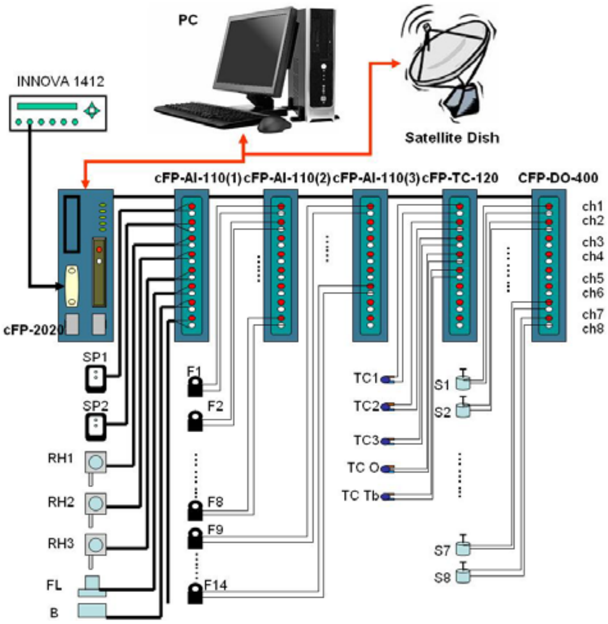


Figure 2. Schematic of the DAQ system

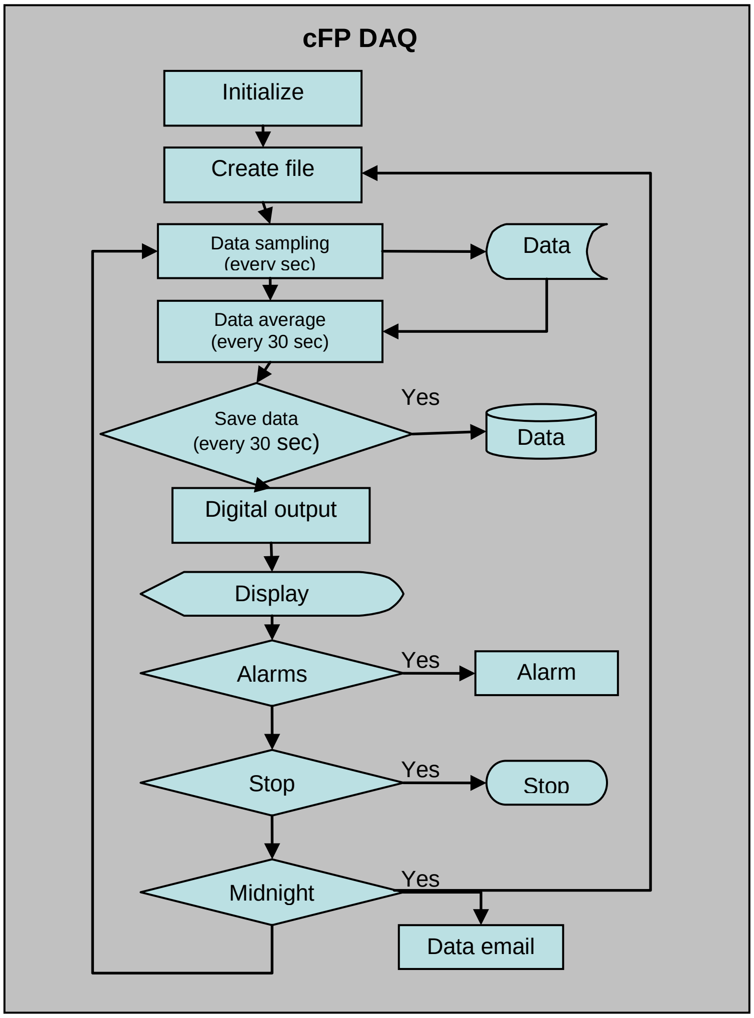


Figure 3. Flow chart of the DAQ program

Finally, the data is processed to calculate the NH_3 emission rate (ER).

Testing and Running the DAQ Program at Initial Operation

Bugs and Suggestions

Bugs found in the DAQ program and suggestions of improvement can be directed by email or phone call to Iowa State University. Upgraded DAQ program files will be sent from Iowa State University to the test computer via internet connection.

Manufacturer Contact Information

National Instruments Corporation
11500 N Mopac Expwy
Austin, TX 78759-3504

Tel: (800) 531-5066
Fax: 512-683-8411

Reference

cFP-DO-400, cFP-AI-110, cFP-AI-112, cFP-CTR-500, cFP-TC-120, FieldPoint Operating Instructions, October, 2002.
cFP-20xx and cFP-BP-x User Manual, April 2004.

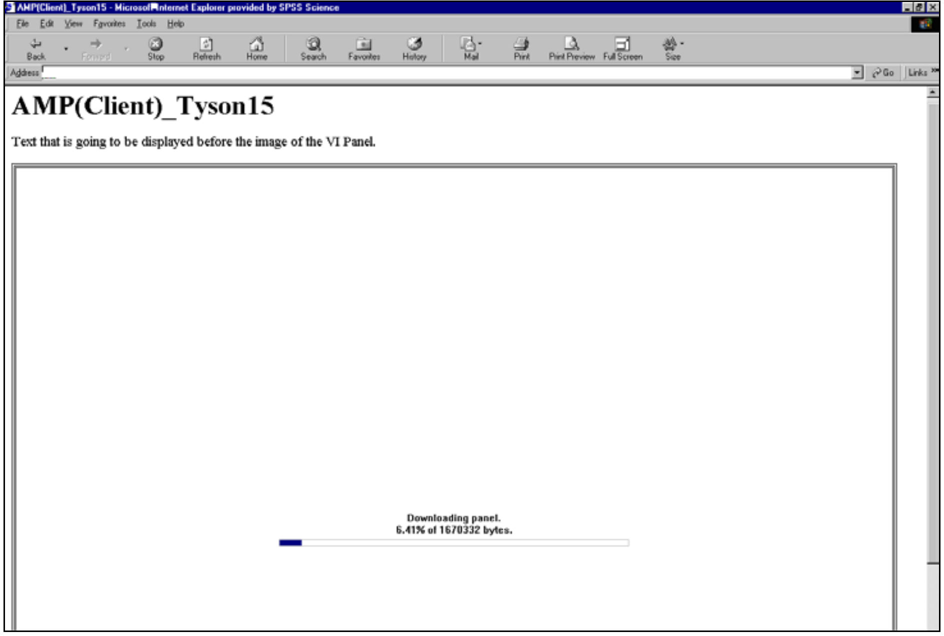
Appendix H: SOP of Using Remote Panel of Southeast Broiler Emission Monitoring Program (Client)

1. View the front panel remotely (Fig.1-2)

Before you start, make sure you have downloaded and run the free software on your computers: ftp://ftp.ni.com/support/labview/windows/runtime/7.1/LVRunTimeEng.exe .
Enter the following URLs into ***Address*** or URL field at the top of the Web browser ***Internet Explorer***:

http://XXX.XXX.XXX.XXX/t15.htm
http://XXX.XXX.XXX.XXX /t33.htm

The plug-in displays the remote panel in the Web browser window.



AMP(Client)_Tyson15 - Microsoft Internet Explorer provided by SPSS Science

AMP(Client)_Tyson15

Text that is going to be displayed before the image of the VI Panel.

Downloading panel.
6.41% of 1670332 bytes.

Fig.1

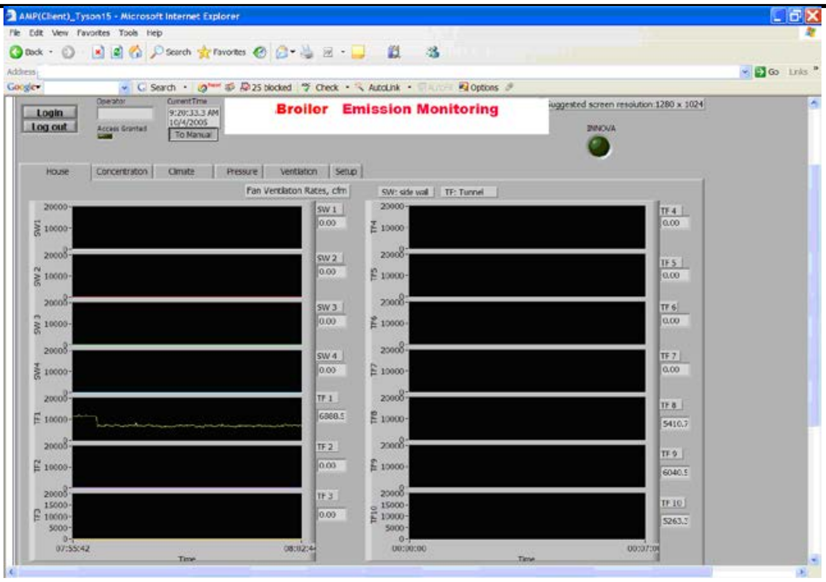


Fig.2

2. Receive access of control (Fig.3-5)

Request control by right-clicking anywhere on the remote panel window and selecting ***Request control of VI*** from the shortcut menu. A message will pop up: Control granted or Waiting for control. If multiple users request control, the control time limit is 300 sec. If control is granted, right-click anywhere and select ***Release control of VI*** for next user to control the remote panel.

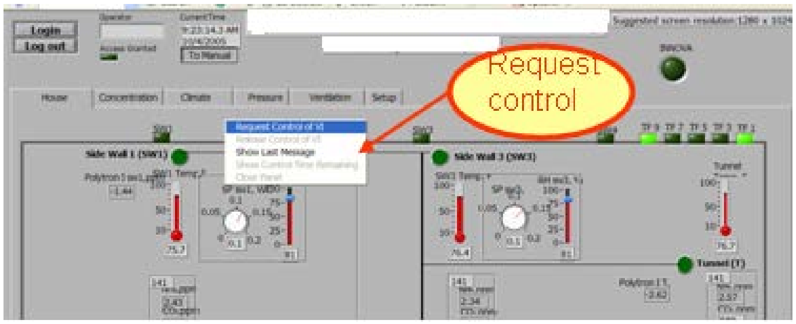
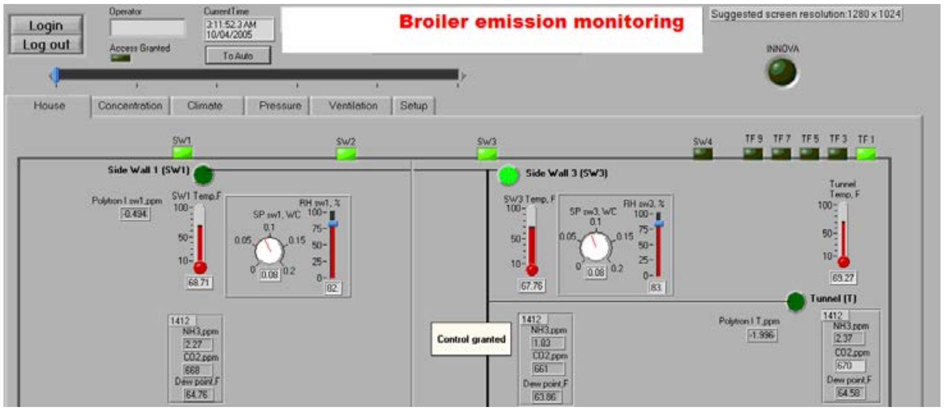
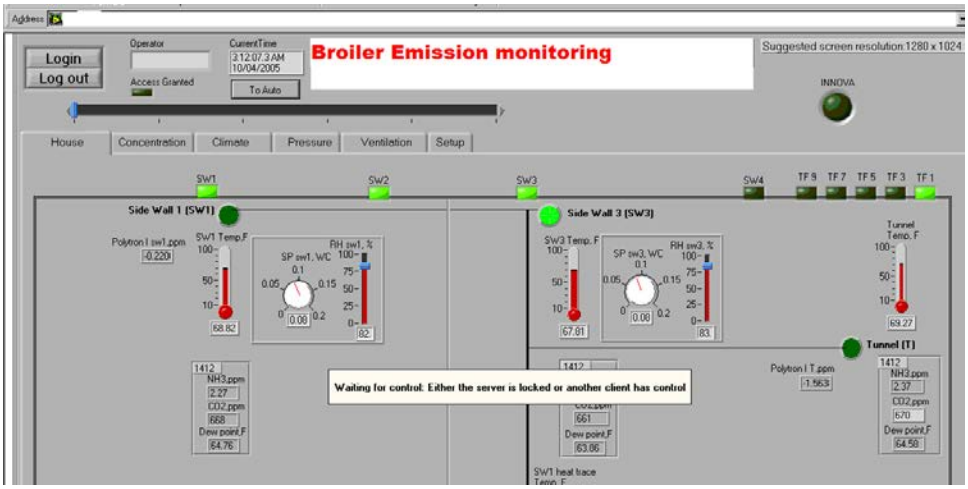


Fig.3



Control granted

Fig.4



Waiting for control: Either the server is locked or another client has control

Fig.5

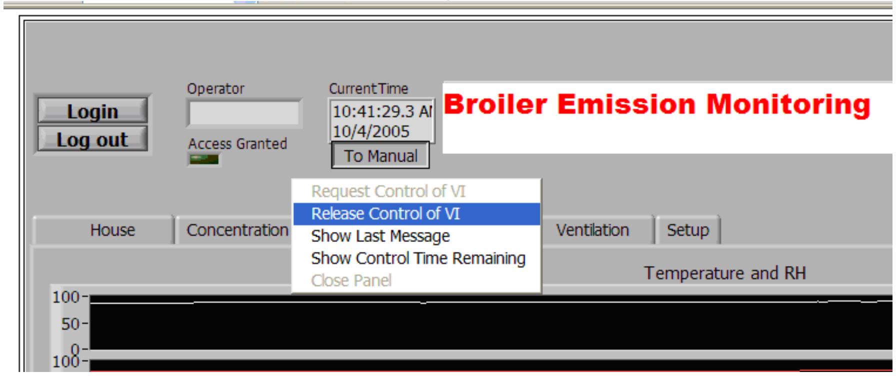


Fig.6

3. Manipulate the remote panel (Fig.7-109)

If the display switch button is ***To manual***, the five display tab will automatically rotate with 20-sec intervals. Click ***To manual*** and change the display to manual control. Click the slide control for desired display tab. Click ***Login*** for requesting change the setup of the program.

Fig.7

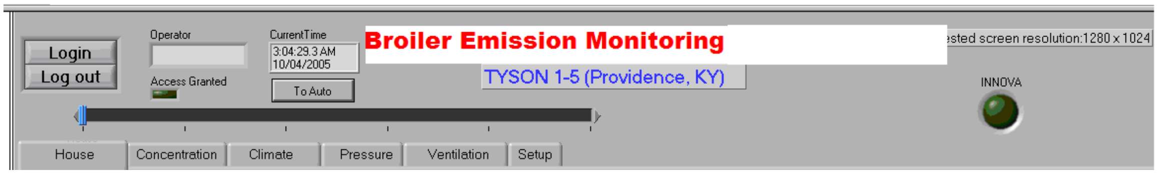


Fig.8

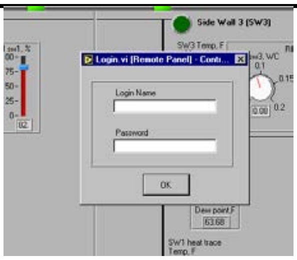
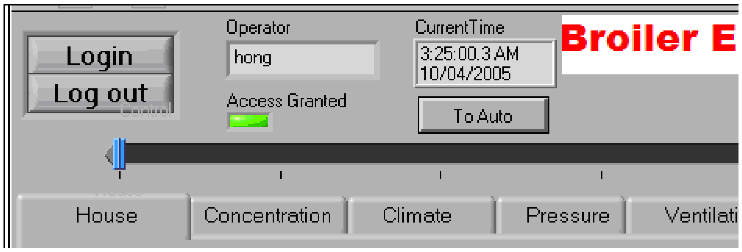


Fig.9



Operator: hong

CurrentTime: 3:25:00.3 AM 10/04/2005

Access Granted

Fig.10

4. Rules for manipulating the remote panel:

a) If you are a system administrator, please log out when you finish changing any setup. If not, please do not try to log in.

b) For other user's convenience, please release control of VI after you finish and change the display mode to automatic.

c) Please avoid keeping online too long time or running the remote panel all the time, it will slow down the internet service due to a limited daily throughput allowance.

d) Please email Hong Li your IP address if your computers have a static IP address. If your computers used DHCP, please give IP address range. If your computer connected to a router, which has a static IP, provide the router's IP.

e) The remote panels are only open for the specific IPs from ISU, UK, TYSON and your home. If you want to view it during travel, please let system administrator know in advance what time you want it to be open. So, the system administrator can open the servers for you. After that, I will close the unlimited access to keep out computers safe.

Appendix I: SOP of Data Management at ISU

The objectives of data management are to:

1. Ensure data security;
2. Provide convenient data retrieval;
3. Minimize labor and cost involved in data management, and
4. Minimize possible interference with the on-going data acquisition.

1. Data Store and Back-up

All original and final data will be reviewed and/or validated by technically qualified staff, and so documented in the program records. The documentation will include the dates the work was performed, the name of the reviewer(s), and the items reviewed or validated.
Corrections and additions to original data must be made as follows:

- After correction, original entries must remain legible (for manual corrections) or intact (for computerized corrections).
- The correction or addition must be readily traceable to the date and staff who performed the correction or addition.
- Corrections must be explained.

1.1 Measurement data file Creating and Storing

All the project specific program and data files will be saved in a single folder in the field computer:

C:\TYSON

Three subfolders will be under **C:\TYSON**:

a. **C:\ TYSON \AMP\Final Programs**

This folder stores DAQ program and hardware configuration files:
- OHSITE mmddyy.llb (DAQ program, of which part of the file name “mmddyy” records the month/date/year related version information)
- OHSITE.iak (configuration file of FieldPoint data acquisition hardware)

b. **C:\ TYSON\AMP \DAQfiles**

This folder stores program setting and calibration files that are all tab delimited:
- Heading&format.txt (defines the headings and format of the data in the recorded data files)
- Sampling sequence.txt (defines automatic air sampling locations and sequence)

- Analyzers.txt (stores gas analyzer ranges, correction coefficients, calibration gas concentrations, and calibration data)
- Settings.txt (stores configuration and settings of the temperature controller, etc.)

c. C:\ TYSON \Data\

This folder stores acquired measurement data files created by the LabView program. To facilitate the identification of data files from different sits, a project ID (two letters, “**B**” for the Tyson 1-5 site, “**D**” for the Tyson 3-3 site) is placed at the beginning of data file names.

Measurement signals from the sensors/analyzers and control signals are sampled every second. Sampled signals are averaged every 30 seconds and are saved in data file 1 (IDsyyyymmdd?.txt) and data file 2 (IDyyyymmdd?.txt, where “?” is a letter from "a" to "z"), respectively. Each time the program is started or when a new day begins at midnight, the two data files are created and saved in the "Data" folder. During DAQ program testing, if the program is started for 26 times during the same day, the “?” will be "z" and cannot go up further. If this happens, the "*z.txt" file in the "Data" folder will be cleaned in order to re-run the program.

As more and more data files are generated in the C:\ TYSON \Data\ folder, the folder becomes too big for backing up in a single CD. It is recommended that old data files be moved to a new folder **C:\ TYSON Data\.**

The project data files created by the embedded program running in the cFP-2020 control module will be saved in a compact flash memory card in the module:

d. D:\

There is no subfolder. This folder stores acquired measurement data files created by the LabView program. To facilitate the identification of data files from different sites, a project ID (two letters, “**A**” for the Tyson 1-5 site, “**B**” for the Tyson 3-3 site) is placed at the beginning of data file names.

Measurement signals from the sensors/analyzers and control signals are sampled every second. Sampled signals are averaged every 30 seconds and are saved in data file 1 (IDsyyyymmdd?.txt) and data file 2 (IDyyyymmdd?.txt, where “?” is a letter from "a" to "z"), respectively. Each time the program is started or when a new day begins at midnight, two data files are created and saved in the "Data" folder. During DAQ program testing, if the program is started for 26 times during the same day, the “?” will be "z" and cannot go up further. If this happens, the "*z.txt" file in the "Data" folder will be cleaned in order to re-run the program.

As more and more data files are generated in the D:\ folder, the folder becomes too big for backing up in a single memory card, so the data files will be downloaded from the memory card to the folder **C:\ Data** of the on-site computers and the older data files will be automatically deleted from the memory card.

1.2 Data Alarm, transfer and Back-up

Electronic data is stored on the on-site computer and downloaded daily with a scheduled time (2:00 p.m.) via a high-speed Internet connection to a dedicated project computer at ISU. The data is backed-up weekly to CDs on-site by the UK personnel and to an external hard drive at ISU. As the data redundant system, compact Fieldpoint stand-alone controller, records the electronic raw data in a compact flash memory and sends the data out by email via a high-speed Internet connection (see Appendix G) at midnight, daily. The emailed data, including the alarm emails from any critical on-site incident, power failure, out-of range and instrumentation failures, also are backed-up weekly to the project computer at ISU (Figure 1). For the precise data post process in the dedicated project computer, all the processed data is stored in the computer and backed-up to the external hard drive. In addition to computer storage, raw tables or graphs are printed out and stored in loose-leaf notebooks.

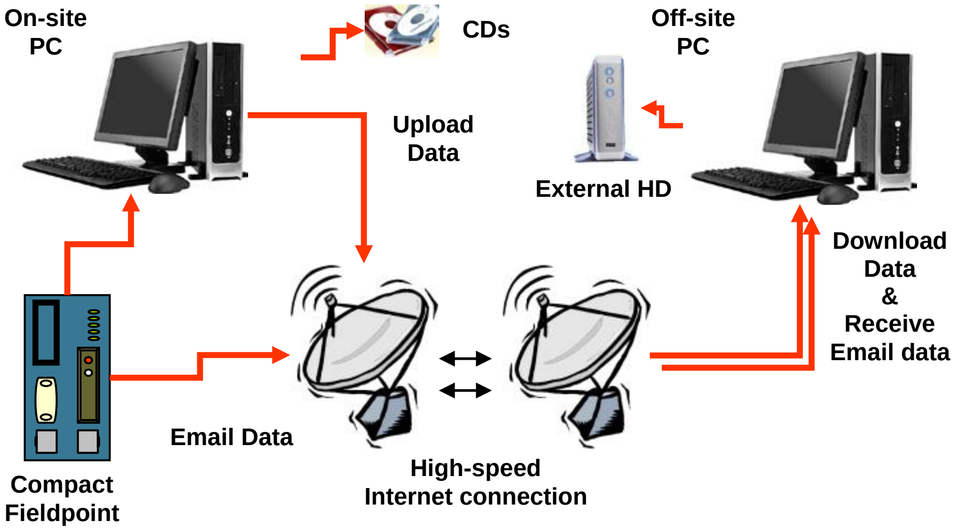


Figure 1. Flow chart of electronic data back up and store

Field test documentation and electronic data storage are maintained in accordance with standard operating procedures, including storage of all raw electronic data in ASCII file format for later analysis using commercially-available spreadsheet and statistical programs. A large portion of the data is also maintained electronically in the form of spreadsheets. All pollutants, temperature, pressure, RH and fan ON/OFF data is electronically stored and compiled in a manner that facilitates computation of hourly and daily averages.

Reports are prepared by qualified staff only from properly reviewed and validated data. All data is reported in units consistent with other measurements. Assumptions are clearly explained as to validity and limitations.

Accurate working files of all documentation, including logbook entries, original data, calculations, deviations from approved procedures, data uncertainties, assumptions, QA/QC results and external performance data, audits, and review, inspection, and validation are maintained by the principal investigator as appropriate until archived after the completion of the project. Project records are maintained in a systematic and logical form and adequately filed for rapid retrieval, accounted for and appropriately indexed.

1.3 Procedure

1. Arrange all project-relevant files together at an easily-found location under C: drive for backup and retrieval.
2. Arrange folder/file structure in the field PC based on file importance and file types. Each folder in the C: drive should be limited to 700 Mb size for easy backup in a single CD.
3. Make records of the LabView program settings and coefficients whenever there are changes. Most settings and coefficient data are recorded in the Settings.txt file. An alternative method is used to make screen shots of part of the LabView program including diagram and front panels that have been changed.
4. Use the LabView automatic email feature to email data files that LabView acquired daily to the campus at midnight.
5. Back up the project folder in the field computer on a CD every two weeks.
6. Back up the operating system when there are significant changes in the system. Store the backup CDs in a location other than the field lab.

2. Classification of data files (with level “1” being the most important)

Management of data files, and method and frequency of file backup depends on the importance of the files.

a. Unique files created before or during the project. These files, once lost, usually cannot be rebuilt. They include:
    - Measurement data
    - Calibration data
    - Field notes
    - Email messages
    - Image files (digital photos or computer screen shots) relevant to the project
b. Program files and system configurations created for the project. These files, once lost, will require extra time to rebuild or recover. They include:
    - LabView data acquisition and control program
    - Configuration files for data acquisition and control hardware (e.g., Compact Fieldpoint)
    - Firewall configurations, etc.
    - Email message rules
    - Favorites lists
c. Specific software and documents needed for the project. These files are provided by manufacturers. They can usually be obtained on the Internet or from the manufacturer

by request, but having them ready on the computer increases working efficiency. They include:

- Instrument manuals
- Software like compact Fieldpoint, INNOVA 1412 for windows, etc.

d. Operating system (installed and configured Windows) and installed commercial software, e.g., MS Office.

3. Data Post Processing

A data post processing program (MAEMU_v1.2) is developed by using Microsoft Visual Basic, which is embedded in Microsoft Excel (2003). The downloaded data from two sites are processed in two days after receiving the data. The daily emission rate for each pollutant is reported with the completeness of each pollutant. At the end of each flock, the flock emission data is reported based on the daily emission data for each pollutant.

3.1 Daily Emission Reporting

First, the original data is verified and validated by a data flagging procedure based on the routine check data and the flags are generated and stored in a separate worksheet, named “Flag”. Validation of measurement data requires two parts, one for the environment condition measurement value, and the second for the air sample measurement. Records of all invalid samples are filed. The information includes a brief summary of why the sample was invalidated along with the associated flags. This record is available on the post process, since all data is recorded. The flags are showed in the Table I.1. In the “Flag” worksheet, the “1” represents no flag and “0” represents a flag. For example, an “OET” flag shows in the summary table and “0” must be appearing in column “OET” of the “Flag” worksheet. Then, the data flag is tracked and the reason for this flag will be found out and the corresponding action will be performed. Here, the thermocouple sensors are inspected.

Table I.1 Verification and Validation data flags and action

Requirement	**Data Range**	**Acceptance criteria**	**Flag**	**Action**
Temperature	32^oF ~ $105\ ^oF$	> $105\ ^oF$ < 32^oF	OET	Reanalysis/ Confirmation by on-site visit / calibrate / replace Thermocouple/document
Relative humidity	0~100 %	>100% < 0	OEH	Reanalysis/ Confirmation by on-site visit / calibrate / replace RH Sensor/document
Barometric pressure	900~1050 kpa	>1050 < 900	OEB	Reanalysis/Confirmation by on-site visit / calibrate / replace Barometric pressure sensor/document
Static pressure	-0.05 ~ 0.5 inch Water	>0.25 < -0.02	OEP	Reanalysis/Confirmation by on-site visit / calibrate / replace Static pressure sensor/document
Fan current switch	ON/OFF	OFF (all the time)	FCS	Reanalysis/Confirmation by on-site visit / replace Fan Current Switch/document
Temperature	<±1^oF (Checking)	>±1^oF	OCT	Reanalysis/Confirmation by on-site visit / replace Thermocouple/document
Relative humidity	<±5 % of Standard (Checking)	>±5 %	OCH	Reanalysis/Confirmation by on-site visit / Calibration/document
Barometric pressure	<±5 % of Standard (Checking)	>±5 %	OCB	Reanalysis/Confirmation by on-site visit/ Calibration/document
Static pressure	<±5 % of Standard (Checking)	>±5 %	OCP	Reanalysis/Confirmation by on-site visit / Calibration/document
NH_3	<±5 % of Standard	>±5 %	CIA	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
CO_2	<±5 % of Standard	>±5 %	CIC	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
H_2S	<±5 % of Standard	>±5 %	CHS	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
Non-Methane Hydrocarbon (NMHC)	<±5 % of Standard	>±5 %	CVN	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
Methane	<±5 % of Standard	>±5 %	CVM	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
Total Hydrocarbon (THC)	<±5 % of Standard	>±5 %	CVT	Data qualification Reanalysis/Confirmation by on-site visit / Calibration/document
H_2S measurement range	0~100 ppb	> 100 < 0	OHS	Reanalysis/Confirmation by on-site visit / Calibration/document
NMHC measurement range	0-10 ppm	> 10 < 0	OVN	Reanalysis/Confirmation by on-site visit / Calibration/document

Methane measurement range	0-100 ppm	> 100 < 0	OVM	Reanalysis/Confirmation by on-site visit / Calibration/document
THC measurement range	0-100 ppm	> 100 < 0	OVY	Reanalysis/Confirmation by on-site visit / Calibration/document
TSP flow	0.98~1.02 LPM (<0.15 leak check)	> 1.02 < 0.98 (>0.15 leak)	OTF	Data qualification Reanalysis/Confirmation by on-site visit / Leak check & correction/document
TSP measurement range	0~100 mg/m^3	> 100 < 0	OTR	Reanalysis/Confirmation by on-site visit / Instrument Inspection
PM10 flow	0.98~1.02 LPM (<0.15 leak check)	> 1.02 < 0.98 (>0.15 leak)	OPF	Data qualification Reanalysis/Confirmation by on-site visit / Leak check & correction/document
PM10 measurement range	0~50 mg/m^3	> 50 < 0	OPR	Reanalysis/Confirmation by on-site visit / Instrument Inspection/document
PM2.5 flow	0.98~1.02 LPM (<0.15 leak check)	> 1.02 < 0.98 (>0.15 leak)	OMF	Data qualification Reanalysis/Confirmation by on-site visit / Leak check & correction/document
PM2.5 measurement range	0~20 mg/m^3	> 20 < 0	OMR	Reanalysis/Confirmation by on-site visit / Instrument Inspection/document

After all data is flagged, validated values are used for the emission calculation based upon the emission calculation equation in Section 11. The daily average, standard deviation, maximum, and minimum values for each pollutant concentration, ventilation rate, temperature, relative humidity and pressure are calculated and summarized in the “Results “worksheet. The final daily cumulative emission of each pollutant with the data flag will be summarized in the “Summary” worksheet. The daily emission report files are saved and backed up by following the flock number and bird age manner. The folder, “C:\Tyson\Processed data\”, is used to store all the post processed data.

3.2 Flock Emission Reporting

After each flock, the daily emissions of each pollutant during the whole flock period are summarized with the completeness of daily emission. If the daily completeness of one pollutant is less than 75%, the daily emission data for this pollutant is invalidated and marked. Summary tables and charts are generated for each flock bird. The folder, “C:\Tyson\Data Reports\”, is used to store all the post processed data.

Appendix J: SOP of Reporting and Calculation of Contaminant Concentrations, Ventilation and Emissions

This SOP gives instructions for calculating and reporting gas (ammonia, carbon dioxide, hydrogen sulfide, non-methane hydrocarbon) and dust (PM2.5, PM10, TSP) concentrations and barn emission rates.

Concentration Defined

Concentration is broadly defined as the fraction of a constituent of interest contained within a sample. Concentration of gaseous contaminants are generally reported in volumetric, mass-based, or mixed units (see next section). Concentrations of particulates can be provided as number of particles in a sample, or mass of particulates in a certain size range in a mass of sample gas.

Gaseous Contaminants -Units of Measurement[2]

Concentration of gaseous contaminants may be expressed in volumetric, mass-based, or mixed units fractions. The first two are dimensionless except for any scale factor, whereas mixed units fractions are typically expressed as mass of contaminant per unit volume of sample mixture, e.g. mg m^{-3}.

Volumetric concentration is generally expressed in parts per million (ppm) or parts per billion (ppb), defined as the parts of contaminant per million or billion parts of air by volume (1000 ppb = 1ppm).

Mass-based concentration is expressed in either mg kg^{-1} or µg kg^{-1}, with the numerator referring to the mass of contaminant and the denominator to the mass of sample air.

Mixed-unit concentration is most convenient for this work, and is generally expressed as either mg m^{-3} or µg m^{-3}. While this is technically a mixed-unit expression for concentration, it is often called “mass concentration”, and we adopt this naming convention in this SOP. It is convenient because when multiplied by volumetric flow rate of air, an emission rate is directly determined.

Conversion between volumetric $[C]_V$ (ppm) and mass $[C]_M$ (mg m^{-3}) concentrations, assuming the mixture behaves as an ideal gas, is[1]:

$$[C]_V = 8.309T/(Mp)\,[C]_M \qquad (1)$$

$$[C]_M = 0.1204Mp/T \qquad (2)$$

where:

---

[2] Air Contaminants. Chapter 12. ASHRAE HOF. 2005. American Society of Heating Ventilation and Air-Conditioning Engineers, Atlanta GA.

p = sample mixture pressure, kPa
T = sample mixture temperature, K
M = relative molar mass of contaminant, dimensionless

Gaseous Contaminants – Standard Conditions

The relation between $[C]_M$ and $[C]_V$ for standard conditions of 25 °C and 101.325 kPa, is given by:

$$[C]_M = (M/24.45)\,[C]_V \qquad (3)$$

For ammonia, carbon dioxide, hydrogen sulfide and methane, the relative molecular masses are 17.03, 44.01, 34.08 and 16.04, respectively. From equation (3) the relation between standard concentration on mass and volumetric basis are:

$$[C]_{M,NH3} = 0.6965\,[C]_{V,NH3}$$
$$[C]_{M,CO2} = 1.8\,[C]_{V,CO2}$$
$$[C]_{M,H2S} = 1.3939\,[C]_{V,H2S}$$
$$[C]_{M,CH4} = 0.6560[C]_{V,CH4}$$

Gaseous Contaminants – Effects of Temperature and Pressure

A volumetric concentration measurement (ppm) taken at non-standard conditions may be converted to mass concentration (mg m^{-3}) by equation (2) for a given pressure, p, and absolute temperature, T.

Particulate Contaminants -Units of Measurement

Concentration of particulate contaminants may be expressed in mixed units (mass of particulate in a unit volume of sample air), or as a particle count per unit volume of sample air. If the latter is used, the particle count is understood to be within a particle size range, e.g. up to 2.5 µm or 10 µm (PM2.5 and PM10). Total suspended solids may be expressed as either particle count or particle mass per unit volume of sample air. In this SOP, we shall always use mixed units for particulate concentrations, i.e. mg m^{-3}.

Ventilation Rates – Units of Measurement

Fan ventilation rates (standard m^3 s^{-1}, or sm^3 s^{-1}) for each running fan are determined from building static pressure difference (SP, Pa) and the calibration equation for the fan, as follows:

$$Q_{FAN} = a + b\,SP$$

where the parameters a,b are different for each fan and are obtained from regression of the FANS calibration data explained elsewhere in this SOP.

Building ventilation rate, Q'_o, is determined by summing all fans that are running at any time. In the event that large spatial variations are noted, building ventilation rate can be broken into representative amounts near each sampling location, typically two values in the broiler housing, e.g. $Q'o_1$ and $Q'o_2$.

The relations between actual (Q), moist standard (Q'), and dry standard (Q'') volumetric flow rates are:

$$Q'' = (1-W)Q' = (1-W)\,Q(p/p')(T'/T) \qquad (4)$$

where:

W = humidity ratio of air, kg H_2O per kg dry air
= $0.62198\,p / (p-p_v)$
p_v = water vapor pressure (kPa)
= $(rh/100)p_{v,sat}$
rh = air relative humidity, %
$p_{v,sat}$ = saturation water vapor pressure
p = actual pressure (kPa)
p' = standard pressure, 101.325 kPa
T = actual absolute temperature, K
T' = standard absolute temperature, K
Q = actual (moist) volumetric flow, $m^3\ s^{-1}$
Q' = moist standard volumetric flow, $sm^3\ s^{-1}$
Q'' = dry standard volumetric flow, $dsm^3\ s^{-1}$

Emission Rates – Units of Measurement

Emission rate (E) of a gaseous or particulate contaminant is expressed as a mass flow per unit time, e.g. g $NH_3\ s^{-1}$. It may be further refined on a per live-weight, per animal or per animal-unit basis. Consideration should be given to avoid expressing E on a time interval that is shorter than the minimum sampling frequency used to obtain the data. Thus for example, if several minutes are required to acquire concentration data then it is unrealistic to report E on a mass per second basis.

Emission Rates – Calculations

Emission rate (E) is difference in mass flow between all inlet and outlets, for the contaminant of interest. Mass flow of contaminant entering a building can be expressed as the background volumetric concentration $[C]_{Vi}$ multiplied by the incoming volumetric flow rate, Q_i. Similarly, the exhaust mass flow of contaminant is the product of exhaust volumetric concentration $[C]_{Vo}$ multiplied by the exhaust volumetric flow rate, Q_o. Note that volumetric flow rates Q_i and Q_o are typically not equal, since air density differences usually exist between inlet and outlets. Mass flow rate of ventilation air, M_i and M_o, are equal. Equation (4) expresses the general definition of emission rate:

$$E = Q'_o[C]_{Mo} - Q'_i\,[C]_{Mi} \qquad (5)$$

In equation (4), the volumetric flow rates Q'_o and Q'_i may be either actual flow rate, or standardized flow rates (either moist standard = $sm^3\ s^{-1}$ or dry standard = $dsm^3\ s^{-1}$). Moist standard conditions are most appropriate. The mass concentrations of outside and inside samples should be adjusted to standard temperature and pressure, as per equation (3).

In equation (5), the volume units used for volumetric flow rate (denominator) and mass concentration (denominator) must match. For example, non-standard moist air, standard moist air, or standard dry air would be the consistent units to use. Further, typically Q'_o is measured (see SOP for airflow measurement), but Q'i must be computed from continuity:

$$Q_i/\upsilon_i = Q_o/\upsilon_o$$

or,

$$Q'i = (\upsilon_i / \upsilon_o) Q'_o \qquad (6)$$

where υ_i , υ_o are inside air and outside air specific volumes, m^3 moist air per kg dry air. Specific volume may be calculated from air density (kg moist air per m^3 dry air, or kg ma per kg da) and humidity ratio W (kg H_2O per kg da), by:

$$\upsilon = (1+W) / \rho \qquad (7)$$

Summary of Measurements and Calculations for Emission Rate

Measurements required to compute E include:

1. Interior and exterior air state points: dry-bulb temperature, relative humidity
2. Interior and exterior mass volumetric concentrations
3. Building static pressure differences, and atmospheric pressure

Intermediate calculations to compute E include:

1. Interior and exterior saturation and partial water vapor pressure, humidity ratio, air density, specific volume (from equations 4 and 7)
2. Exhaust standard ventilation rate, Q'_o (from FANS calibration and measured static pressure)
3. Incoming standard volumetric ventilation rate, Q'_i (from equation 6)

Combining equations (4)-(7), compute emission rate E from:

$$E = Q'_o ([C]_{Mo} - (\upsilon_i / \upsilon_o) [C]_{Mi}) \qquad (\text{mg contaminant } s^{-1})$$
(8)

Adjust E time basis to reflect issues described in next section.

Concentration Data Extraction, Averaging and Interpolation

Gas Concentration Extraction and Averaging

When analyzing each of the house air samples, four 30-second measurement cycles by the ammonia analyzer will be performed to ensure attainment of 97% or better of the expected concentration value. If fans at all three sampling locations are running, the time interval of a complete sampling cycle will be 120 x 3 = 360 s. If SW3 and/or TF1 are not running, their sample analysis will be skipped, and the sampling will go back to SW1 or fresh/background air. Airflow rates corresponding the measured concentrations will be used in the calculation of the overall house emission rate. Since compositions of the background air are much more stable than the house air, it will be sampled only once every 2 hours. Due to the larger step change in ammonia concentration between the house air and background air, a longer sampling time (i.e., 5 minutes) will be used to allow full stabilization of the analyzer readings. Only the concentration readings at the end of the sampling cycle will be considered as valid measurements.

Gas Concentration Interpolation

When there is only 1 valid reading per location during a 360 sec sampling cycle. To account for potential concentration changes during this period, linear interpolation between the two adjacent readings of the same location will be performed to determine the concentrations in between.

Complete Data Sets

To avoid errors introduced into calculated average values due to partial data days that result in biased time weights, only complete-data days (CDD) that include over 75% valid data should be used for calculating average daily means (ADM). Similarly, hourly averages should be reported only if over 75% of the data during that hour is valid and monthly averages are reported only if over 75% of the days are valid.

Quantity Names and Terminology

Reading: One data point read by LabVIEW. It is not necessarily recorded by LabVIEW.
Data record: A single data point recorded in data files by the LabView data acquisition program. A data record consists of an average of 1-s readings collected over the data recording interval. LabVIEW takes a reading every second and write a data file. LabVIEW also records an average of 30 readings every 30 s and records that in another data file.

Daily mean: Average of all valid and interpolated data records during CDD.
Average daily means (ADM): Average of valid daily means. It can be obtained over a month, a season or a year.
Overall test mean: Average of all valid data over the entire test.

Appendix K: SOP of Model 101E UV Fluorescence H_2S Analyzer

Introduction

The M101E UV Fluorescence H_2S Analyzer is a microprocessor controlled analyzer that determines the concentration of hydrogen sulfide (H_2S), in a sample gas drawn through the instrument. It requires that sample and calibration gases be supplied at ambient atmospheric pressure in order to establish a constant gas flow through the sample chamber where the H_2S in the sample gas is converted into SO_2 which is then exposed to ultraviolet light causing the SO_2 to become excited (SO_2*). As these SO_2* molecules decay back into SO_2 they fluoresce. The instrument measures the amount of fluorescence to determine the amount of SO_2 present in the sample chamber and by inference therefore the amount of H_2S present in the sample gas.

The M101E H_2S analyzer is basically a SO_2 analyzer with a $H_2S \rightarrow SO_2$ conversion stage inserted into the gas stream before the sample gas enters the sample chamber. The H_2S to SO_2 converter receives sample gas from which the SO_2 has been removed by a scrubber. Once the naturally occurring SO_2 is removed from the sample gas, the special converter changes the H_2S in the sample stream to SO_2 using a high-temperature catalytic oxidation.
The chemical process is:

$$2H_2S + 3O_2 \longrightarrow 2H_2O + 2SO_2$$

The physical principle of the M101E's measurement method relies on the fluorescence that occurs when Sulfur dioxide (SO2) is excited by ultraviolet light with wavelengths in the range of 190 nm - 230 nm. This reaction is a two-step process.
The first stage occurs when SO2 molecules are struck by ultraviolet photons of the appropriate wavelength (19 nm - 230 nm). The SO_2 retains some excess energy that causes one of the electrons of the SO_2 molecule to move to a higher energy orbital state. In the case of the Model 101E, a band pass filter between the source of the UV light and the affected gas limits the wavelength of the UV light to approximately 214 nm.

$$SO_2 + hv_{214nm} \xrightarrow{Ia} SO2\,*$$

The second stage of this reaction occurs after the SO_2 reaches its excited state (SO_2*). Because the system will seek the lowest available stable energy state, the SO_2* molecule quickly returns to wavelength of this fluoresced light is also in the ultraviolet band but at a longer (lower energy) wavelength centered at 330nm.

$$SO_2\,* \xrightarrow{kF} SO_2 + hv_{330nm}$$

The linearity of the API 101E was checked. Figure 1 shows the linearity results for the two analyzer (SN: 965 and 966) accuracy checks. For each check, a linear regression was calculated from API 101E response versus the nominal H2S gas standard concentration over the range of 0 to 500 ppb.

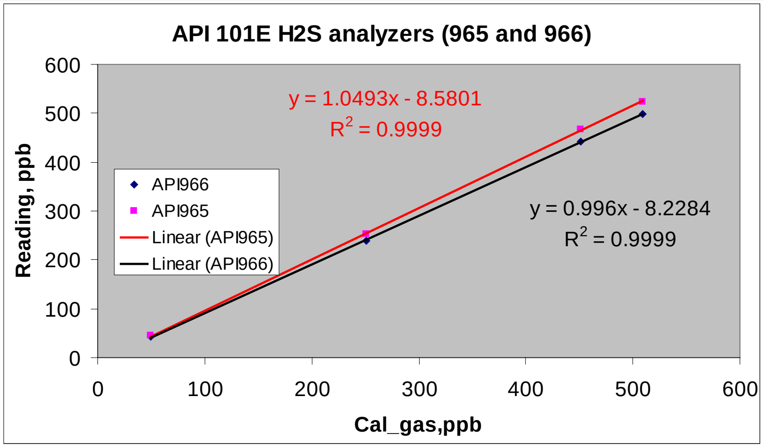
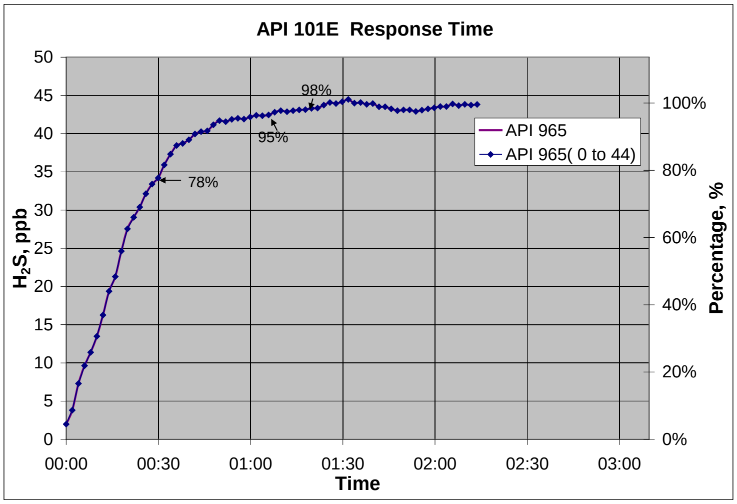


Figure 1. APl 101E Linearity Results

For 965, the slope of the regression line was 1.05, with an intercept of -8.58 and r^2 value of 0.9999. For 965, the slope of the regression line was 0.996, with an intercept of -8.23 and r^2 value of 0.9999. Over the range of concentrations tested (0 to 500 ppb H2S), the API 101E demonstrated a high degree of linearity.



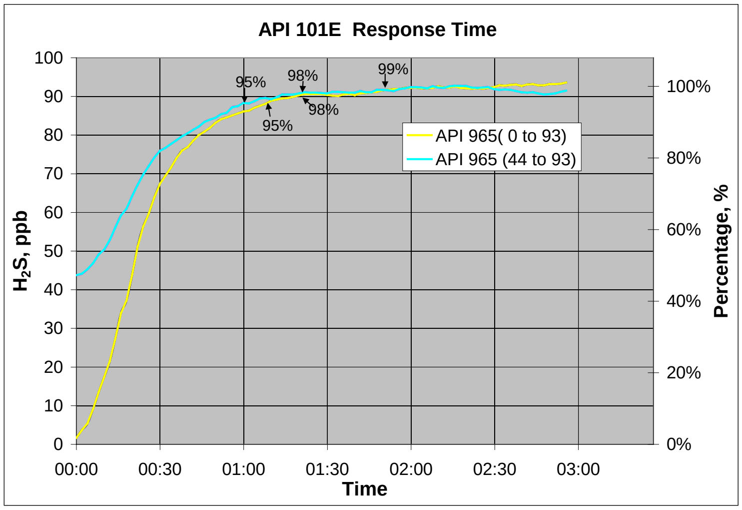


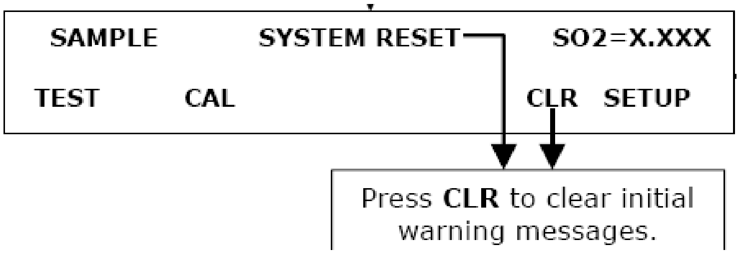
Figure 2. API response time

The response time of the analyzer to step changes in gas concentrations was tested (figure 2). The analyzer was challenged with two H_2S calibration span gases, 44 ppb and 93ppb H_2S respectively in a N_2 balance (±2% accuracy) (Matheson Gas Products, Inc., Montgomeryville, PA). Response time was determined from the amount of time required for the Model 101E to reach 95% of the change in response during the zero air to 44 ppb H2S span gas, 0 to 93 ppb and 44 to 93 ppb shown in Figure 2. The response time was approximately 75 seconds.

Start up

After electrical and pneumatic connections are made, turn on the power switch on the front panel. The exhaust and PMT cooler fans should start. The display should immediately display a single, horizontal dash in the upper left corner of the display. This will last approximately 30 seconds while the CPU loads the operating system.

Once the CPU has completed this activity it will begin loading the analyzer firmware and configuration data. During this process, string of messages will appear on the analyzer's front panel display:



Press **CLR** to clear initial warning messages.

The "fault", red LED will be blinking. Then push the "CLR" key to clear the "SYSTEM RESET" message. The M101E requires about 60 minutes warm-up time before reliable H_2S measurements can be taken.

If the warning messages persist after 60 minutes, investigate their cause using the troubleshooting guidelines in Chapter 11 of Manual.

Functional check

After the analyzer's components have warmed up for at least 30 minutes, verify that the software properly supports any hardware options that were installed.

Check to make sure that the analyzer is functioning within allowable operating parameters. Please check with the values listed in the manufactory data sheet with the operation manual. To view the current values of these parameters press the following key sequence on the front panel.

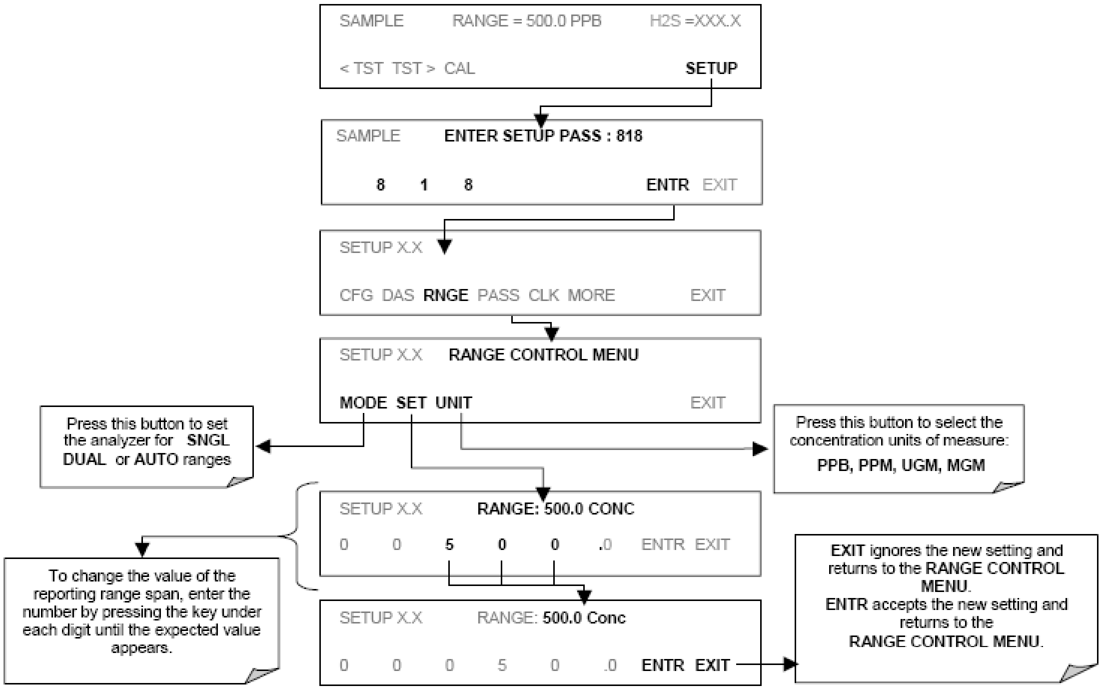
Changing the Sample Particulate Filter

The particulate filter should be inspected often for signs of plugging or excess dirt. It should be replaced according to the service interval in Table 9-1 of manual (every week) even without obvious signs of dirt. Filters with 1 and 5 µm pore size can clog up while retaining a clean look. We recommend handling the filter and the wetted surfaces of the filter housing with gloves and tweezers. Do not touch any part of the housing, filter element, PTFE retaining ring, glass cover and the O-ring with bare hands.

1. Turn OFF the analyzer to prevent drawing debris into the sample line.
2. Open the M101E's hinged front panel and unscrew the knurled retaining ring of the filter assembly.
3. Carefully remove the retaining ring, glass window, PTFE O-ring and filter element.
4. Replace the filter element, carefully centering it in the bottom of the holder.
5. Re-install the PTFE O-ring with the notches facing up, the glass cover, then screw on the hold-down ring and hand-tighten the assembly. Inspect the (visible) seal between the edge of the glass window and the o-ring to assure proper gas tightness.
6. Re-start the analyzer.

Calibration Procedure

Step one: Set/verify the analog output reporting range of the 101E.



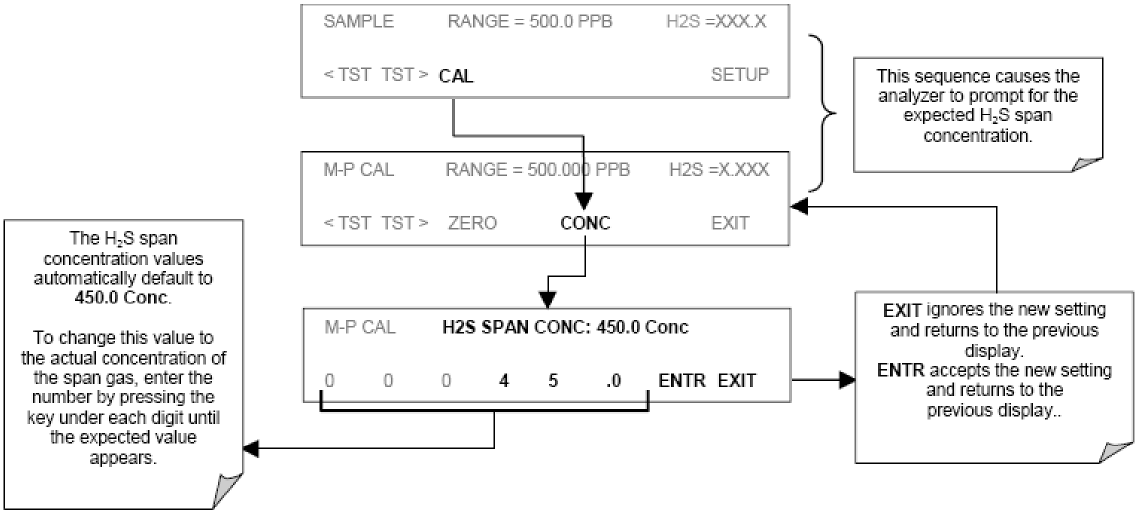
Press this button to set the analyzer for **SNGL DUAL** or **AUTO** ranges

Press this button to select the concentration units of measure: **PPB, PPM, UGM, MGM**

To change the value of the reporting range span, enter the number by pressing the key under each digit until the expected value appears.

EXIT ignores the new setting and returns to the **RANGE CONTROL MENU**.
ENTR accepts the new setting and returns to the **RANGE CONTROL MENU**.

Step two: Set the expected H_2S span gas concentration.



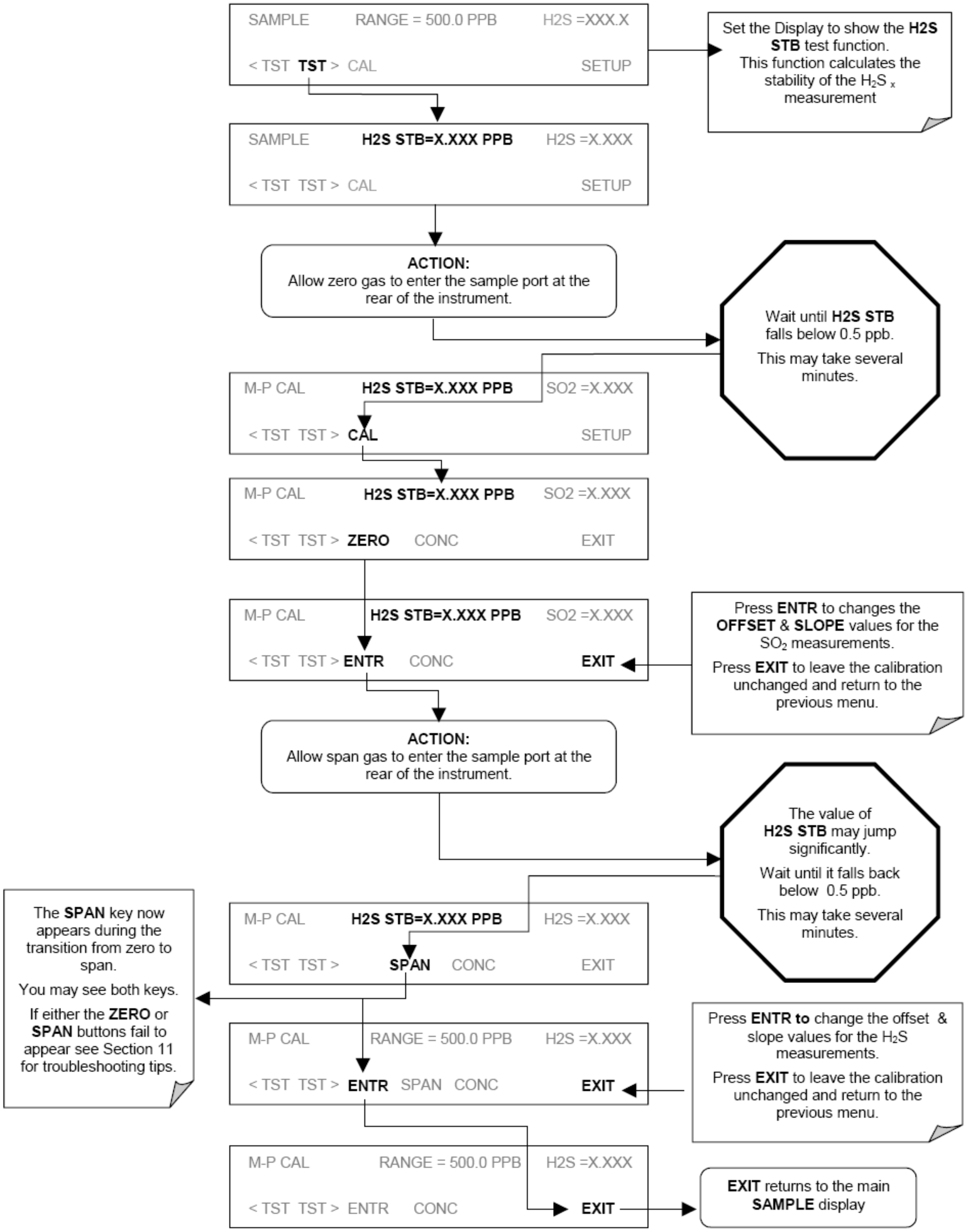
This sequence causes the analyzer to prompt for the expected H_2S span concentration.

The H_2S span concentration values automatically default to **450.0 Conc**.

To change this value to the actual concentration of the span gas, enter the number by pressing the key under each digit until the expected value appears.

EXIT ignores the new setting and returns to the previous display.
ENTR accepts the new setting and returns to the previous display..

Step three: Perform the zero/span calibration procedure:



Set the Display to show the **H2S STB** test function. This function calculates the stability of the H_2S_x measurement

ACTION:
Allow zero gas to enter the sample port at the rear of the instrument.

Wait until **H2S STB** falls below 0.5 ppb.

This may take several minutes.

Press **ENTR** to changes the **OFFSET** & **SLOPE** values for the SO_2 measurements.

Press **EXIT** to leave the calibration unchanged and return to the previous menu.

ACTION:
Allow span gas to enter the sample port at the rear of the instrument.

The value of **H2S STB** may jump significantly.

Wait until it falls back below 0.5 ppb.

This may take several minutes.

The **SPAN** key now appears during the transition from zero to span.

You may see both keys.

If either the **ZERO** or **SPAN** buttons fail to appear see Section 11 for troubleshooting tips.

Press **ENTR to** change the offset & slope values for the H_2S measurements.

Press **EXIT** to leave the calibration unchanged and return to the previous menu.

EXIT returns to the main **SAMPLE** display

Manufacturer Contact Information

TELEDYNE ADVANCED POLLUTION INSTRUMENTATION
9480 CARROLL PARK DRIVE
SAN DIEGO, CA 92121-5201
USA

Toll-free Phone: 800-324-5190
Phone: 858-657-9800
Fax: 858-657-9816
Email: api-sales@teledyne.com
Website: http://www.teledyne-api.com/

Reference:

INSTRUCTION MANUAL OF MODEL 101E UV FLUORESCENCE H2S ANALYZER , REV. A2 , 26 September, 2005

Maintenance/Calibration Record Sheet for API 101 E H_2S analyzer

Date of Calibration: ___________________ Calibrated by: ___________________

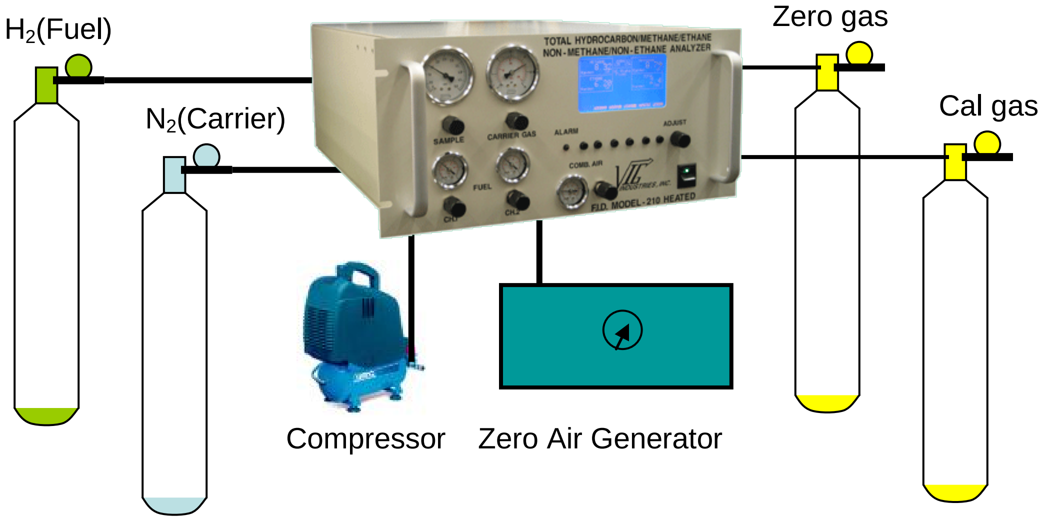
Time	Items	Unit =	Notes
: :	Ambient pressure, (mm Hg)		
	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	H_2S Reading		
: :	H_2S (______ ppm) applied	---	Cylinder P: ___ psi
: :	H_2S Reading		
: :	New Calibration	Yes/No	
: :	Zero air applied		
	H_2S applied		
: :	Finish calibration	Yes/No	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

Appendix L: SOP of VIG Model 200 (Methane/Non-methane/Total Hydrocarbon) Analyzer

Introduction

The methane/non-methane/total hydrocarbon analyzer VIG200 measures concentrations of a wide variety of hydrocarbons in gas mixtures and in air, and can separate the methane component from the non-methane component by using a GC column. This makes VIG-200 ideal for stack monitoring, laboratory or process control use. The model 200 uses column technology to separate methane and non-methane from total hydrocarbons (THC). When a small sample is fed though a column, the column separates each components of the THC one at a time, lightest first and heaviest last. The lightest hydrocarbon is methane. A small sample is sent through the column, wait for the methane to come out, measure the methane, and the rest of the sample is sent backward through the column, and measure the rest and call it non-methane. The measurement is achieved by the use of a FID (flame ionization detector) coupled with a very precise amplifier. The FID injects the gas into a hydrogen-based flame. The flame helps to break the electrons from their orbit, along with a high voltage surrounding the flame. The voltage forces the electrons to jump from the flame on to the electrode giving a measurable medium. The amplifier takes this information and makes it linear and in scale.

Installation



Fuel: Hydrogen (100%), Ultra High Purity Grade @ 18 psi.
Combustion Air: Hydrocarbon free, oil free, dry air @ 18 psi. (From Zero Air Generator)
Zero Air: Zero air Ultra High Purity Grade @ 9-10 psi.
Compressed air: Oil free, dry, Compressed air@ 55 psi. (From Air Compressor)
Calibration gas: Methane/Propane mixture balanced in air @ 9-10 psi.
Carrier gas: Nitrogen Ultra High Purity Grade @ 30 psi.

Startup

- Connect compressed air to the unit and set the incoming pressure to 55 psi.
- Press “Power” switch. Connect Nitrogen to the unit at the carrier gas port and set the carrier gas pressure on the front panel to 22 psi.
- Press any key to continue.
- Find the “Oven” key. If no, push the “More”.
- Set the desired oven temperature to 275^{o}F by turning front panel knob.
- Connect all required gases to the proper ports on the rear panel.
- Go the “Burner 1” and Burner 2”. Press the “Ignite”. Make sure that “Auto” is flashing. If not, press the “Auto” key.
- After the alarm lamp on the front panel goes out, check and adjust the fuel, combustion air, carrier gas and compressed air to the desired value in the **Table 1** on the **VIG 200 user manual**.

Warming Up the Monitor

A period of 6-hr is suggested to warm up the analyzer before a calibration task is started. This will reduce the time required for calibration.

Calibration

Before calibration, make sure the display and output values are the peak value.

- Press “Main” / “More” / “Menu” until “Modes” is displayed.
- Press “Modes”.
- Press “Peak” for Display and Output.
- On the front panel of the Labview program, click the “Manually control” and put all four SVs (solenoid valves) on “OFF”.

<u>Zero Gas Calibration</u>

15. Close regulator valve on the zero gas cylinder.
16. Open main valve on zero gas cylinder.
17. Insert the 1/4” ID tubing (from the gas cylinder) into the inlet of the flow meter mounting on the side of instruments rack.
18. Adjust regulator valve until vent airflow is about 5 L/min (read from bottom of ball of the vent monitoring flow meter). This provides a little extra zero air to the analyzers and keeps the pressure inside the manifold close to the atmospheric pressure.
19. Flow Zero gas for 2 minutes.
20. Press “Main” / “More” / “Menu” until “GC” is displayed and Press “GC”. Press “Single”.
21. Wait for about 3 minutes until the CH_4 and Residual analysis is finished.
22. If the CH_4 or Residual reading is not in the range of ± 0.1 ppm, the potentiometer needs to be adjusted.
    i. Press “Setup”.
    ii. Press “Methane” or “Residual” and Press “Zero”.

    iii. Turn the front panel knob. If the reading is larger than “0”, reduce the potentiometer value. If the reading is smaller than “0”, increase the potentiometer value.
    iv. Press Main” / “More” / “Menu” until “GC” is displayed and Press “GC”.

23. Press “Single”.
24. Wait for about 3 minutes until the CH4 and Residual analysis is finished.
25. Repeat steps 6-10 for both Methane and Residual until an acceptable zero reading is reached.
26. Press “Main” / “More” / “Menu” until “Modes” is displayed.
    i. Press “Modes”.
    ii. Press “Track” for Display.
    iii. Press “Main” / “More” / “Menu” until “GC” is displayed.
    iv. Press “GC” and Press “Setup”
    v. Press “Total”.
    vi. Press “Zero”.
    vii. Turn the front panel knob until the Total reading in the display window reads 0.0 ppm.
27. Close regulator and remove tubing from the zero gas cylinder.
28. Change the Modes display setup back to “Peak”.

Span Gas Calibration

1. Close regulator valve on the span gas cylinder.
2. Open main valve on span gas cylinder.
3. Insert the 1/4” ID tubing (from the gas cylinder) into the inlet of the flow meter mounting on the side of instruments rack.
4. Adjust regulator valve until vent airflow is about 5 L/min (read from bottom of ball of the vent monitoring flow meter). This provides a little extra span gas to the analyzers and keeps the pressure inside the manifold close to the atmospheric pressure.
5. Flow Span gas for 2 minutes.
6. Press “Main” / “More” / “Menu” until “GC” is displayed and Press “GC”. Press “Single”.
7. Wait for about 3 minutes until the CH4 and Residual analysis is finished.
8. If the CH4 or Residual reading is not in the range of span gas concentration ± 0.1 ppm, the potentiometer needs to be adjusted.
    i. Press “Setup”.
    ii. Press “Methane” or “Residual” and Press “Span”.
    iii. Turn the front panel knob. If the reading is larger than span gas concentration, reduce the potentiometer value. If the reading is smaller than span gas concentration, increase the potentiometer value.
    iv. Press Main” / “More” / “Menu” until “GC” is displayed and Press “GC”.
9. Press “Single”.
10. Wait for about 3 minutes until the CH_4 and Residual analysis is finished.

11. Repeat steps 6-10 for both Methane and Residual until an acceptable zero reading is reached.
12. Press “Main” / “More” / “Menu” until “Modes” is displayed.
    i. Press “Modes”.
    ii. Press “Track” for Display.
    iii. Press “Main” / “More” / “Menu” until “GC” is displayed.
    iv. Press “GC” and Press “Setup”
    v. Press “Total”.
    vi. Press “Span”.
    vii. Turn the front panel knob until the Total reading in the display window reads 0.0 ppm.
13. Close regulator and remove tubing from the zero gas cylinder.
14. Change the Modes display setup back to “Peak”.
15. Press “Main” / “More” / “Menu” until “GC” is displayed and Press “GC”. Press “Auto”.
16. On the front panel of the Labview program, click the “Manually control” and close the manually control.

Manufacturer Contact Information

VIG Industries, Inc.
4051 East La Palma Ave., Suite C
Anaheim, California 92807-1751
Toll Free in the US: (800) 862 - 7844
Phone: (714) 632 - 8200
Fax: (714) 632 - 8201
Email: Service@vigindustries.com

Reference:

Manual of model 200 methane/non-methane/total hydrocarbon analyzer

Maintenance/Calibration Record Sheet for VIG 200

Date of Calibration: __________________   Calibrated by: __________________

Time	Items	Unit =	Notes
: :	Ambient pressure, (mm Hg)		
	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	Total Reading		
: :	CH_4 Reading		
: :	Propane Reading		
: :	CH_4 (______ ppm) applied	---	Cylinder P: ___ psi
	CH_4 Reading		
: :	Propane (______ ppm) applied	---	Cylinder P: ___ psi
	Propane Reading		
: :	New Calibration	${}^{Yes}/_{No}$	
: :	Zero air applied		
	Total adjustment: CH_4 adjustment:	Propane adjustment:	
	Total Reading: CH_4 Reading:	Propane Reading:	
: :	CH_4 applied		
	Total adjustment: CH_4 adjustment:	Propane adjustment:	
	Total Reading: CH_4 Reading:	Propane Reading:	
: :	Propane applied		
	Total adjustment: CH_4 adjustment:	Propane adjustment:	
	Total Reading: CH_4 Reading:	Propane Reading:	
: :	Finish calibration	${}^{Yes}/_{No}$	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

Appendix M: SOP of Tapered Element Oscillating Microbalance (TEOM) for TSP Measurement

Introduction

The TEOM instrument (TEOM 1400 Ambient Particulate (PM-10) Monitor) is a continuous PM monitoring device designated by USEPA as an equivalent method (EPA Designation No. EQPM-1090-079) for PM_{10} (≤10 μm aerodynamic diameter). The acronym TEOM stands for "Tapered Element Oscillating Microbalance," an inertial measurement technique that operates on changes in the resonant frequency of an oscillating element as a function of increases in particle mass collected on a filter attached to the element. Changes in the element's resonant frequency are sampled electronically in quasi-real time, providing both continuous and time-averaged measures of mass accumulation that are directly proportional to instantaneous and time-averaged mass concentrations in air, respectively. The device operates at an industry-standard, volume-controlled flow rate of 16.7 L/min so that it can be outfitted with a variety of commercially available pre-separator inlets suitable for measuring PM. **The unit is fitted with a TSP inlet head in this application.**

Switching Instrument on/off

Since the airflow is maintained at a constant volume, corrected for local temperature and barometric pressure, the operation of this monitor requires that the temperature and pressure sensors are connected for proper temperature and pressure readings and flow corrections.

Turn on unit

Supply power to the instrument by plugging in the power cord to 120 VAC, and pressing the power button on the front panel of the TEOM control unit. The main screen (four-line display) will soon appear after showing the name of the instrument. Turn on the pump to draw the sample streams by plugging in the power cord to 120 VAC. The monitor waits at least 30 min after being powered up to compute the first mass concentration data.

Turn off unit

Press the power button on the front panel of the TEOM control unit. The four-line display becomes blank. Turn off the vacuum pump by pressing the power button and disconnect the control unit from 120 VAC by unplugging the power cord.

Status Line on Main Screen

Whenever a status code other then "OK" is shown on the display, the instrument automatically turns on the "Check Status" light on the front of the control unit. The information displayed on the main screen includes status condition, operating mode, A/O 1 mode, RS-232 mode, protection, and time. For example, the screen will show the following line at time XX:XX:

```
OK     4+       51%    NU      XX:XX
```

Status condition

OK	Normal operation
M	No frequency signal
T	Temperature(s) outside of operational bounds
F	Flow(s) outside of operational bounds
X	Filter nearing capacity—exchange filter

Operating mode

1	Temperature/flow stabilization
2	Begin TM computation
3	TM computed, begin MR/MC computation
4	Normal operating mode
S	Set up mode
X	Stop all mode

A/O 1 mode

(Blank)	Analog output 1 normal definition
+	Analog output 1 used for status watch
XX%	Filter loading (percent)

RS-232 mode

N	None
P	Print online
R	R&P protocol
A	AK protocol
G	German network protocol
S	Storage to printer
F	Fast storage output

Protection

U	Unlocked
L	Low lock
H	High lock
XX:XX	Current time (24-hr format)

Using the Keypads and Software

User should refer to Section 4.5 of the operating manual and become familiar with the incorporated menu-driven software and keypads.

Filter Storage and Exchange

The measurements must be conducted with TEOM filter cartridges that are made of Teflon-coated glass fiber filter paper. Filters should be stored inside the sensor unit for easy access and to keep them dry and warm. Do not handle new filter with your fingers. Instead, use the filter exchange tool and follow the procedures given in the operating manual. Keep the sample pump running to facilitate filter exchange. Use the two pockets on the right side of the mass transducer (inside) to store the next two new TEOM filters, for pre-conditioning and removal of excessive moisture build-up prior to use.

System Operation after Power Failure

The system resets itself when power is regained, and enters the same mode as before. All operating parameters are maintained in the system's battery backed-up CMOS memory.

Setting Variables Stored in Data Logger

The <Step Screen> key toggles the instrument between the View Storage Screen and Set Storage Screen, or, pressing 09<Enter> can gain direct access to the Set Storage Screen from any screen. The first eight lines of the Set Storage Screen contain the titles of the variables currently being stored in the data logger (Program Register Codes listed in Appendix A of operating manual). The "Interval" variable defines the time (in seconds) between successive writings of data to the circular buffer.

Some popular program register codes:

Code	**Variable**	**Units**
008	Mass concentration	μg/m^3
009	Total mass	μg
035	Pressure drop	%
039	Current main flow	L/min
040	Current auxiliary flow	L/min
041	Status condition	code
057	30-min average mass concentration	μg/m^3
130	Current ambient temperature	^{o}C
131	Current ambient pressure	atm

Setting Analog Outputs

The instrument's three analog output channels are accessible from the identical 15-pin connectors on the front and back panels of the control unit. Details regarding the pin assignments and voltage (VDC) of outputs are given in the operating manual (Section 5.1). To bring up the Set Analog Output Screen, press <A/O>, or select "Set Analog Output" from Menu Screen, or press 04<Enter>.

Setting Sampling Average Time

The <Step Screen> key toggles the instrument to "Set Hardware", then press <Enter>. Press the "Data Stop" to start stetting the sampling average time.

Nomenclature

TM	Total mass

MR	Mass rate
MC	Mass concentration
A/O	Analog output
atm	atmosphere, 746 mBar

Calibration

Procedures are based on routine flow auditing, leak checking, and mass calibration verification. Since the TEOM monitor can be directly mass calibrated, it can be directly quality assured using a mass standard. All QA procedures should be coordinated with routine maintenance procedures to minimize down time.

Flow Audit

A flow audit adapter is provided and the procedures are outlined in the operating manual. Both the sample flow rate and total flow rate may be checked using the flow audit adapter with a capped nut for closing the flow splitter bypass line port. It is recommended that the volumetric flow rates be within ±7% of the set points. The United States Environmental Protection Agency (USEPA) requires a tolerance of ±10% for the total flow through the PM-10 inlet. If measured flows differ by more than the stated tolerances, recheck all settings, and perform the test again. Large errors in the flow may indicate other sources of error, such as a malfunctioning flow controller, a system leak, or improper temperature and pressure settings.

Leak Check

The leak check procedures are included in the operating manual (Section 7.6). The leak check should be performed with NO sample filter attached to the mass transducer, which will prevent accidental damage from occurring to the sample filter cartridge when exposed to the high pressure drop (vacuum) in the sample line that the leak check creates. Flow rates should indicate less than 0.15 L/min for the main flow and less than 0.65 L/min for the auxiliary flow with the end of the sample line closed, if not, systematically check plumbing for connector leaks.

Mass Calibration Verification

The mass transducer is permanently calibrated and never requires recalibration under normal use. However, the mass measurement accuracy of the instrument may be verified following procedures in the operating manual. R&P offers a mass calibration verification kit to help perform this procedure.

Maintenance

The lifetime of a **TEOM filter cartridge** depends on the nature and concentration of the particulate sampled, and the main flow rate setting (1, 2, or 3 l/min). The filter must be exchanged when the filter loading value (as shown on the status line of the main menu) **approaches 70%**. At a flow rate of 3 l/min, 100% filter loading generally corresponds to a total mass accumulation of approximately 3 to 5 mg of particulate. Filter lifetime at a main flow rate of 3 l/min is generally 21 days at an average PM-10 concentration of 50 $\mu g/m^3$. Flow splitter adapters for 1 and 2 l/min operation are available for use in areas with higher particulate concentrations.

The factory recommended schedule of periodic maintenance and the schedule to be adopted for use in livestock barns are as follows:

Maintenance item	**Factory**	**This Project**
Clean air inlet head	Upon filter exchange	Twice a Week
Replace TEOM filter cartridge	70% load	Weekly
Exchange in-line filters	6 mon. or when loaded	When loaded
Leak test	Annually	Every flock
Analog board calibration	Annually	Every 6 months

The TEOM TSP air inlet requires regular maintenance in livestock barns. The TEOM inlet itself should be cleaned weekly. In order to do this one must first push the <Data Stop> button on the keypad. Remove the dirty TEOM inlet and replace it with a clean inlet. The dirty TSP inlet will be taken back to work station for cleaning and ready for next inlet swap. For cleaning the dirty inlet, please see Manual **Appendix G: Inlet Maintenance**. Grease as needed to maintain a slight layer of Silicon Grease. Carefully replace the inlet unit, and return to the control unit of the TEOM system, and press the <Data Stop> button once more. This will prevent skewed data from being recorded. It will automatically begin recording in approximately 30 min.

Other Settings

Flow rate through sample inlet	16.7 L/min (1 m^3/hr)
Main flow rate	1 L/min
Temperature of sample stream	50 ^{o}C
Particulate concentration	< 5 μg/m^3 to several g/m^3
Standard Conditions	1 atm pressure, 20°C

Spare Parts and Consumables

Slow blow 2A, 250 V fuse
2A & 250 V in-line fuse, P/N 04003419
Box of 20 TEOM filter cartridges (TX40 media), P/N 57-000397-0020
Large bypass in-line filter, P/N 57-002758
Flow controller filter, P/N 30-003097

Manufacturer Contact Information

Rupprecht & Patashnick Co., Inc.
25 Corporate Circle
Albany, NY 12203

Timothy Morphy
Assistant Product Manager
518.452.0065 voice

518.452.0067 fax
tmorphy@rpco.com (email)

Peggy O'Gormon
Marketing Associate
X3229, email: pogorman@rpco2.com

Reference:
TEOM 1400 Operation manual

Appendix N: SOP of Tapered Element Oscillating Microbalance (TEOM) for PM10

Introduction

The TEOM instrument (TEOM 1400 Ambient Particulate (PM-10) Monitor) is a continuous PM monitoring device designated by USEPA as an equivalent method (EPA Designation No. EQPM-1090-079) for PM_{10} (≤ 10 μm aerodynamic diameter). The acronym TEOM stands for "Tapered Element Oscillating Microbalance," an inertial measurement technique that operates on changes in the resonant frequency of an oscillating element as a function of increases in particle mass collected on a filter attached to the element. Changes in the element's resonant frequency are sampled electronically in quasi-real time, providing both continuous and time-averaged measures of mass accumulation that are directly proportional to instantaneous and time-averaged mass concentrations in air, respectively. The device operates at an industry-standard, volume-controlled flow rate of 16.7 L/min so that it can be outfitted with a variety of commercially available pre-separator inlets suitable for measuring PM. **The unit is fitted with a PM_{10} inlet head in this application.**

Switching Instrument on/off

Since the airflow is maintained at a constant volume, corrected for local temperature and barometric pressure, the operation of this monitor requires that the temperature and pressure sensors are connected for proper temperature and pressure readings and flow corrections.

Turn on unit

Supply power to the instrument by plugging in the power cord to 120 VAC, and pressing the power button on the front panel of the TEOM control unit. The main screen (four-line display) will soon appear after showing the name of the instrument. Turn on the pump to draw the sample streams by plugging in the power cord to 120 VAC. The monitor waits at least 30 min after being powered up to compute the first mass concentration data.

Turn off unit

Press the power button on the front panel of the TEOM control unit. The four-line display becomes blank. Turn off the vacuum pump by pressing the power button and disconnect the control unit from 120 VAC by unplugging the power cord.

Status Line on Main Screen

Whenever a status code other then "OK" is shown on the display, the instrument automatically turns on the "Check Status" light on the front of the control unit. The information displayed on the main screen includes status condition, operating mode, A/O 1 mode, RS-232 mode, protection, and time. For example, the screen will show the following line at time XX:XX:

```
OK    4+    51%   NU    XX:XX
```

Status condition

OK	Normal operation
M	No frequency signal
T	Temperature(s) outside of operational bounds
F	Flow(s) outside of operational bounds
X	Filter nearing capacity—exchange filter

Operating mode

5	Temperature/flow stabilization
6	Begin TM computation
7	TM computed, begin MR/MC computation
8	Normal operating mode
S	Set up mode
X	Stop all mode

A/O 1 mode

(Blank)	Analog output 1 normal definition
+	Analog output 1 used for status watch
XX%	Filter loading (percent)

RS-232 mode

N	None
P	Print online
R	R&P protocol
A	AK protocol
G	German network protocol
S	Storage to printer
F	Fast storage output

Protection

U	Unlocked
L	Low lock
H	High lock
XX:XX	Current time (24-hr format)

Using the Keypads and Software

User should refer to Section 4.5 of the operating manual and become familiar with the incorporated menu-driven software and keypads.

Filter Storage and Exchange

The measurements must be conducted with TEOM filter cartridges that are made of Teflon-coated glass fiber filter paper. Filters should be stored inside the sensor unit for easy access and to keep them dry and warm. Do not handle new filter with your fingers. Instead, use the filter exchange tool and follow the procedures given in the operating manual. Keep the sample pump running to facilitate filter exchange. Use the two pockets on the right side of the mass transducer (inside) to store the next two new TEOM filters, for pre-conditioning and removal of excessive moisture build-up prior to use.

System Operation after Power Failure

The system resets itself when power is regained, and enters the same mode as before. All operating parameters are maintained in the system's battery backed-up CMOS memory.

Setting Variables Stored in Data Logger

The <Step Screen> key toggles the instrument between the View Storage Screen and Set Storage Screen, or, pressing 09<Enter> can gain direct access to the Set Storage Screen from any screen. The first eight lines of the Set Storage Screen contain the titles of the variables currently being stored in the data logger (Program Register Codes listed in Appendix A of operating manual). The "Interval" variable defines the time (in seconds) between successive writings of data to the circular buffer.

Some popular program register codes:

Code	**Variable**	**Units**
008	Mass concentration	$\mu g/m^3$
009	Total mass	μg
035	Pressure drop	%
039	Current main flow	L/min
040	Current auxiliary flow	L/min
041	Status condition	code
057	30-min average mass concentration	$\mu g/m^3$
130	Current ambient temperature	^oC
131	Current ambient pressure	atm

Setting Analog Outputs

The instrument's three analog output channels are accessible from the identical 15-pin connectors on the front and back panels of the control unit. Details regarding the pin assignments and voltage (VDC) of outputs are given in the operating manual (Section 5.1). To bring up the Set Analog Output Screen, press <A/O>, or select "Set Analog Output" from Menu Screen, or press 04<Enter>.

Setting Sampling Average Time

The <Step Screen> key toggles the instrument to "Set Hardware", then press <Enter>. Press the "Data Stop" to start stetting the sampling average time.

Nomenclature

TM	Total mass
MR	Mass rate
MC	Mass concentration
A/O	Analog output
atm	atmosphere, 746 mBar

Calibration

Procedures are based on routine flow auditing, leak checking, and mass calibration verification. Since the TEOM monitor can be directly mass calibrated, it can be directly quality assured using a mass standard. All QA procedures should be coordinated with routine maintenance procedures to minimize down time.

Flow Audit

A flow audit adapter is provided and the procedures are outlined in the operating manual. Both the sample flow rate and total flow rate may be checked using the flow audit adapter with a capped nut for closing the flow splitter bypass line port. It is recommended that the volumetric flow rates be within ±7% of the set points. The United States Environmental Protection Agency (USEPA) requires a tolerance of ±10% for the total flow through the PM-10 inlet. If measured flows differ by more than the stated tolerances, recheck all settings, and perform the test again. Large errors in the flow may indicate other sources of error, such as a malfunctioning flow controller, a system leak, or improper temperature and pressure settings.

Leak Check

The leak check procedures are included in the operating manual (Section 7.6). The leak check should be performed with NO sample filter attached to the mass transducer, which will prevent accidental damage from occurring to the sample filter cartridge when exposed to the high pressure drop (vacuum) in the sample line that the leak check creates. Flow rates should indicate less than 0.15 L/min for the main flow and less than 0.65 L/min for the auxiliary flow with the end of the sample line closed, if not, systematically check plumbing for connector leaks.

Mass Calibration Verification

The mass transducer is permanently calibrated and never requires recalibration under normal use. However, the mass measurement accuracy of the instrument may be verified following procedures in the operating manual. R&P offers a mass calibration verification kit to help perform this procedure.

Maintenance

The lifetime of a **TEOM filter cartridge** depends on the nature and concentration of the particulate sampled, and the main flow rate setting (1, 2, or 3 l/min). The filter must be exchanged when the filter loading value (as shown on the status line of the main menu)

approaches 70%. At a flow rate of 3 l/min, 100% filter loading generally corresponds to a total mass accumulation of approximately 3 to 5 mg of particulate. Filter lifetime at a main flow rate of 3 l/min is generally 21 days at an average PM-10 concentration of 50 $\mu g/m^3$. Flow splitter adapters for 1 and 2 l/min operation are available for use in areas with higher particulate concentrations.

The factory recommended schedule of periodic maintenance and the schedule to be adopted for use in livestock barns are as follows:

Maintenance item	**Factory**	**This Project**
Clean air inlet head	Upon filter exchange	Twice a week
Replace TEOM filter cartridge	70% load	Weekly
Exchange in-line filters	6 mon. or when loaded	When loaded
Leak test	Annually	Every flock
Analog board calibration	Annually	Every 6 months

The TEOM PM10 air inlet requires regular maintenance in livestock barns. The TEOM inlet itself should be cleaned weekly. In order to do this one must first push the <Data Stop> button on the keypad. Remove the dirty TEOM inlet and replace it with a clean inlet. The dirty PM 10 inlet will be taken back to work station for cleaning and ready for next inlet swap. For cleaning the dirty inlet, please see Manual **Appendix G: Inlet Maintenance**. Grease as needed to maintain a slight layer of Silicon Grease. Carefully replace the inlet unit, and return to the control unit of the TEOM system, and press the <Data Stop> button once more. This will prevent skewed data from being recorded. It will automatically begin recording in approximately 30 min.

<u>Other Settings</u>

Flow rate through sample inlet	16.7 L/min (1 m^3/hr)
Main flow rate	1 L/min
Temperature of sample stream	50 ^{o}C
Particulate concentration	< 5 $\mu g/m^3$ to several g/m^3
Standard Conditions	1 atm pressure, 20°C

Spare Parts and Consumables

Slow blow 2A, 250 V fuse
2A & 250 V in-line fuse, P/N 04003419
Box of 20 TEOM filter cartridges (TX40 media), P/N 57-000397-0020
Large bypass in-line filter, P/N 57-002758
Flow controller filter, P/N 30-003097

Manufacturer Contact Information

Rupprecht & Patashnick Co., Inc.
25 Corporate Circle

Albany, NY 12203

Timothy Morphy
Assistant Product Manager
518.452.0065 voice
518.452.0067 fax
tmorphy@rpco.com (email)

Peggy O'Gormon
Marketing Associate
X3229, email: pogorman@rpco2.com

Reference:
TEOM 1400 Operation manual

Appendix O: SOP of Tapered Element Oscillating Microbalance (TEOM) for PM2.5

Introduction

The TEOM instrument (TEOM 1400a Ambient Particulate (PM-10) Monitor) is a continuous PM monitoring device designated by USEPA as an equivalent method (EPA Designation No. EQPM-1090-079) for PM_{10} (≤10 µm aerodynamic diameter). The acronym TEOM stands for "Tapered Element Oscillating Microbalance," an inertial measurement technique that operates on changes in the resonant frequency of an oscillating element as a function of increases in particle mass collected on a filter attached to the element. Changes in the element's resonant frequency are sampled electronically in quasi-real time, providing both continuous and time-averaged measures of mass accumulation that are directly proportional to instantaneous and time-averaged mass concentrations in air, respectively. The device operates at an industry-standard, volume-controlled flow rate of 16.7 L/min so that it can be outfitted with a variety of commercially available pre-separator inlets suitable for measuring PM. **The unit is fitted with a $PM_{2.5}$ inlet head in this application.**

Switching Instrument on/off

Since the airflow is maintained at a constant volume, corrected for local temperature and barometric pressure, the operation of this monitor requires that the temperature and pressure sensors are connected for proper temperature and pressure readings and flow corrections.

Turn on unit

Supply power to the instrument by plugging in the power cord to 120 VAC, and pressing the power button on the front panel of the TEOM control unit. The main screen (four-line display) will soon appear after showing the name of the instrument. Turn on the pump to draw the sample streams by plugging in the power cord to 120 VAC. The monitor waits at least 30 min after being powered up to compute the first mass concentration data.

Turn off unit

Press the power button on the front panel of the TEOM control unit. The four-line display becomes blank. Turn off the vacuum pump by pressing the power button and disconnect the control unit from 120 VAC by unplugging the power cord.

Status Line on Main Screen

Whenever a status code other then "OK" is shown on the display, the instrument automatically turns on the "Check Status" light on the front of the control unit. The information displayed on the main screen includes status condition, operating mode, A/O 1 mode, RS-232 mode, protection, and time. For example, the screen will show the following line at time XX:XX:

```
OK    4+    51%   NU    XX:XX
```

Status condition

OK	Normal operation
M	No frequency signal
T	Temperature(s) outside of operational bounds
F	Flow(s) outside of operational bounds
X	Filter nearing capacity—exchange filter

Operating mode

9	Temperature/flow stabilization
10	Begin TM computation
11	TM computed, begin MR/MC computation
12	Normal operating mode
S	Set up mode
X	Stop all mode

A/O 1 mode

(Blank)	Analog output 1 normal definition
+	Analog output 1 used for status watch
XX%	Filter loading (percent)

RS-232 mode

N	None
P	Print online
R	R&P protocol
A	AK protocol
G	German network protocol
S	Storage to printer
F	Fast storage output

Protection

U	Unlocked
L	Low lock
H	High lock

XX:XX Current time (24-hr format)

Using the Keypads and Software

User should refer to Section 4.5 of the operating manual and become familiar with the incorporated menu-driven software and keypads.

Filter Storage and Exchange

The measurements must be conducted with TEOM filter cartridges that are made of Teflon-coated glass fiber filter paper. Filters should be stored inside the sensor unit for easy access and to keep them dry and warm. Do not handle new filter with your fingers. Instead, use the filter exchange tool and follow the procedures given in the operating manual. Keep the sample pump running to facilitate filter exchange. Use the two pockets on the right side of the mass transducer (inside) to store the next two new TEOM filters, for pre-conditioning and removal of excessive moisture build-up prior to use.

System Operation after Power Failure

The system resets itself when power is regained, and enters the same mode as before. All operating parameters are maintained in the system's battery backed-up CMOS memory.

Setting Variables Stored in Data Logger

The <Step Screen> key toggles the instrument between the View Storage Screen and Set Storage Screen, or, pressing 09<Enter> can gain direct access to the Set Storage Screen from any screen. The first eight lines of the Set Storage Screen contain the titles of the variables currently being stored in the data logger (Program Register Codes listed in Appendix A of operating manual). The "Interval" variable defines the time (in seconds) between successive writings of data to the circular buffer.

Some popular program register codes:

Code	**Variable**	**Units**
008	Mass concentration	$\mu g/m^3$
009	Total mass	μg
035	Pressure drop	%
039	Current main flow	L/min
040	Current auxiliary flow	L/min
041	Status condition	code
057	30-min average mass concentration	$\mu g/m^3$
130	Current ambient temperature	^oC
131	Current ambient pressure	atm

Setting Analog Outputs

The instrument's three analog output channels are accessible from the identical 15-pin connectors on the front and back panels of the control unit. Details regarding the pin assignments and voltage (VDC) of outputs are given in the operating manual (Section 5.1). To bring up the Set Analog Output Screen, press <A/O>, or select "Set Analog Output" from Menu Screen, or press 04<Enter>.

Setting Sampling Average Time

The <Step Screen> key toggles the instrument to "Set Hardware", then press <Enter>. Press the "Data Stop" to start stetting the sampling average time.

Nomenclature

TM	Total mass
MR	Mass rate
MC	Mass concentration
A/O	Analog output
atm	atmosphere, 746 mBar

Calibration

Procedures are based on routine flow auditing, leak checking, and mass calibration verification. Since the TEOM monitor can be directly mass calibrated, it can be directly quality assured using a mass standard. All QA procedures should be coordinated with routine maintenance procedures to minimize down time.

Flow Audit

A flow audit adapter is provided and the procedures are outlined in the operating manual. Both the sample flow rate and total flow rate may be checked using the flow audit adapter with a capped nut for closing the flow splitter bypass line port. It is recommended that the volumetric flow rates be within ±7% of the set points. The United States Environmental Protection Agency (USEPA) requires a tolerance of ±10% for the total flow through the PM-10 inlet. If measured flows differ by more than the stated tolerances, recheck all settings, and perform the test again. Large errors in the flow may indicate other sources of error, such as a malfunctioning flow controller, a system leak, or improper temperature and pressure settings.

Leak Check

The leak check procedures are included in the operating manual (Section 7.6). The leak check should be performed with NO sample filter attached to the mass transducer, which will prevent accidental damage from occurring to the sample filter cartridge when exposed to the high pressure drop (vacuum) in the sample line that the leak check creates. Flow rates should indicate less than 0.15 L/min for the main flow and less than 0.65 L/min for the auxiliary flow with the end of the sample line closed, if not, systematically check plumbing for connector leaks.

Mass Calibration Verification

The mass transducer is permanently calibrated and never requires recalibration under normal use. However, the mass measurement accuracy of the instrument may be verified following procedures in the operating manual. R&P offers a mass calibration verification kit to help perform this procedure.

Maintenance

The lifetime of a **TEOM filter cartridge** depends on the nature and concentration of the particulate sampled, and the main flow rate setting (1, 2, or 3 l/min). The filter must be exchanged when the filter loading value (as shown on the status line of the main menu)

approaches 70%. At a flow rate of 3 l/min, 100% filter loading generally corresponds to a total mass accumulation of approximately 3 to 5 mg of particulate. Filter lifetime at a main flow rate of 3 l/min is generally 21 days at an average PM-10 concentration of 50 μg/m^3. Flow splitter adapters for 1 and 2 l/min operation are available for use in areas with higher particulate concentrations.

The factory recommended schedule of periodic maintenance and the schedule to be adopted for use in livestock barns are as follows:

Maintenance item	**Factory**	**This Project**
Clean air inlet head	Upon filter exchange	Twice a week
Replace TEOM filter cartridge	70% load	Weekly
Exchange in-line filters	6 mon. or when loaded	When loaded
Leak test	Annually	Every flock
Analog board calibration	Annually	Every 6 months

The TEOM PM2.5 air inlet requires regular maintenance in livestock barns. The TEOM inlet itself should be cleaned weekly. In order to do this one must first push the <Data Stop> button on the keypad. Remove the dirty TEOM inlet and replace it with a clean inlet. The dirty PM 2.5 inlet will be taken back to work station for cleaning and ready for next inlet swap. For cleaning the dirty inlet, please see Manual **Appendix G: Inlet Maintenance**. Grease as needed to maintain a slight layer of Silicon Grease. Carefully replace the inlet unit, and return to the control unit of the TEOM system, and press the <Data Stop> button once more. This will prevent skewed data from being recorded. It will automatically begin recording in approximately 30 min.

Other Settings

Flow rate through sample inlet	16.7 L/min (1 m^3/hr)
Main flow rate	1 L/min
Temperature of sample stream	50 ^{o}C
Particulate concentration	< 5 μg/m^3 to several g/m^3
Standard Conditions	1 atm pressure, 20°C

Spare Parts and Consumables

Slow blow 2A, 250 V fuse
2A & 250 V in-line fuse, P/N 04003419
Box of 20 TEOM filter cartridges (TX40 media), P/N 57-000397-0020
Large bypass in-line filter, P/N 57-002758
Flow controller filter, P/N 30-003097

Manufacturer Contact Information

Rupprecht & Patashnick Co., Inc.
25 Corporate Circle

Albany, NY 12203

Timothy Morphy
Assistant Product Manager
518.452.0065 voice
518.452.0067 fax
tmorphy@rpco.com (email)

Peggy O’Gormon
Marketing Associate
X3229, email: pogorman@rpco2.com

Reference:
TEOM 1400 Operation manual

Appendix P: SOP of Barometric Pressure sensor

The purpose of Barometric Pressure measurements is for the correction of the emission calculations.

The sensor is a two-wire sensor using the red wire for power and the black wire for the output signal. Warning: Always connect the sensor with the power turned off.

The barometric pressure sensor may be stored without any special provisions. Place the sensor inside a bag to keep the sensor clean and store on a shelf or hang it on a wall.

Barometric Pressure will be monitored continuously outside of the houses using a WE100 with a range of 80,000 to 110,000 Pa and an accuracy of ± 300pa. One barometric static pressure sensor is required for each house.
The barometric pressure sensor will be compared and calibrated with a calibrated portable pressure sensor at various span pressures.

WE100 barometric pressure transducer specifications
Output: 4-20mA
Range: 800-1100 millibars
Accuracy: +1% of full scale
Operating Voltage: 10-36VDC
Current Draw: Same as sensor output
Warm Up Time: 3 seconds minimum
Operating Temperature: -40° to +55°C

Calibration

- Calibrate the sensor every year or at a different frequency if specified by the QAPP for a particular project.
- Calibrate the sensor system (sensor and data logger) against a Fortin Barometer.
- Follow the procedures for reading and adjusting the Fortin barometer documented.
- Read instantaneous measurements from data logger/sensor system at the time of each Fortin Barometer reading.
- Conduct six paired measurements over a two–day period, average mean of their respective readings are taken out and if this matches then it is calibrated.
- Record the results of the calibration on the sensor lab notebook form.
- If the mean difference between Fortin barometer and senor/data logger measurement is less than or equal to 4 hPa, then the sensor passes calibration and the drift will be back-corrected.
- If the mean difference is > 42 hPa, the barometer will be adjusted against a Fortin Barometer

Manufacturer Contact Information

Global Water
Instrumentation, Inc.
11257 Coloma Road
Gold River, CA 95670
T: 800-876-1172
F: (916) 638-3270

Appendix Q: SOP for Use of Rotem RSC-2 Scale System

References:

1. Rotem Poultry Scale System RSC-2 User Manual.
2. Scalenet Communications Program for RSC-2 User Manual.

Routine Check

1. Check scales for clearance between scales and litter. Optimum separation is 1 inch. Adjust scales as needed

Routine Download

1. Startup the computer notebook with USB-Serial Adapter connected.
2. Hookup Serial Communications between notebook and Rotem Serial Cable
3. Start up Rotem Scalenet Application
4. As soon as software establishes communications with Rotem Scales, the main screen will popup on the computer screen displaying the current growth day and if the scales are weighing.
5. On the application's pull down menu, click on "*Setup*", "*Farm Name*" to change to the current house name (i.e., Tyson 1-5) (This changes only the software data reference, not the data retained in the actual scale's database)
6. On the application's pull down menu, click on "*Setup*", "*Set Flock Number*" to verify current Project Flock Designation Number (i.e., 2). (This changes only the software data reference, not the data retained in the actual scales database)
7. Click on **Collect** icon button to start download of history file for the current flock. Save the download file as both a Rotem (*.his) and Excel (*.xls) file. Designate the files to be saved in the corresponding folder (….\House 1-5\ or ….\House 3-3\) on the computer notebook (C:\Documents and settings\Administrator\My Documents\Rotem Data\).
8. As soon as download is complete, close the Scalenet application, disconnect the communications cables, and turn off the computer
9. Repeat this process each visit. When downloading the file, overwrite the previous saved file.
10. At the end of the flock, email the final excel file (*.xls) to ISU for evaluation.

Between Flocks

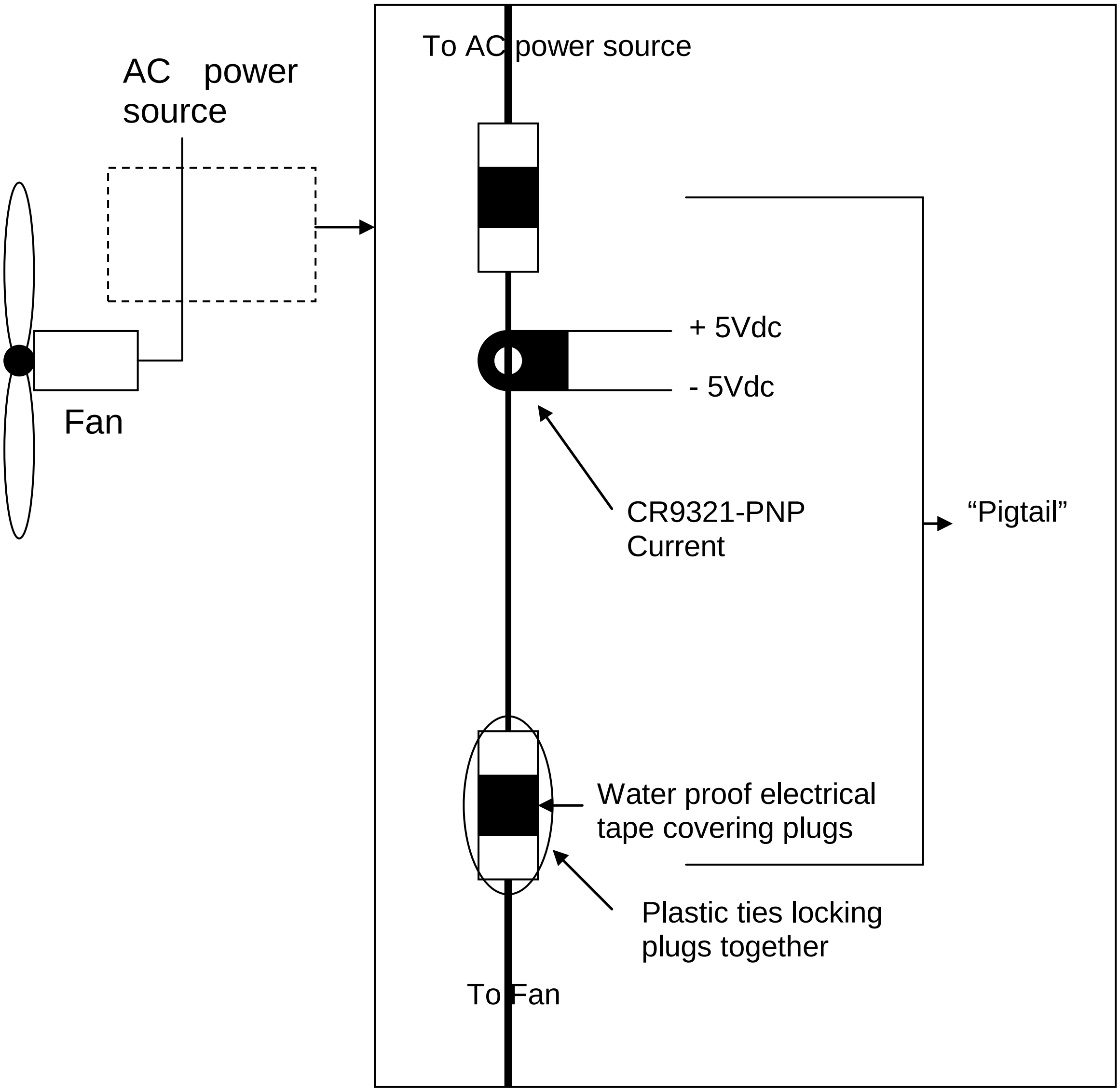
1. Immediately prior to bird catch, remove the scale platform from the load cell, clean, and store in a safe location.
2. Download the final flock weights and email the final excel file (*.xls) to ISU for evaluation.
3. Sometime prior to placement of the next flock, check the accuracy of the scales using known weights. Upon verification, remove the platform and store in a safe location.
4. Immediately after placement of the next flock birds, place the platform back on the load cell. Using the Scalenet application, click on the **Setting** icon button and reset the scales database. A different screen will appear. In the left column, click on "Growth Day" to

change the day to 1; click on “Flock Number” to change to the current flock number designation, and click on “Time” to verify the correct time with the computer time.

Appendix R: SOP for Fan Current Switch Application

Figure 1 shows the induction operated current switch (CS) (CR9321, CR Magnetics, St. Louis, MO) application in monitoring fan operational status. The CS is used in a "pigtail" which acts as a short extension cord. The "pigtail" is put in line between the fan motor and its AC power source. Water proof electrical tape is wrapped extensively around the plug connections to protect them from water and dust. The plugs are then "locked" together using multiple plastic ties as a deterrent to being separated. When AC current is present the CS returns a user defined amount of DC current to the MAEMU.

Figure 1. CS Application



Appendix S: Litter Sample Analytical Methods

Determination of manure pH:

Safety notes:

- Use lab coats, close-toed shoes and hand gloves.
- Mix liquid or semi-liquid manure thoroughly in the fume hood with the front panel pulled down.
- Do not immerse the pH electrode to the bottom of beaker

Equipment:

- pH meter
- 100 ml glass or plastic beakers
- Glass stirring rods
- Distilled water

Calibration:

Calibrate the pH meter using standard buffer solutions (pH 4.0 and 7.0), if necessary

Procedure for liquid manure

(EPA SW-846, Method 9040)

U.S. Environmental Protection Agency. 1986. Test methods for evaluating solid waste. USEPA report SW-846.

- Thoroughly mix liquid manure (manure should be at room temperature)
- Take 25 ml of liquid manure into a beaker
- Immerse pH electrode
- Record pH value when the meter has stabilized
- Repeat above steps for replicates

Procedure for semi-liquid manure

Wolf, N. 2003. Determination of manure pH. p. 48-49. *In*: Peters et al. (eds.) Recommended Methods of Manure Analysis. University of Wisconsin System. http://ecommerce.uwex.edu/pdfs/A3769.PDF (accessed on May 23, 2006)

- Thoroughly mix semi-liquid manure (manure should be at room temperature)
- Take 20 ml of semi-solid manure into a beaker
- Add 40 ml of distilled water
- Stir and mix it well with a glass rod
- Allow for 30 minutes to settle down solution
- Measure pH by immersing electrode into the supernatant solution
- Record pH value when the meter has stabilized
- Repeat above steps for replicates and report the result as pH (water 1:2)

Procedure for solid manure

Wolf, N. 2003. Determination of manure pH. p. 48-49. *In*: Peters et al. (eds.) Recommended Methods of Manure Analysis. University of Wisconsin System. http://cecommerce.uwex.edu/pdfs/A3769.PDF (accessed on May 23, 2006)

- Take 20 g of solid manure into a beaker
- Add 40 ml distilled water
- Stir and mix it well with a glass rod
- Allow for 30 minutes to settle down solution
- Measure pH by immersing electrode into the supernatant solution
- Record pH value when the meter has stabilized
- Repeat above steps for replicates and report the result as pH (water 1:2)

Total Solids or Moisture Content

Standard Method: 2540 B. Total Solids Dried at 103-105*C

Dish Preparation

**ALWAYS handle dishes with gloves on

1. Place clean evaporating dishes in oven at 103-105*C for 1 hour
2. Remove dishes from oven and cool to room temperature in a desiccator. This takes about 2-3 hours.

Testing

Liquids

**ALWAYS handle dishes with gloves on

1. Measure and record the weight of each measuring dish, using the enclosed balance
2. Place three 10-15 ml of samples (about 2/3 full) into separate evaporating dishes. Measure the samples with a broken 10 mL pipet.
3. Do not get any sample on the outside of the dish. If it happens, wipe it off quickly
4. Measure and record weight of each sample and dish, using the enclosed balance
5. Place sample into oven at 103-105*C for 24 hours
6. Remove dishes from oven and cool to room temperature in a desiccator which takes about 2-3 hours
7. Measure and record final weight of samples and dishes, using the enclosed balance

Solids

**ALWAYS handle dishes with gloves on

1. Measure and record the weight of each measuring dish, using the enclosed balance
2. Use about 1 gram of sample for each dish
3. Measure and record the weight of each sample and dish, using the enclosed balance
4. Place sample in 103-105°C oven for 24 hours
5. Remove samples from oven and cool to room temperature in a desiccator which takes about 2-3 hours
6. Measure and record the final weight of the sample and dish, using the enclosed balance
7. Repeat steps 4-6 until the weight is within 4% of the last drying cycle

Calculations

% total solids

$$1 - \frac{\text{(initial weight-final weight)}}{\text{initial weight}} \times 100$$

% Moisture

100 – TS

Ammonia , Rapidstill II

Standard Procedure
Standard Method: 4500-NH3 B. Preliminary Distillation Step & 4500-NH3 C. Titrimetric Method

Safety Precautions: When mixing acids, use the fume hood with the front pulled down. Wear a lab coat, safety glasses, and gloves. **Mix small amounts of acid into larger amounts of water not reversed!** Strong acids will burn holes in your clothing and will burn your skin.

Reagents Required

*Label all reagents with their name, date they were made, and your initials

Sodium Tetraborate (0.025M)

1. Measure 9.5 g $Na_2B_4O_7$*10 H_2O in a weigh boat
2. Dilute to 1 L with distilled water in a 1000 ml volumetric flask
3. Add a stir bar to the flask and mix on a stir plate until all the solid is dissolved, it may take 5 to 10 minutes

Borate buffer solution

1. Using a 500 mL volumetric flask, measure 500 mL of 0.025*M* Sodium Tetraborate and put in a 1000 mL volumetric flask.
2. Measure 88 mL 0.1 *N* NaOH by filling a 50 ml volumetric flask with 0.1 N NaOH, then measuring 38 mL with a 10mL pipet. Put into the 1000 mL volumetric flask along with the Sodium Tetraborate.
3. Dilute to 1 L with distilled water
4. Add a stir bar and mix well on a stir plate for approximately 5 minutes

Mixed indicator solution

*Prepare Monthly

1. Measure 20 mg methyl red indicator in a weigh boat and put it into a 100 mL volumetric flask
2. Dissolve in 100 mL 95% Ethyl Alcohol added to the flask.
3. Measure 100 mg methylene blue and put it into a 100 mL volumetric flask.
4. Dissolve in 100 mL 95% Ethyl Alcohol added to the flask.
5. Mix the two 100 mL flask together in a 250 volumetric flask, add a stir bar, and mix well on a stir plate for approximately 5 minutes

Indicating boric acid solution

*Prepare Monthly

1. Measure 20g H_3BO_3 in a weigh boat and add to a 1000 mL volumetric flask.
2. Add approximately 700 mL distilled water to the flask and dissolve the H_3BO_3 with a stir bar and a stir plate, it may take 10 to 15 minutes
3. Add 10 mL mixed indicator solution to the flask
4. Dilute to 1 L with distilled water, add a stir bar and mix well on a stir plate for approximately 5 minutes

Standard sulfuric acid titrant, 0.02N

1. Measure 2.8 mL concentrated Sulfuric Acid with a 10 mL pipet
2. Dilute to 1 L with distilled water in a 1000 mL volumetric flask to make 0.1*N* Sulfuric Acid. Add a stir bar and mix well on a stir plate for 5 to 10 minutes
3. Measure 200 mL 0.1*N* Sulfuric Acid with a 200 mL volumetric flask
4. Pour the 200 mL of 0.1 *N* Sulfuric Acid in a 1000 mL and dilute to 1 L with distilled water.
5. Add a stir bar and mix well on a stir plate for approximately 5 minutes

Sodium Hydroxide (6N)

1. Measure 240g NaOH in a large weigh boat
2. Dilute to 1 L with distilled water in a 1000 mL volumetric flask.
3. Add a stir bar to the flask and mix well on a stir plate until all the solid is dissolved this could take up to 30 minutes.

Distillation Preparation

1. Turn on cooling water by going under the sink and looking way in the back. In the top right corner there is a silver handle. Turn it 45° to the left, allowing water to flow through condenser
2. Depress *Boiler Water* switch, and fill to the top line on the flask (see #10. under distillation procedure)
3. Turn on the *Boiler Heater* by pressing the button
4. When water is at a steady boil, the unit is ready for operation
5. Make sure the NaOH inlet tube located on the left side of the Rapidstill is in a 100 mL graduated cylinder that is full of NaOH.

Manure dilution

20:1 water to manure ratio serial dilution

1. Add 25 mL distilled water to a 50 mL volumetric flask
2. Mix liquid manure for 1 minute at low speed with a drill mixer
3. With a carefully broken 10 mL pipet, fill the flask up to the line with manure sample to ensure there is exactly 25 mL of manure sample
4. Pour the contents of the 50 mL volumetric flask into a 500 mL volumetric flask.
5. Dilute the sample to 500 mL with distilled water

Sample Preparation

75 mL samples, 10:1 water to dilute-manure ratio

1. Mix liquid manure for 1 minute at low speed with drill mixer
2. Extract a 6.815 mL dilute-manure sample, place in a digestion tube
   *break a 10 mL pipet at the correct volume using the proper tools
3. Add 68.15 mL distilled water by filling a 50 mL volumetric flask, adding that to the digestion tube, and then adding the rest (18.15 mL) with a 10 mL pipet

4. Add 3.75 mL borate buffer solution with a 10 mL pipet

Sample Preparation of Known Sample for Calibration

150 mL samples with 100 mg/L NH_3

Manure and 100 mg/L NH_3 Sample

1. Extract a 13.7 mL of mixed sample, place in beaker
2. Add 15.0 mL 1000 mg/L NH_3 solution
3. Add 121.3 mL distilled H_2O
4. Add 7.5 mL borate buffer solution

Distilled H_2O and 100 mg/L NH_3 Sample

1. Place 15.0 mL 1000 mg/L NH_3 solution in a digestion tube using a 10 mL pipet
2. Add 135.0 mL distilled H_2O to the digestion tube by filling a 100 mL volumetric flask first then adding 35 mL with a 10 mL pipet
3. Add 7.5 mL borate buffer solution with a 10 mL pipet

Preparation of Blank Sample

Carry a blank sample through all steps of procedure to use in final calculations.

1. Measure 75 mL distilled H_20 using a 50 mL volumetric flask and a 10 mL pipet for the rest
2. Add 3.75mL borate buffer solution with a 10 mL pipet

Distillation Procedure

1. Open the protective casing, pull down on the bottom lever piece, and place the digestion tube containing the sample in the clamping device.
2. Place a 500 mL Erlenmeyer flask containing 50 mL indicating boric acid solution under the Distillate Outlet tube. Make sure the holes in the tube are completely immersed in liquid.
3. Make sure the boiler is full of water. If not, depress the *Boiler Water* Switch to refill the boiler.
4. Turn the *Boiler Heater* on.
5. Depress *NaOH Addition* button to add 5 mL 6N NaOH solution to the digestion tube according to the graduated cylinder the NaOH is in.

6. When the water reaches boiling begin distillation by setting the timer knob to the desired distilling time.
7. Distill for 20 minutes or until froth reaches the condenser arm
8. Collect distillate in the 500 mL Erlenmeyer flask.
9. Lower the flask so that the end of the outlet tube is free of contact with the liquid and continue distillation during the last minute or two to cleanse condenser and outlet tube.
10. When distillation has completed, the until will return to standby position, with the boiler heater still in operation. DON'T let the boiler stay on, switch the *Boiler Heater* button to the off position
11. Once the boiler is cool, depress *Boiler Water* switch to refill the boiler after each run. If doing additional distillations, turn the boiler heater back on, and the machine is ready when boiling resumes.
12. Run samples in duplicate, if numbers are not in agreement (up to 10%), then run a third sample.

Titration

1. Fill a 50 mL buret with 0.02 *N* H2SO4 and add a stirbar to the 500 mL flask containing the distillate.
2. Titrate, drop wise, the distillate in the flask.
3. Titrate ammonia in distillate with standard sulfuric acid titrant until indicator in distillate turns pale lavender

Calculation

1. Liquid samples: $\text{mg NH}_3\text{-N/L} = \dfrac{(A - B) \text{ x } 280}{\text{mL sample}} \text{ x } 20$

2. Sludge or sediment samples: $\text{mg NH}_3\text{-N/kg} = \dfrac{(A - B) \text{ x } 280}{\text{g dry wt sample}} \text{ x } 20$

Where:

A = volume of H_2SO_4 titrated for sample, mL
B = volume of H_2SO_4 titrated for blank, mL

Rapidstill II

Routine Maintenance

After Every Day

1. Install a clean, empty digestion tube.
2. Remove caustic, *NaOH* supply tubing from vessel containing *NaOH* and place in vessel of purified water.
3. Turn on cooling water and fill boiler. **Turn on boiler heater**.
4. Depress *NaOH Addition* until all of the caustic *NaOH* has been purged out of the system and into digestion tube.
5. Remove the digestion tube and dispose of the liquid properly.
6. Replace digestion tube and fill half full by depressing *NaOH Addition.*
7. When water is at a rolling boil, turn distillation timer to 10 minutes.
8. At end of distillation cycle, turn off the boiler heater and cooling water.
9. Remove digestion tube and dispose of liquid properly.
10. Clean exterior surfaces of machine using a soft cloth and a mild soap and water solution.

Weekly

1. Examine boiler for any build up of deposits. Accumulated deposits may be removed by a dilute solution of hydrochloric acid, or by using commercially available descaling solutions that are compatible with glass.
2. Examine all plumbing and steam lines, ensuring that the tubing is intact. Examine all tubing connections. Examine the connection stopper for deterioration or cracking.

Total Kjeldahl Nitrogen

Standard Procedure
Standard Method:

Safety Precautions:

1. Equipment should not be used until adequate training has been obtained, and the equipment manuals have been read.
2. Read the MSDS for sulfuric acid, sodium hydroxide, hydrochloric acid and boric acid. There are strong acids and bases (both heated) being used.
3. Wear long pants, lab coat, and close-toed shoes. Safety glasses and various types of gloves should also be worn.
4. This analysis should be conducted when there are other personnel in the area.

Reagents Required:

<u>Note:</u> Unless otherwise stated, prepare solutions in deionized water.
* Label all reagents with their name, date they were made, and your initials

Concentrated Sulfuric Acid (90-98%)

1. Store in the cabinet labeled *Corrosives* underneath the fume hood.
2. When using, place the bottle of acid in a spill tray.

Fishertab Kjeldahl tablets

1. Contains 15 mg Selenium in 1.5 gm K2SO4

Indicator Solution

1. Measure 225 mg of methyl red with a weigh boat using the enclosed balance
2. Measure 83 mg of methylene blue with a weight boat using the enclosed balance
3. Dissolve the methyl red and methylene blue in a 100 mL volumetric flask with 100 mL of 95% ethanol. This may take 10-20 minutes to dissolve.
4. Store the solution in an amber-colored bottle and label

4% Boric Acid

1. Measure 80 gm (500 gm) of powdered boric acid with a large weight boat
2. Slowly add the boric acid to about 1.5 L (10 L) of deionized water and allow the acid to dissolve by using a stir bar and a stir plate (it might take 30 minutes to 1 hour), (several hours for greater amounts)
3. Bring the volume up to **2 L** (12.5 L) with deionized water and continue stirring on the stir plate for 5 to 10 minutes

30% Sodium Hydroxide

1. Measure 750 gm (1800 gm) of dry NaOH using a large weigh boat
2. Slowly add the NaOH to 1.5 to 2 L (~5 L) water and allow the base to dissolved by using a stir bar and a stir plate
3. This is an exothermic reaction, container will get hot!!!

4. Bring the volume up to **2.5 L** (6 L) with deionized water and continue stirring on a stir plate for 5 to 10 minutes

Methyl Red Indicator solution

1. Measure 20 mg of methyl red using a weigh boat
2. Dissolve the methyl red in 60 mL absolute ethanol using a 100 mL volumetric flask. This may take 10-15 minutes.
3. Bring the volume of the solution up to 100 mL by adding 40 mL distilled water, and continue stirring for 5-10 minutes

0.1N Hydrochloric Acid: 1:120 dilution

1. Measure out 12.5 mL (125 mL) of concentrated HCl using a 10 mL pipet.
2. Put ~1 L (10 L) of deionized water in a container and add to it, slowly, the HCl
3. Add a stir bar to the solution and let it mix for 10-15 minutes on a stir plate
4. Bring the volume up to **1.5 L** (15 L) with deionized water and continue stirring

Standardization of Hydrochloric Acid:

1. THAM (Tris(hydroxymethyl)aminomethane) is a primary standard base that will be used to standardized the hydrochloric acid
2. Dry THAM in a desiccator (it should not be subjected to heat greater than 100°C
3. Measure about 0.25 gm or less (record exact weight) of THAM using a weigh boat.
4. Add the THAM to three 125 mL Erlenmeyer flasks and dissolve in about 30 mL distilled water by swirling the mixture
5. Add two drops of the Methyl Red Indicator (will be a yellow color)
6. Titrate the THAM solution to a red color with the HCl solution being standardized using the 25 mL buret.
7. Record the volume of acid required for each flask and calculate the normality of the HCl. Average the normality of the three flasks.

Normality of HCl = (gm THAM x 1000)/(121.1 x mL of HCl)

8. Indicate normality and the date standardized on the label of the *0.1N HCl*

Sample Preparation:

<u>Liquids</u>

1. Mix liquid manure for 1 minute at low speed with a drill mixer
2. Measure the liquid sample with a broken tipped pipet. If the sample is not able to be sucked up with a pipet, treat it as a solid sample.
3. At first we will try a range of sample volumes from 0 to 1.00 mL. Prepare duplicates or triplicates of each sample.
4. To improve accuracy using a 25 mL buret to titrate the ammonia, more than 15 mL of HCl should be used for the titration of each sample.

5. Use at least two blank tubes without sample in a run of 25 digestion tubes. The blanks should contain all reagents, receiving the same treatment as the samples. There will be an indicator color change in the blank. If not, something has gone wrong. Also, if new Boric acid or HCl is made during the day, blanks are needed for the new reagents. Blanks *must* be run everyday.
6. Samples can be weighed into digestion tubes one or more days before digesting if tubes are covered so they do not become contaminated.
7. 0.05-0.06 gm urea or 0.2 gm tryptophan can be used to check the system for complete digestion without loss of nitrogen.

Solids

1. Weight representative sample in a tarred weigh boat and record the weight.
2. Transfer the sample to a digestion tube making sure that everything get to the bottom of the tube. Prepared duplicates or triplicates of each sample.
3. To improve accuracy using a 25 mL buret to titrate the ammonia, more than 15 mL of HCl should be used for the titration of each sample.
4. For solid samples we will first test a range of sample weights from 0 to 1.00 gm
5. Use at least two blank tubes without sample in a run of 25 digestion tubes. The blanks should contain all reagents, receiving the same treatment as the samples. There will be an indicator color change in the blank. If not, something has gone wrong. Also, if new Boric acid or HCl is made during the day, blanks are needed for the new reagents. Blanks *must* be run everyday.
6. Samples can be weighed into digestion tubes one or more days before digesting if tubes are covered so they do not become contaminated.
7. 0.05-0.06 gm urea or 0.2 gm tryptophan can be used to check the system for complete digestion without loss of nitrogen.

Digestion Procedure:

1. Carefully insert the digestion tubes into the holes provided in the flask rack. The flask rack can be used for convenient handling and transportation of the digestion tubes.
2. Add 4 Fishertab Kjeldahl tablets to each digestion tube
3. Carefully add 20 mL of concentrated sulfuric acid using a 10 mL pipet to each tube prior to placing the tubes in the digestion block.
4. Turn the main power switch located on front of controller to ON position. *The digestion block must be totally contained in a chemical fume hood, and must have as much space between the back of it and the back of the hood as possible.* Set temperature to 410°C using temperature dial on control unit. Allow approximately one hour for unit to reach pre-set temperature (digestor is at pre-set temperature when lights located on front of the digestor are flashing).
5. After completing sample and reagent addition to the digestion tubes, carefully elevate the rack by grasping the handles provided and place in position on the digestor unit. As the rack is lifted, each tube will rest on its top rim. Carefully lower the rack so that each tube enters its respective hole and bottoms in the base of the unit.

6. Place end plates on the flask rack. These plates completely close the ends of the flask rack and allow the temperature of the upper portion of the tube to elevate proving for proper refluxing and condensation of the sulfuric acid. (A certain amount of foaming will occur at the beginning of the digestion. The refluxing of the acid washes any carbonized material back into the digestion solution. **If foaming is uncontrollable, reduce digestion temperature and/or sample size.**
7. Digest samples at 410 °C until the acid in the flask is clear, and fumes are contained within the digestion tube, and not thick in appearance. A time of two hours is minimal for complete digestion. The “clearness” of the acid (color and absence of particulate matter) and fume density are indicators for completeness of digestion.
8. After digestion is complete, remove flask rack containing tubes from digestor and place on heat resistant pad. **Wear heat-protective gloves!** Turn heat settings on the digestion block back to zero and turn off power if there is no more digestion runs for the day.
9. With the heat-protective gloves, carefully remove manifolds from the digestion tubs. **Caution:** The manifolds may leak condensed acid and the flask may emit fumes. Carry the manifolds to a sink. Clean manifolds and racks with water and running a lot of water down the drain to dilute the acid.
10. After the tubes containing the digest have cooled to room temperature, slowly add 75 mL of deionized water to each tube, swirling to mix. There may be some fume emissions from the tubes so **be careful**. Dilution must be made before a cake is formed from precipitated salts, but not before the digest is cool enough to contain the exothermic reaction.
11. *Contents in the tubes might turn orange or red-orange. This is common and will not affect results.* This distillation should be performed after water is added. If the tubes cannot be distilled, gently vortex the tubes, cover them with aluminum foil and place in the fume hood.

Setup of the Rapidstill Distillation Unit:

1. Add 70 mL of 4% Boric acid to each of the receiving flasks. Add five drops of Indicator solution (methyl red and methylene blue) to each receiving flask. Swirl to mix. (You can mix the boric acid and indicator solution together prior to putting it into the receiving flask).
2. Turn on cooling tap water by going under the sink and looking way in the back. In the top right corner there is a silver handle. Turn it 45° to the left, allowing water to flow through the condenser. The distillate should be cold as it comes out. The distillation coil should be cold at the bottom and somewhat warm at the top. *Check this flow rate periodically, as the water pressure can vary. If there is inadequate water flow to cool the distillation coil, ammonia will be lost with steam instead of being condensed as a liquid in the receiving flask.*
3. Depress *Boiler Water* switch, and fill to the line on the flask (back of the distillation unit)
4. Turn on the *Boiler Heater* by pressing the button. When water is at a steady boil, the unit is ready for operation

5. Make sure the NaOH inlet tube located on the left side of the Rapidstill is in a 500 mL graduate cylinder that is full of NaOH.

Distillation Procedure:

1. Open the safety screen, pull down on the bottom lever piece, and place the digestion tube containing the digestor sample in the clamping device. Close the safety screen.
2. Place the 500 mL Erlenmeyer receiving flask containing the 70 mL 4% Boric acid and 5 drop Indicator Solution under the Distillate Outlet tube on the front right part of the Rapidstill. Make sure the holes in the tube are completely immersed in liquid.
3. Make sure the boiler is full of water. If not, depress the *Boiler Water* switch to refill the boiler.
4. Turn the *Boiler Heater* on.
5. Depress the *NaOH Addition* button to add 85-90 mL of NaOH per 20 mL of acid used in the digestion. Measure this value according to the graduate cylinder the NaOH is contained in.
6. When the water is boiling nicely, being distillation by setting the timer knob to the desired distillation time.
7. Distill for 20 minutes or until froth reaches the condenser arm. The distillate is collected in the 500 mL Erlenmeyer flask.
8. Lower the flask so that the end of the outlet tube is free of contact with the liquid and continue distillation during the last minute or two to cleanse condenser and outlet tube.
9. When distillation is complete, the Rapidstill will return to standby position, with the boiler heater still in operation. DON'T let the boiler stay on, switch the *Boiler Heater* button to the off position.
10. Once the boiler is cool, depress *Boiler Water* switch to refill the boiler after each run. If doing additional distillations, turn the boiler heater back on, and the machine is ready when boiling resumes.
11. There may be a few mLs of sample left in the tube. Pour the remaining residue into waste container designated for selenium waste. When the container is full or the container has been in the lab for 90 days, the liquid needs to be disposed of through EH&S.

Titration:

1. Before titrating a sample, completely fill the buret with 0.1N HCl and drain to waste enough so the initial reading of the buret can be made. Record initial reading.
2. Place a small stir bar in the receiving flask and place on a stir plate beneath of the buret. Stir gently.
3. Add HCl from the buret and allow the color to change from emerald green to a gray to light purple.
4. Titrate to the graph to light purple endpoint. ***Note:*** *It is easy to overshoot the endpoint. When it takes longer for the green color to reappear, slow the addition of the acid down to one drop at a time. If too much acid is added (darker purple) the sample has been over titrated and is lost.*

5. Refill the buret for the next sample.

Calculations:

$$\%\ \text{Nitrogen in sample} = \frac{\text{Normality of acid} \times (\text{mL HCl added} - \text{mL from blank}) \times 1.4}{\text{Sample size}}$$

* Use an average of the replicates of each sample for the final value.

Routine Maintenance/Cleaning:

Digestion

* Clean with a detergent and water solution when the unit is cool.

1. Condensed sulfuric acid will accumulate in the digestion manifold. If acid drop on the digestion block, digestion tubes, support rack, or counter top in the hood, the acid should immediately be wiped up with a wet paper towel.
2. Wipe down outer surfaces of the digestion block. Wipe down hood bench if acid has spilled. Wipe out glass attachments at the end of the aspiration tubes. (Use wet paper towels.)
3. Wipe off metal tops of the racks, and the racks themselves using wet paper towels.

Calibration: The controller has been factory calibrated and should not require re-calibration. In the event re-calibration is required the following procedure should be followed.

1. Insert calibration resistor into the 2-pin sensor connector located on the rear of the control unit.
2. Place ON-OFF switch, located on the controller, to the ON position.
3. Adjust set-point indicator dial to a position where the indicator lights, located on front panel of digestor, are illuminated 50% of the time.
4. Loosen setscrew on set-point indicator dial and align calibration mark on dial with pointer label.
5. The digestor is now calibrated to give digestion temperature indicated on set-point dial.

Distillation

After Every Day

1. Wash digestion/distillation tubes in hot water (no detergent). Use a scrub brush to clean the outside and inside. Rinse 2 or 3 times with hot water. Rinse twice with distilled water. Place in drying oven or on a rack so they will dry.
2. Rinse receiving flasks three times with hot water, and twice with distilled water. Place in dry oven or on a rack so they will dry.
3. Install a clean, empty distillation tube.
4. Remove caustic, *NaOH* supply tubing from vessel containing *NaOH* and place in vessel of purified water.
5. Turn on cooling water and fill boiler. **Turn on boiler heater**.
6. Depress NaOH Addition until all of the caustic NaOH has been purged out of the system and into the digestion tube.
7. Remove the digestion tube and dispose of liquid properly.

8. Replace digestion tube and fill half full by depressing NaOH Addition.
9. When water is at a rolling boil, turn distillation timer to 10 minutes
10. At the end of the distillation cycle, turn off the boiler heater and cooling water. Remove the digestion tube and dispose of liquid properly.
11. Clean exterior surfaces of machine using a soft cloth and a mild soap and water solution.

Weekly

1. Examine boiler for any build up of deposits. Accumulated deposits may be removed by a dilute solution of hydrochloric acid, or by using commercially available descaling solutions that are compatible with glass.
2. Examine all plumbing and steam lines, ensuring that the tubing is intact. Examine all tubing connections. Examine the connection stopper for deterioration or cracking.

Appendix T: Maintenance Checklist

Southeastern Broiler Emissions Project Between Flock Requirements Checklist

House I.D.______________ Date _____________ Incoming Flock No. __________

☐ Clean screens and replace filters on the gas sample line intakes

☐ Check air flow rate in sample lines and solenoid valves

☐ Replace TEOM filters and exchange TEOM inlet heads and 2.5 micron cut cyclones

☐ Leak test the TEOMs after all other maintenance has been performed on them

☐ Instrument Calibration/Verification

____ INNOVA for NH_3

____ API for H_2S

____ VIG for NMH

____ Polytron I

☐ Check all solenoid valves (ON/OFF)

☐ Perform a system check on fan operational status and monitoring

☐ Check airflow rate at 20% of the exhaust fans (randomly selected)

☐ Replace any critical spare parts utilized during the previous flock

☐ Collect copies of calibration and event log sheets from previous flock and submit to Lara Moody for archiving.

☐ Collect litter samples and deliver to ISU for analysis

Checklists of needed items for between flock audits

Item	Quantity	In stock
Inclined Manometer (red liquid)	1	
Setra 264 sensor (New)	1	
Humidity sensor (New + calibrator)	2	
24 VDC power supply	1	
Barometric sensor (calibrated)	1	
4-20 mA HOBO cable	2	
4-Channel HOBO logger	1	
Thermometer (-8 to 50 oC) (NIST) (LEAP lab?)	1	
Cooler (1-2 Gal)	2	
Pump (10 LPM)	1	
Tubing 1/8” ID	10 feet	
TEE (1/4 “ OD)	1	
Valve (ball)	1	
Box with adjustable open (cardboard) -Setra 264 calibration	1	
Solt (Li Cl and Na Cl)	500 gm	
Distilled water	1	
Clean syringe (0-10mL)	2	
Wide mouth bottle (changeable cover)?	2B + 4 C	
Ruler (for TEOM)	1	
Fitting box (Screw drivers, Hex drivers)	1	
Electrical BOX	1	
Coverall and sprinkler (disinfect)	1	
30 ft power extension cord	4	
cFP + crossover cable	1	
Dilutor+ manual	1	
H2S gas + regulator	1	
Manuals and checklist (TEOM, INNOVA)		
Power tool + drill bits	1	

☐ **Thermocouple Check (Unit: °C)**

Time	**Location**	**Temp 1/Standard**	**Temp 2/Standard**	**Temp 3/Standard**

☐ **Check air flow rate in sample lines and solenoid valve**

Time	Temp., °C	Location	Flow rate, LPM	Valve
		SW1		
		SW3		
		Tunnel		
		Ambient		

☐ **Gal-gas injection from sampling port**

Time	Temp., °C	Location	Flow rate, LPM	NH_3 Concentration, ppm
		SW1		
		SW3		
		Tunnel		
		Ambient		

☐ **Leak test the TEOMs**

Time	**Temp., °C**	**Location**	**TEOM SN**	**Main Flow rate, LPM**	**Aux Flow rate, LPM**

☐ **API 101 E check**

Time	Items	Unit =	Notes
	Ambient pressure, (mm Hg)		
: :	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	H_2S Reading		
: :	H_2S (______ ppb) applied	---	Cylinder P: ___ psi
: :	H_2S Reading		
: :	New Calibration	$^{Yes}/_{No}$	
: :	Zero air applied		
: :	H_2S applied (______ ppb)		
: :	Finish calibration	$^{Yes}/_{No}$	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

☐ **Polytro I Calibration**

Time	Items	Unit =	Notes
	Ambient pressure, (mm Hg)		
: :	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	H_2S Reading		Calibration
: :	H_2S (______ ppb) applied	---	Cylinder P: ___ psi
: :	H_2S Reading		Calibration
: :	New Calibration	$^{Yes}/_{No}$	Calibration
: :	Finish calibration	$^{Yes}/_{No}$	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

Innova check Time	Items	Unit =	Notes
	Ambient pressure, (mm Hg)		
: :	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	NH_3 Reading		
: :	CO_2 Reading		
	N_2O Reading		
	CH_4 Reading		
	Propane Reading		
: :	CO_2 (______ ppm) applied (With Nafion Tubing)	---	Cylinder P: ___ psi
: :	CO_2 Reading		
: :	NH_3 (______ ppm) applied	---	Cylinder P: ___ psi
: :	NH_3 Reading		
: :	CH_4 (______ ppm) applied	---	Cylinder P: ___ psi
	CH_4 Reading		
: :	Propane (______ ppm) applied	---	Cylinder P: ___ psi
	Propane Reading		
: :	N_2O (______ ppm) applied	---	Cylinder P: ___ psi
	N_2O Reading		
: :	New Calibration	Yes/No	
: :	Zero air applied		
: :	Zero humidity air applied		
: :	NH_3 applied		
: :	CO_2 applied (With Nafion Tubing)		
: :	Propane applied		
: :	CH_4 applied		
: :	N_2O applied		
: :	Download to Bank	Yes/No	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

☐ VIG 200 check

Time	Items	Unit =	Notes
: :	Ambient pressure, (mm Hg)		
	Sample airflow (L/min)		
: :	Zero air applied	---	Cylinder P: ___ psi
: :	Total Reading		
: :	CH_4 Reading		
: :	Propane Reading		
: :	CH_4 (______ ppm) applied	---	Cylinder P: ___ psi
	CH_4 Reading		
: :	Propane (______ ppm) applied	---	Cylinder P: ___ psi
	Propane Reading		
: :	New Calibration	Yes/No	
: :	Zero air applied		
	Total adjustment: CH_4 adjustment: Propane adjustment:		
	Total Reading: CH_4 Reading: Propane Reading:		
: :	CH_4 applied		
	Total adjustment: CH_4 adjustment: Propane adjustment:		
	Total Reading: CH_4 Reading: Propane Reading:		
: :	Propane applied		
	Total adjustment: CH_4 adjustment: Propane adjustment:		
	Total Reading: CH_4 Reading: Propane Reading:		
: :	Finish calibration	Yes/No	
: :	Time switch off	---	
: :	Connect analyzer back to sampling system.		
Note:			

☐ **Check all solenoid valves (ON/OFF)**

SV#	NO1	NC1	NO2	NC2	NO3	NC3	NO4	NC4

☐ **Fan current switch check**

Fan #	SW1	SW2	SW3	SW4	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10

☐ **Check airflow rate at 20% of the exhaust fans (randomly selected)**

Fan #	Flow rate, cfm (previous calibration)				Flow rate, cfm				Diff, %
	0.04”	0.08”	0.12”	0.16”	0.04”	0.08”	0.12”	0.16”	

☐ **Replace any critical spare parts utilized during the previous flock**

Part	**Description**	**Note**

☐ **Collect copies of calibration and event log sheets from previous flock and submit to Lara Moody for archiving.**

☐ **Collect litter samples and deliver to ISU for analysis**

Appendix U: Monitoring Equipment Specifics

1. INNOVA 1412 Photoacoustic Field Gas-Monitor

Product Data

1412 Photoacoustic Field Gas-Monitor

USES:

- Indoor Air Quality measurements
- Ventilation measurements using tracer-gas
- Occupational Health and Safety measurements – of possible production or accumulation of toxic/carcinogenic substances in working areas
- Monitoring of anaesthetic agents in hospitals
- Emission monitoring of greenhouse gases from agricultural production
- Emission monitoring of exhaust from chemical processes

FEATURES:

- Selectively measures a wide range of gases/vapours
- Linear response over a wide dynamic range
- High stability (low drift) makes calibration only necessary 1-2 times a year
- Extremely reliable due to self-testing procedures
- User-friendly procedures for calibrating the monitor, presenting and analysing measurement data via the PC user-interface
- Accurate – compensates for temperature and pressure fluctuations, water-vapour interference and interference from other known gases
- Extremely low-volume flushing possible
- Operates immediately – no warm-up time necessary
- Presents measurement data via connected PC both in tabular and graphic formats – up to 5 gas concentration and water vapour graphs displayed, simultaneously

Introduction

The 1412 Photoacoustic Field Gas-Monitor is a highly accurate, reliable and stable quantitative gas monitoring system. It uses a measurement system based on the photoacoustic infra-red detection method, and is capable of measuring almost any gas that absorbs infra-red light.

Gas selectivity is achieved through the use of optical filters. By installing up to 5 of these filters in the 1412, it can measure the concentration of up to 5 component gases and water vapour in any air sample. Although the detection limit is gas-dependent, it is typically in the ppb region. The accuracy of these measurements is ensured by the 1412's ability to compensate for temperature and pressure fluctuations, water-vapour interference and interference from other gases known to be present. Reliability of measurement results can be ensured by regular self-tests, which the 1412 performs. By the nature of this measurement system, it requires no consumables and very little regular maintenance, for example for most applications recalibration is only necessary 1-2 times a year.

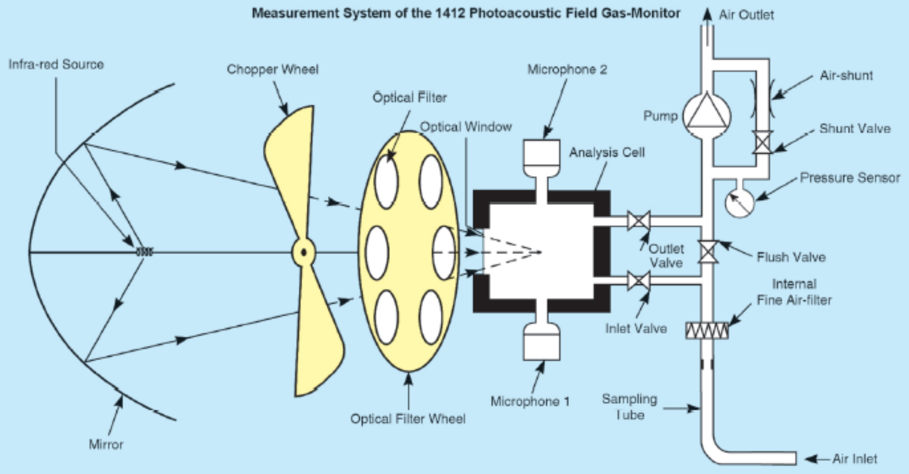
The monitoring system is easily operated through either of the two user interfaces: the front panel with its push-buttons and display providing short explanatory texts, or the PC Software, with its graphical interface. Both interfaces enable the monitor to be set-up, a measurement sequence started and the resulting concentration values of the specified gases viewed while monitoring.

The monitor is equipped with 2 standard interfaces: IEEE-488 and RS-232. These enable the monitor to be integrated into automated process systems. The 1412 has a built-in pump system that allows samples to be drawn from up to 50 m away.

Selectivity

The gas selectivity of the 1412 is determined by the optical filters installed in its filter wheel.

Because water is nearly always present in ambient air and absorbs infra-red light at most wavelengths, it contributes to the total acoustic signal in the analysis cell. Therefore, the monitor is permanently



Measurement System of the 1412 Photoacoustic Field Gas-Monitor

Measurement Cycle

1. The pump draws air from the sampling point through the air-filter to flush out the "old" air in the measurement system and replace it with a "new" air sample. The pressure sensor is used to check that the pump sequence is elapsed successfully and to measure the actual air-pressure.

2. The "new" air sample is hermetically sealed in the analysis cell by closing the inlet and outlet valves.

3. Light from an infra-red light source is reflected off a mirror, passed through a mechanical chopper, which pulsates it, and then through one of the optical filters in the filter wheel.

4. The gas being monitored, causing the temperature of the gas to increase selectively absorbs the light transmitted by the optical filter. Because the light pulsating, the gas temperature increases and decreases, causing an equivalent increase and decrease in the pressure of the gas (an acoustic signal) in the closed cell.

5. Two microphones mounted in the cell wall measure this acoustic signal, which is directly proportional to the concentration of the monitored gas present in the cell.

6. The filter wheel turns so that light is transmitted through the next optical filter, and the new signal is measured. The number of times this is repeated is dependent upon the number of gases being measured.

7. The response time is down to approx. 13 sec. for one gas or water vapour, or approx. 40 sec. if 5 gases and water vapour are measured.

fitted with a special filter, which measures water vapour and enables the 1412 to compensate for watervapour's interference. By selecting different filters, this technique can also be used to cross-compensate for known interferent gases.

Calibration

After the relevant optical filters are installed, the monitor must be calibrated. This is achieved through easy-to-use menudriven instructions. With its high stability, calibration of the 1412, is seldom necessary more than once a year.

Calibration is performed using either the PC Software or directly from the front panel.

Operation

The 1412 monitoring system is easy to operate using either the PC Software or the frontpanel push-keys (which can be locked and accessed at 3 levels using passwords). The monitor can be operated as both an on-line and off-line instrument. Using these user-interfaces with their logical division of information, everything that needs to be defined is achieved prior to starting the monitoring task.

Setting-up the Monitor

The Set-up option enables all the parameters necessary to complete the monitoring task to be defined.

Within this option, the Sample Integration Times (S.I.T.) is set - enabling measurement results to be weighted - sensitivity against speed.

Starting Measurements

Once the set-up parameters have been defined, measurements can be started either immediately or later using a delayed start time. Once started, the monitoring task then continues until it is stopped either manually or using a defined stop time.

Alarms

When measuring, two Alarm trigger levels, which provide high alarm limit 1 and 2 for each measured gas, can be defined. These can also be linked to audible alarms.

Measurement Results

On-line Measurements

Using one or more of the monitor's standard interfaces, measurement results are transferred directly to a PC or control console. Here they can be displayed on screen as real-time values in tables and graphs (see Fig. 1) or integrated into the process system.

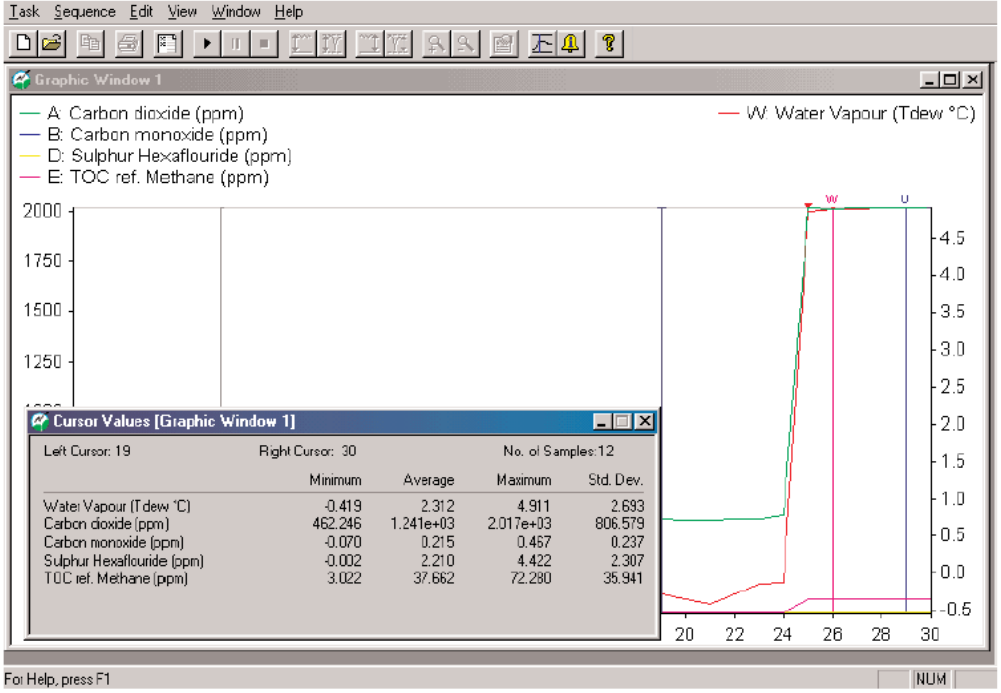
In the PC Software, the graphs can be set up to display only the desired gases, defined concentration ranges and results from statistical analysis.

Also, when using the PC Software, all measurement data is stored in user-defined databases, in a MS-Access format.

Off-line Measurements

Gas-measurement result data is displayed on the 1412's screen (Display Memory) as soon as it is available, and is constantly updated. During a task, the 1412 performs running statistical analysis of the measured gas concentrations, calculating a variety of values for each monitored gas.

The data in Display Memory can be copied to the Background Memory, which is a non-volatile storage area. Data stored in Background Memory can be recalled to Display Memory. From this memory, data can, if necessary, be uploaded to the PC Software and printed out in a list form on any standard text printer via the 1412's IEEE and RS-232 interfaces.



Cursor Values [Graphic Window 1]

Left Cursor: 19 Right Cursor: 30 No. of Samples:12

	Minimum	Average	Maximum	Std. Dev.
Water Vapour (Tdew °C)	-0.419	2.312	4.911	2.693
Carbon dioxide (ppm)	462.246	1.241e+03	2.017e+03	806.579
Carbon monoxide (ppm)	-0.070	0.215	0.467	0.237
Sulphur Hexaflouride (ppm)	-0.002	2.210	4.422	2.307
TOC ref. Methane (ppm)	3.022	37.662	72.280	35.941

Fig.1 Displaying detailed measurement data using the cursors in the graphic or table windows

Reliability

Executive selftest check: software, data integrity, and the 1412's components, to ensure that they function properly. If a fault is found, it is reported in the measurement results, so that the integrity of the results can be ensured.

If the power-supply fails, the 1412 will automatically start-up again when power is restored. Measurement data stored in the monitor's memory is not affected.

Maintenance

The only maintenance tasks necessary are calibration and changing the air-filter. Both tasks are easily performed, and the frequency for changing the air-filter depends on the individual applications.

Remote Control Options

Innova AirTech Instruments offers two additional application software programs, the 7300 Application Software and the 7620 Application Software.

Using 7300, a computer can remotely control a 1412 together with one 1309 Multipoint Sampler for sequentially monitoring air-samples from up to 12 locations.

Using the 7620, a computer can control a 1412 together with up to two 1303 Multipoint Sampler and Doser units. This enables up to 12 locations to be dosed with a tracer-gas and air-samples to be drawn from each location for analysis by the 1412. The software uses the resultant measurements to calculate the air-change or ventilation efficiency of each location.

Ordering Information

1412 Photoacoustic Field Gas-Monitor

Optical filters necessary for the user's monitoring task can be ordered together with the 1412, and installed by *INNOVA*. The 1412 is then delivered zero-point and humidity interference calibrated.

Includes following accessories

AT 2177	PTFE tubing
Mains cable	
WL 0945	RS-232 Interface cable (9pin–25pin) null-modem included

PC Software for Photoacoustic Field Gas-Monitor
Instruction Manual (CD Rom)

Optional Accessories

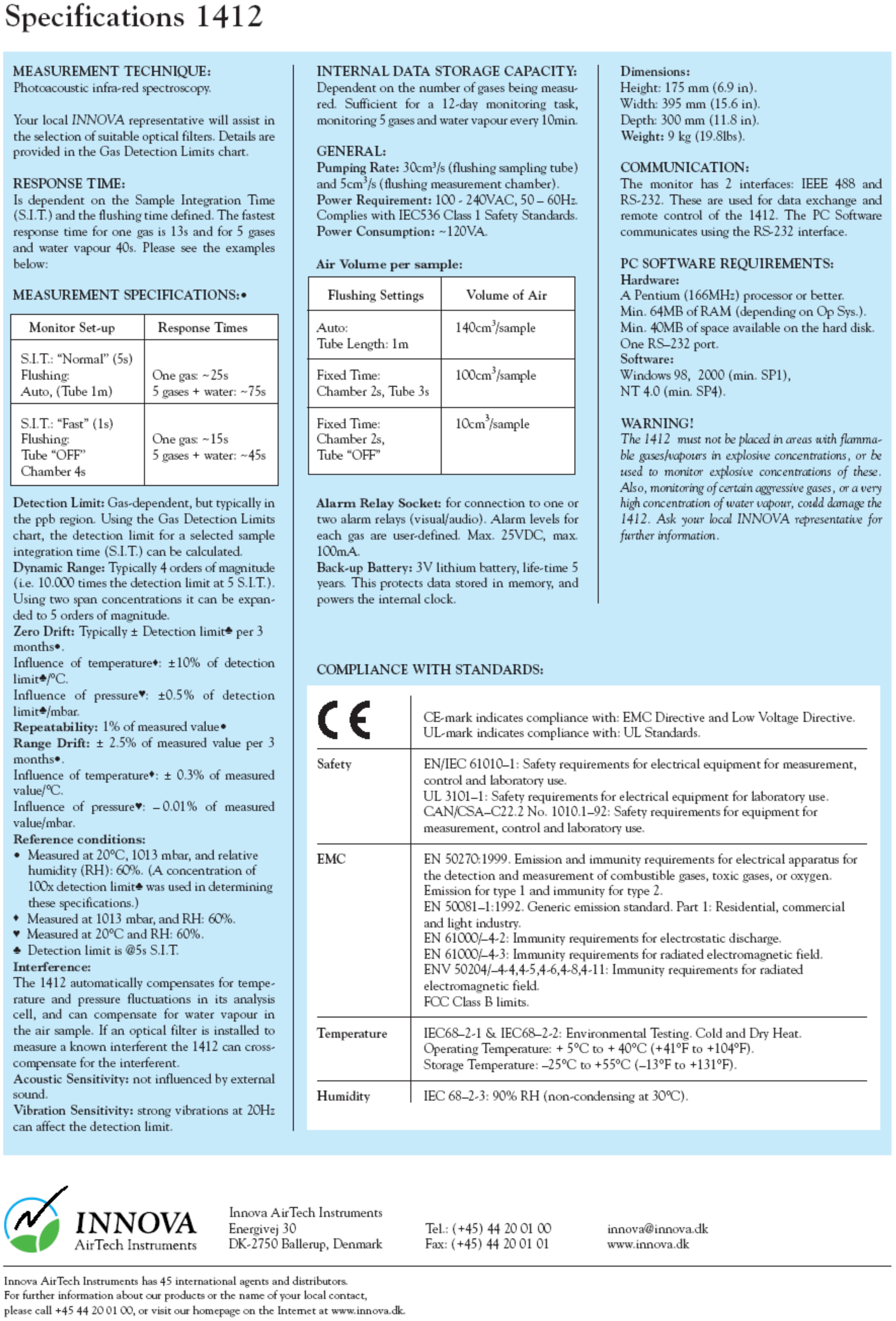
The 1412 can be span-calibrated for certain gases (option UA 1098) — contact your local *INNOVA* representative for details of the gases for which this can be done.

QA 0164	Tweezers

27 optical filters:
UA 0968 – UA 0989 and

UA 0936	Optical Filters
UA 6008	Optical Filter
UA 6009	Optical Filter
UA 6010	Optical Filter
UA 6016	Optical Filter
UA 1098	Span Calibration
UD 5037	Nafion (copolymer of TFE & fluorosuphonyl monomer) tubing
AO 0265	IEEE–IEEE Interface cable
AO 0264	IEEE–IEC 625 Interface cable
WL 0946	RS-232 Interface cable (25pin–25pin) null-modem included
JP 0600	6-pin DIN plug (male) with locking collar for alarm relay
AF 0614	PTFE tubing
UA 1357A	Genie Membrane separator
1303	Multipoint Sampler and Doser
1309	Multipoint Sampler
7300	Application Software
7620	Application Software
BA 6011	Instruction Manual (Printed)

Innova AirTech Instruments A/S reserves the right to change specifications and accessories without notice



Specifications 1412

MEASUREMENT TECHNIQUE:
Photoacoustic infra-red spectroscopy.

Your local *INNOVA* representative will assist in the selection of suitable optical filters. Details are provided in the Gas Detection Limits chart.

RESPONSE TIME:
Is dependent on the Sample Integration Time (S.I.T.) and the flushing time defined. The fastest response time for one gas is 13s and for 5 gases and water vapour 40s. Please see the examples below:

MEASUREMENT SPECIFICATIONS:•

Monitor Set-up	Response Times
S.I.T.: "Normal" (5s) Flushing: Auto, (Tube 1m)	One gas: ~25s 5 gases + water: ~75s
S.I.T.: "Fast" (1s) Flushing: Tube "OFF" Chamber 4s	One gas: ~15s 5 gases + water: ~45s

Detection Limit: Gas-dependent, but typically in the ppb region. Using the Gas Detection Limits chart, the detection limit for a selected sample integration time (S.I.T.) can be calculated.
Dynamic Range: Typically 4 orders of magnitude (i.e. 10.000 times the detection limit at 5 S.I.T.). Using two span concentrations it can be expanded to 5 orders of magnitude.
Zero Drift: Typically ± Detection limit♣ per 3 months•.
Influence of temperature♦: ±10% of detection limit♣/°C.
Influence of pressure♥: ±0.5% of detection limit♣/mbar.
Repeatability: 1% of measured value•
Range Drift: ± 2.5% of measured value per 3 months•.
Influence of temperature♦: ± 0.3% of measured value/°C.
Influence of pressure♥: – 0.01% of measured value/mbar.
Reference conditions:

- Measured at 20°C, 1013 mbar, and relative humidity (RH): 60%. (A concentration of 100x detection limit♣ was used in determining these specifications.)

♦ Measured at 1013 mbar, and RH: 60%.
♥ Measured at 20°C and RH: 60%.
♣ Detection limit is @5s S.I.T.

Interference:
The 1412 automatically compensates for temperature and pressure fluctuations in its analysis cell, and can compensate for water vapour in the air sample. If an optical filter is installed to measure a known interferent the 1412 can cross-compensate for the interferent.
Acoustic Sensitivity: not influenced by external sound.
Vibration Sensitivity: strong vibrations at 20Hz can affect the detection limit.

INTERNAL DATA STORAGE CAPACITY:
Dependent on the number of gases being measured. Sufficient for a 12-day monitoring task, monitoring 5 gases and water vapour every 10min.

GENERAL:
Pumping Rate: 30cm^3/s (flushing sampling tube) and 5cm^3/s (flushing measurement chamber).
Power Requirement: 100 - 240VAC, 50 – 60Hz.
Complies with IEC536 Class 1 Safety Standards.
Power Consumption: ~120VA.

Air Volume per sample:

Flushing Settings	Volume of Air
Auto: Tube Length: 1m	140cm^3/sample
Fixed Time: Chamber 2s, Tube 3s	100cm^3/sample
Fixed Time: Chamber 2s, Tube "OFF"	10cm^3/sample

Alarm Relay Socket: for connection to one or two alarm relays (visual/audio). Alarm levels for each gas are user-defined. Max. 25VDC, max. 100mA.
Back-up Battery: 3V lithium battery, life-time 5 years. This protects data stored in memory, and powers the internal clock.

Dimensions:
Height: 175 mm (6.9 in).
Width: 395 mm (15.6 in).
Depth: 300 mm (11.8 in).
Weight: 9 kg (19.8lbs).

COMMUNICATION:
The monitor has 2 interfaces: IEEE 488 and RS-232. These are used for data exchange and remote control of the 1412. The PC Software communicates using the RS-232 interface.

PC SOFTWARE REQUIREMENTS:
Hardware:
A Pentium (166MHz) processor or better.
Min. 64MB of RAM (depending on Op Sys.).
Min. 40MB of space available on the hard disk.
One RS–232 port.
Software:
Windows 98, 2000 (min. SP1),
NT 4.0 (min. SP4).

WARNING!
The 1412 must not be placed in areas with flammable gases/vapours in explosive concentrations, or be used to monitor explosive concentrations of these. Also, monitoring of certain aggressive gases, or a very high concentration of water vapour, could damage the 1412. Ask your local INNOVA representative for further information.

COMPLIANCE WITH STANDARDS:

CE	CE-mark indicates compliance with: EMC Directive and Low Voltage Directive. UL-mark indicates compliance with: UL Standards.
Safety	EN/IEC 61010–1: Safety requirements for electrical equipment for measurement, control and laboratory use. UL 3101–1: Safety requirements for electrical equipment for laboratory use. CAN/CSA–C22.2 No. 1010.1–92: Safety requirements for equipment for measurement, control and laboratory use.
EMC	EN 50270:1999. Emission and immunity requirements for electrical apparatus for the detection and measurement of combustible gases, toxic gases, or oxygen. Emission for type 1 and immunity for type 2. EN 50081–1:1992. Generic emission standard. Part 1: Residential, commercial and light industry. EN 61000/–4-2: Immunity requirements for electrostatic discharge. EN 61000/–4-3: Immunity requirements for radiated electromagnetic field. ENV 50204/–4-4,4-5,4-6,4-8,4-11: Immunity requirements for radiated electromagnetic field. FCC Class B limits.
Temperature	IEC68–2-1 & IEC68–2-2: Environmental Testing. Cold and Dry Heat. Operating Temperature: + 5°C to + 40°C (+41°F to +104°F). Storage Temperature: –25°C to +55°C (–13°F to +131°F).
Humidity	IEC 68–2-3: 90% RH (non-condensing at 30°C).

INNOVA
AirTech Instruments

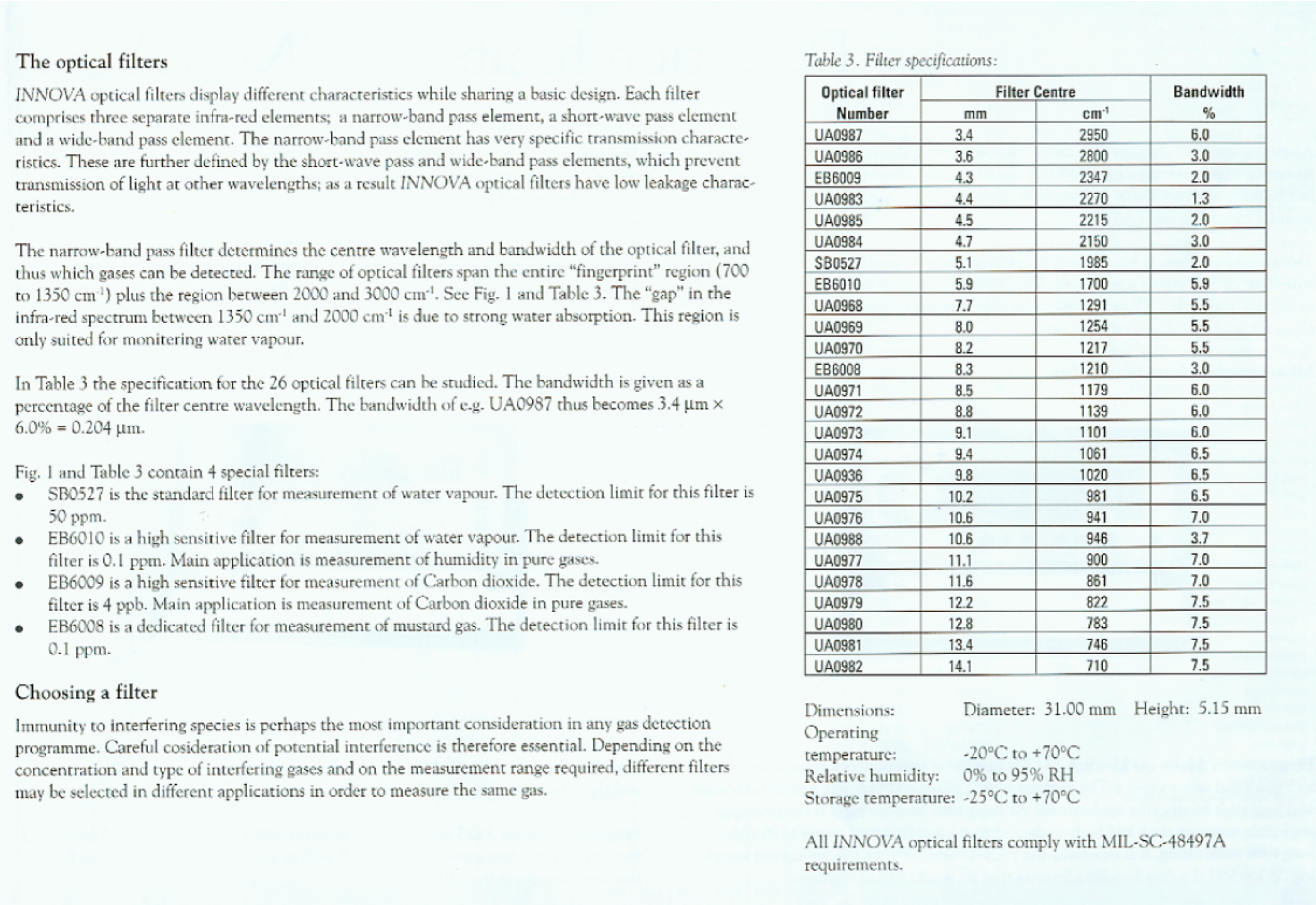
Innova AirTech Instruments
Energivej 30
DK-2750 Ballerup, Denmark

Tel.: (+45) 44 20 01 00
Fax: (+45) 44 20 01 01

innova@innova.dk
www.innova.dk

Innova AirTech Instruments has 45 international agents and distributors.
For further information about our products or the name of your local contact,
please call +45 44 20 01 00, or visit our homepage on the Internet at www.innova.dk.

2. Optical Filters for INNOVA 1412



The optical filters

INNOVA optical filters display different characteristics while sharing a basic design. Each filter comprises three separate infra-red elements; a narrow-band pass element, a short-wave pass element and a wide-band pass element. The narrow-band pass element has very specific transmission characteristics. These are further defined by the short-wave pass and wide-band pass elements, which prevent transmission of light at other wavelengths; as a result *INNOVA* optical filters have low leakage characteristics.

The narrow-band pass filter determines the centre wavelength and bandwidth of the optical filter, and thus which gases can be detected. The range of optical filters span the entire "fingerprint" region (700 to 1350 cm^{-1}) plus the region between 2000 and 3000 cm^{-1}. See Fig. 1 and Table 3. The "gap" in the infra-red spectrum between 1350 cm^{-1} and 2000 cm^{-1} is due to strong water absorption. This region is only suited for monitering water vapour.

In Table 3 the specification for the 26 optical filters can be studied. The bandwidth is given as a percentage of the filter centre wavelength. The bandwidth of e.g. UA0987 thus becomes 3.4 µm × 6.0% = 0.204 µm.

Fig. 1 and Table 3 contain 4 special filters:

- SB0527 is the standard filter for measurement of water vapour. The detection limit for this filter is 50 ppm.
- EB6010 is a high sensitive filter for measurement of water vapour. The detection limit for this filter is 0.1 ppm. Main application is measurement of humidity in pure gases.
- EB6009 is a high sensitive filter for measurement of Carbon dioxide. The detection limit for this filter is 4 ppb. Main application is measurement of Carbon dioxide in pure gases.
- EB6008 is a dedicated filter for measurement of mustard gas. The detection limit for this filter is 0.1 ppm.

Choosing a filter

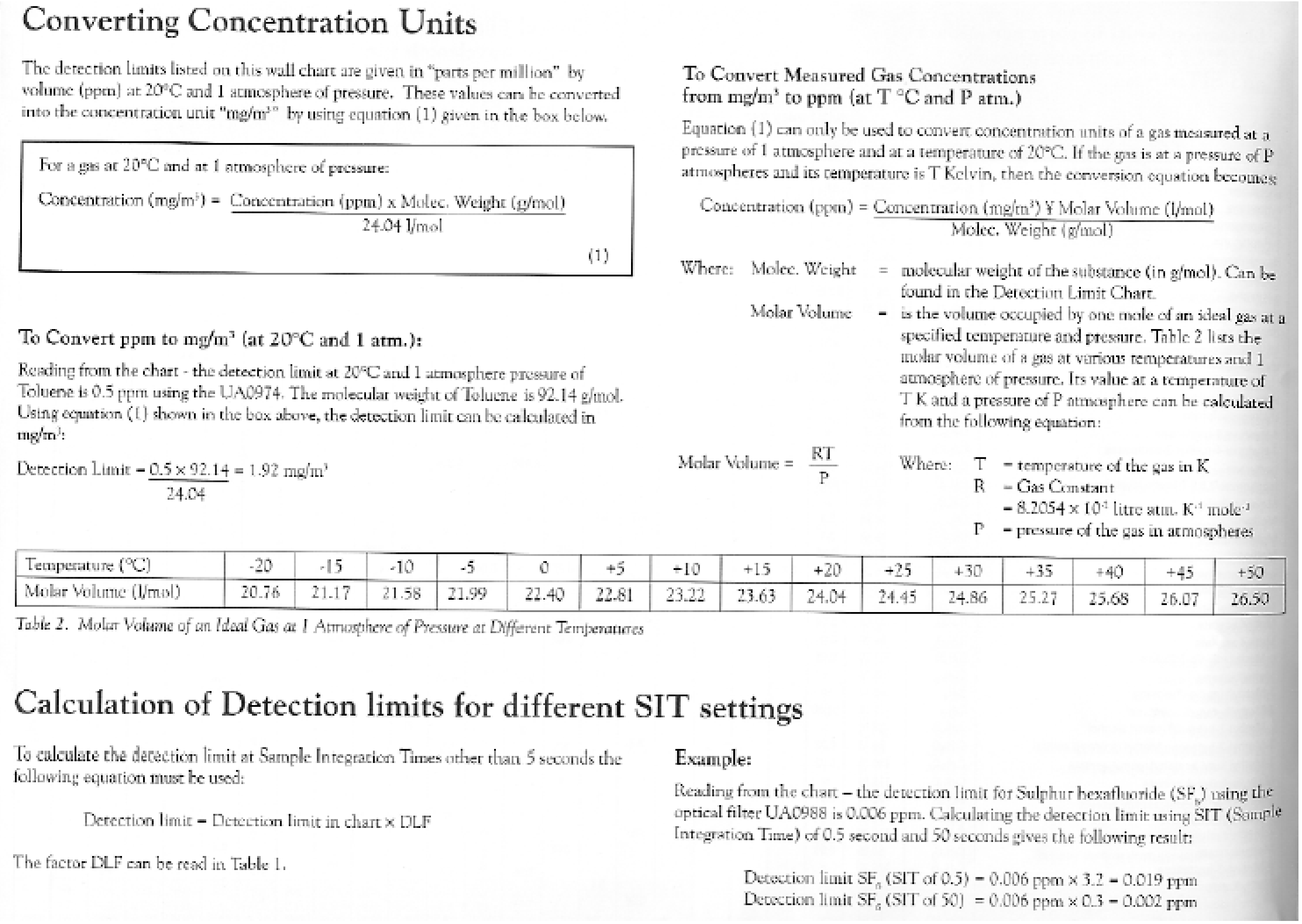
Immunity to interfering species is perhaps the most important consideration in any gas detection programme. Careful cosideration of potential interference is therefore essential. Depending on the concentration and type of interfering gases and on the measurement range required, different filters may be selected in different applications in order to measure the same gas.

Table 3. Filter specifications:

Optical filter Number	Filter Centre		Bandwidth
	mm	cm^{-1}	%
UA0987	3.4	2950	6.0
UA0986	3.6	2800	3.0
EB6009	4.3	2347	2.0
UA0983	4.4	2270	1.3
UA0985	4.5	2215	2.0
UA0984	4.7	2150	3.0
SB0527	5.1	1985	2.0
EB6010	5.9	1700	5.9
UA0968	7.7	1291	5.5
UA0969	8.0	1254	5.5
UA0970	8.2	1217	5.5
EB6008	8.3	1210	3.0
UA0971	8.5	1179	6.0
UA0972	8.8	1139	6.0
UA0973	9.1	1101	6.0
UA0974	9.4	1061	6.5
UA0936	9.8	1020	6.5
UA0975	10.2	981	6.5
UA0976	10.6	941	7.0
UA0988	10.6	946	3.7
UA0977	11.1	900	7.0
UA0978	11.6	861	7.0
UA0979	12.2	822	7.5
UA0980	12.8	783	7.5
UA0981	13.4	746	7.5
UA0982	14.1	710	7.5

Dimensions:	Diameter: 31.00 mm Height: 5.15 mm
Operating temperature:	-20°C to +70°C
Relative humidity:	0% to 95% RH
Storage temperature:	-25°C to +70°C

All *INNOVA* optical filters comply with MIL-SC-48497A requirements.



Converting Concentration Units

The detection limits listed on this wall chart are given in "parts per million" by volume (ppm) at 20°C and 1 atmosphere of pressure. These values can be converted into the concentration unit "mg/m³" by using equation (1) given in the box below.

For a gas at 20°C and at 1 atmosphere of pressure:

$$\text{Concentration (mg/m}^3\text{)} = \frac{\text{Concentration (ppm)} \times \text{Molec. Weight (g/mol)}}{24.04\ \text{l/mol}} \qquad (1)$$

To Convert ppm to mg/m³ (at 20°C and 1 atm.):

Reading from the chart - the detection limit at 20°C and 1 atmosphere pressure of Toluene is 0.5 ppm using the UA0974. The molecular weight of Toluene is 92.14 g/mol. Using equation (1) shown in the box above, the detection limit can be calculated in mg/m³:

$$\text{Detection Limit} = \frac{0.5 \times 92.14}{24.04} = 1.92\ \text{mg/m}^3$$

To Convert Measured Gas Concentrations from mg/m³ to ppm (at T °C and P atm.)

Equation (1) can only be used to convert concentration units of a gas measured at a pressure of 1 atmosphere and at a temperature of 20°C. If the gas is at a pressure of P atmospheres and its temperature is T Kelvin, then the conversion equation becomes:

$$\text{Concentration (ppm)} = \frac{\text{Concentration (mg/m}^3\text{) ¥ Molar Volume (l/mol)}}{\text{Molec. Weight (g/mol)}}$$

Where: Molec. Weight = molecular weight of the substance (in g/mol). Can be found in the Detection Limit Chart.

Molar Volume = is the volume occupied by one mole of an ideal gas at a specified temperature and pressure. Table 2 lists the molar volume of a gas at various temperatures and 1 atmosphere of pressure. Its value at a temperature of T K and a pressure of P atmosphere can be calculated from the following equation:

$$\text{Molar Volume} = \frac{RT}{P}$$

Where:
T = temperature of the gas in K
R = Gas Constant
= 8.2054×10^{-2} litre atm. K^{-1} mole^{-1}
P = pressure of the gas in atmospheres

Temperature (°C)	-20	-15	-10	-5	0	+5	+10	+15	+20	+25	+30	+35	+40	+45	+50
Molar Volume (l/mol)	20.76	21.17	21.58	21.99	22.40	22.81	23.22	23.63	24.04	24.45	24.86	25.27	25.68	26.07	26.50

Table 2. Molar Volume of an Ideal Gas at 1 Atmosphere of Pressure at Different Temperatures

Calculation of Detection limits for different SIT settings

To calculate the detection limit at Sample Integration Times other than 5 seconds the following equation must be used:

Detection limit = Detection limit in chart × DLF

The factor DLF can be read in Table 1.

Example:

Reading from the chart – the detection limit for Sulphur hexafluoride (SF_6) using the optical filter UA0988 is 0.006 ppm. Calculating the detection limit using SIT (Sample Integration Time) of 0.5 second and 50 seconds gives the following result:

Detection limit SF_6 (SIT of 0.5) = 0.006 ppm × 3.2 = 0.019 ppm
Detection limit SF_6 (SIT of 50) = 0.006 ppm × 0.3 = 0.002 ppm

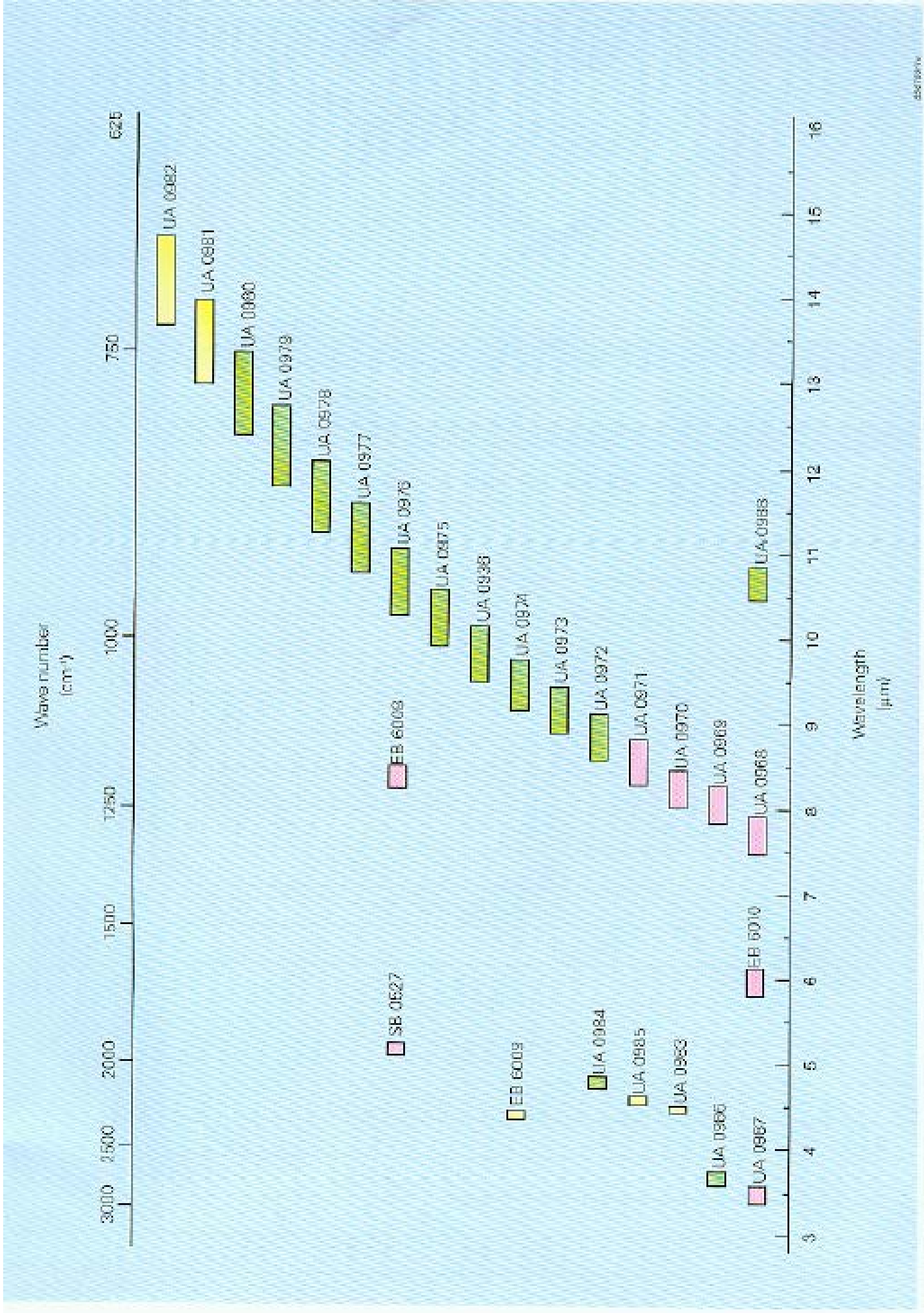
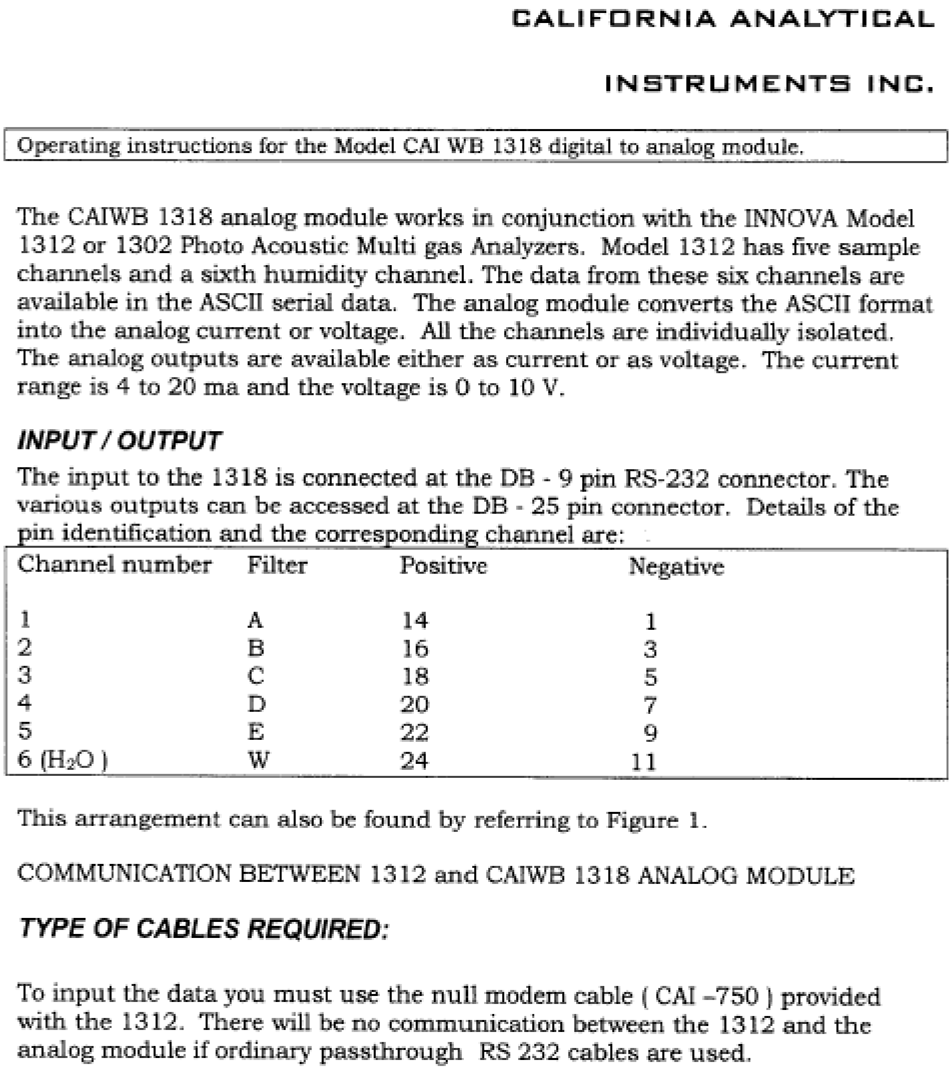


Fig. 1 Centre Wavelengths and Half-power Bandwidths of the INNOVA Optical Filters

3. California Analytical Digital to Analog Module for INNOVA



CALIFORNIA ANALYTICAL

INSTRUMENTS INC.

Operating instructions for the Model CAI WB 1318 digital to analog module.

The CAIWB 1318 analog module works in conjunction with the INNOVA Model 1312 or 1302 Photo Acoustic Multi gas Analyzers. Model 1312 has five sample channels and a sixth humidity channel. The data from these six channels are available in the ASCII serial data. The analog module converts the ASCII format into the analog current or voltage. All the channels are individually isolated. The analog outputs are available either as current or as voltage. The current range is 4 to 20 ma and the voltage is 0 to 10 V.

INPUT / OUTPUT

The input to the 1318 is connected at the DB - 9 pin RS-232 connector. The various outputs can be accessed at the DB - 25 pin connector. Details of the pin identification and the corresponding channel are:

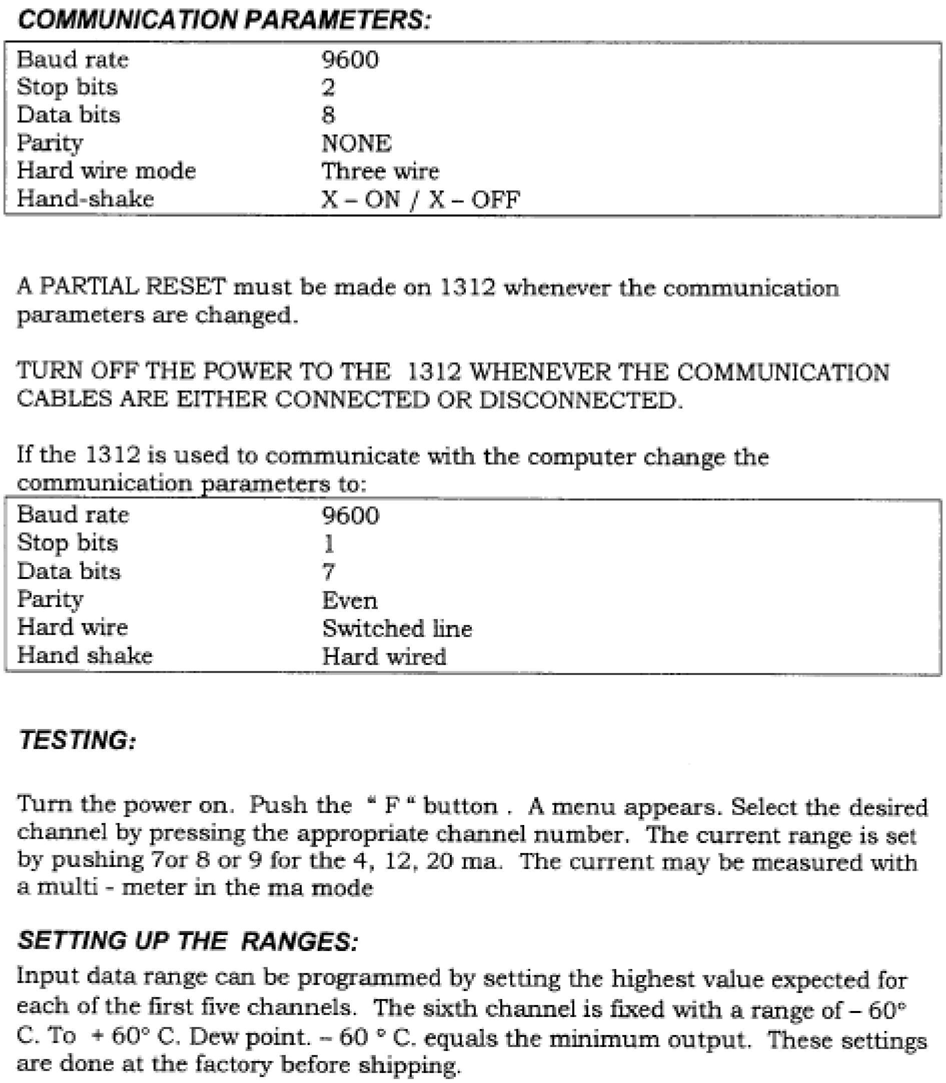
Channel number	Filter	Positive	Negative
1	A	14	1
2	B	16	3
3	C	18	5
4	D	20	7
5	E	22	9
6 (H_2O)	W	24	11

This arrangement can also be found by referring to Figure 1.

COMMUNICATION BETWEEN 1312 and CAIWB 1318 ANALOG MODULE

TYPE OF CABLES REQUIRED:

To input the data you must use the null modem cable (CAI –750) provided with the 1312. There will be no communication between the 1312 and the analog module if ordinary passthrough RS 232 cables are used.



COMMUNICATION PARAMETERS:

Baud rate	9600
Stop bits	2
Data bits	8
Parity	NONE
Hard wire mode	Three wire
Hand-shake	X – ON / X – OFF

A PARTIAL RESET must be made on 1312 whenever the communication parameters are changed.

TURN OFF THE POWER TO THE 1312 WHENEVER THE COMMUNICATION CABLES ARE EITHER CONNECTED OR DISCONNECTED.

If the 1312 is used to communicate with the computer change the communication parameters to:

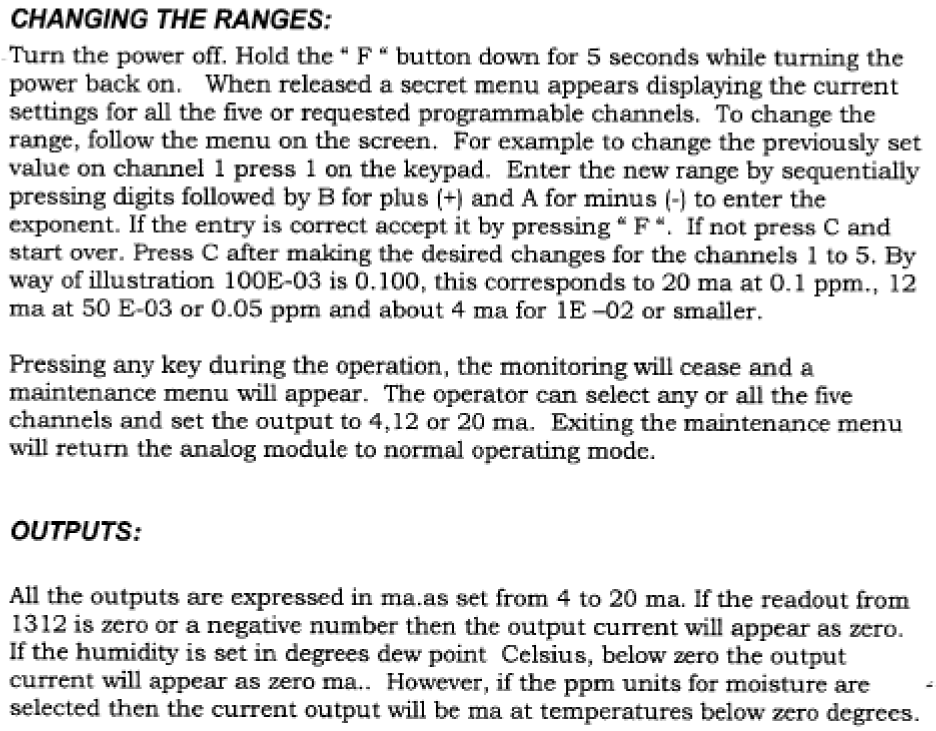
Baud rate	9600
Stop bits	1
Data bits	7
Parity	Even
Hard wire	Switched line
Hand shake	Hard wired

TESTING:

Turn the power on. Push the " F " button . A menu appears. Select the desired channel by pressing the appropriate channel number. The current range is set by pushing 7or 8 or 9 for the 4, 12, 20 ma. The current may be measured with a multi - meter in the ma mode

SETTING UP THE RANGES:

Input data range can be programmed by setting the highest value expected for each of the first five channels. The sixth channel is fixed with a range of – 60° C. To + 60° C. Dew point. – 60 ° C. equals the minimum output. These settings are done at the factory before shipping.



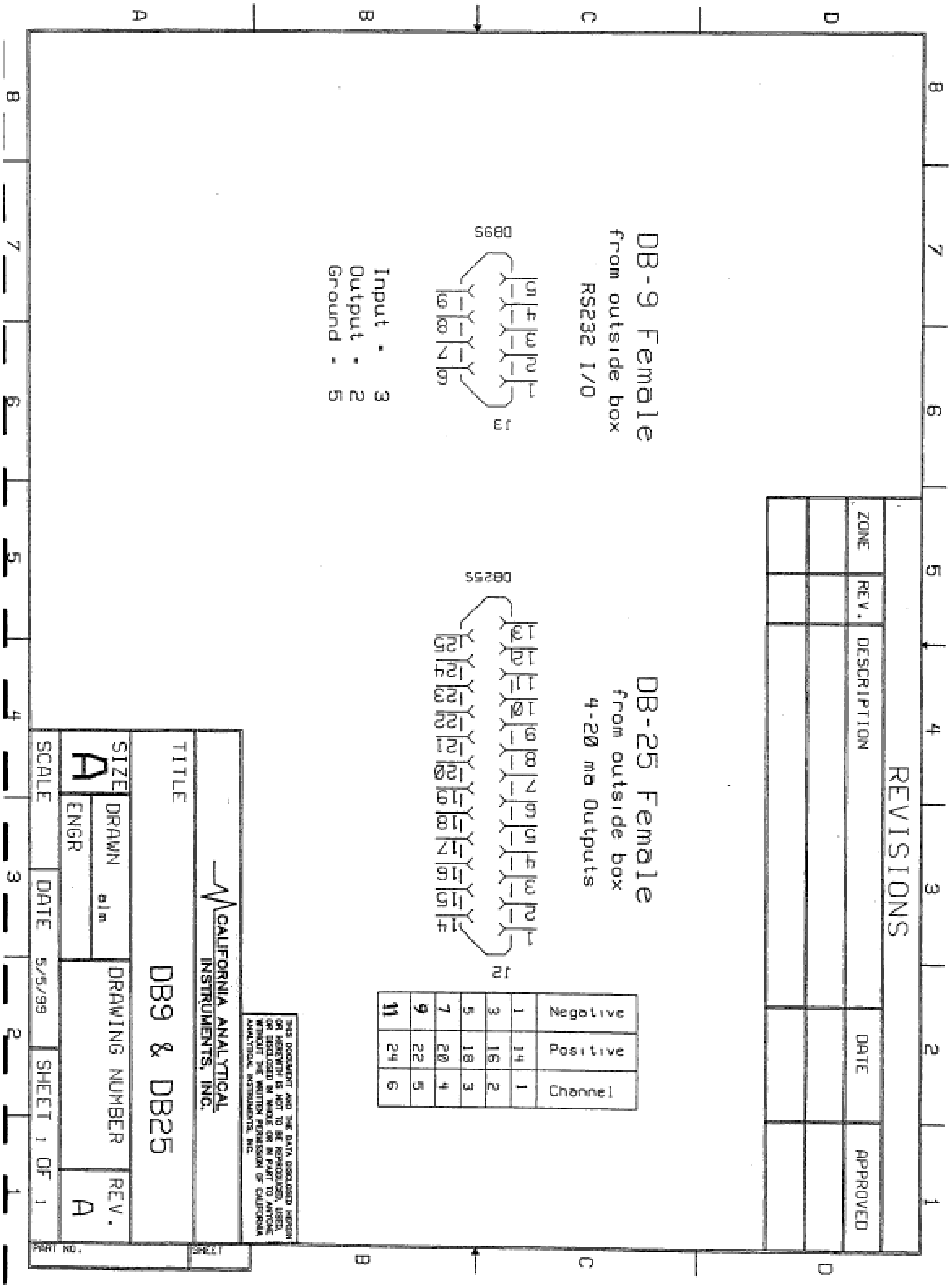
CHANGING THE RANGES:

Turn the power off. Hold the " F " button down for 5 seconds while turning the power back on. When released a secret menu appears displaying the current settings for all the five or requested programmable channels. To change the range, follow the menu on the screen. For example to change the previously set value on channel 1 press 1 on the keypad. Enter the new range by sequentially pressing digits followed by B for plus (+) and A for minus (-) to enter the exponent. If the entry is correct accept it by pressing " F ". If not press C and start over. Press C after making the desired changes for the channels 1 to 5. By way of illustration 100E-03 is 0.100, this corresponds to 20 ma at 0.1 ppm., 12 ma at 50 E-03 or 0.05 ppm and about 4 ma for 1E –02 or smaller.

Pressing any key during the operation, the monitoring will cease and a maintenance menu will appear. The operator can select any or all the five channels and set the output to 4,12 or 20 ma. Exiting the maintenance menu will return the analog module to normal operating mode.

OUTPUTS:

All the outputs are expressed in ma.as set from 4 to 20 ma. If the readout from 1312 is zero or a negative number then the output current will appear as zero. If the humidity is set in degrees dew point Celsius, below zero the output current will appear as zero ma.. However, if the ppm units for moisture are selected then the current output will be ma at temperatures below zero degrees.



Negative	Positive	Channel
1	14	1
3	16	2
5	18	3
7	20	4
9	22	5
11	24	6

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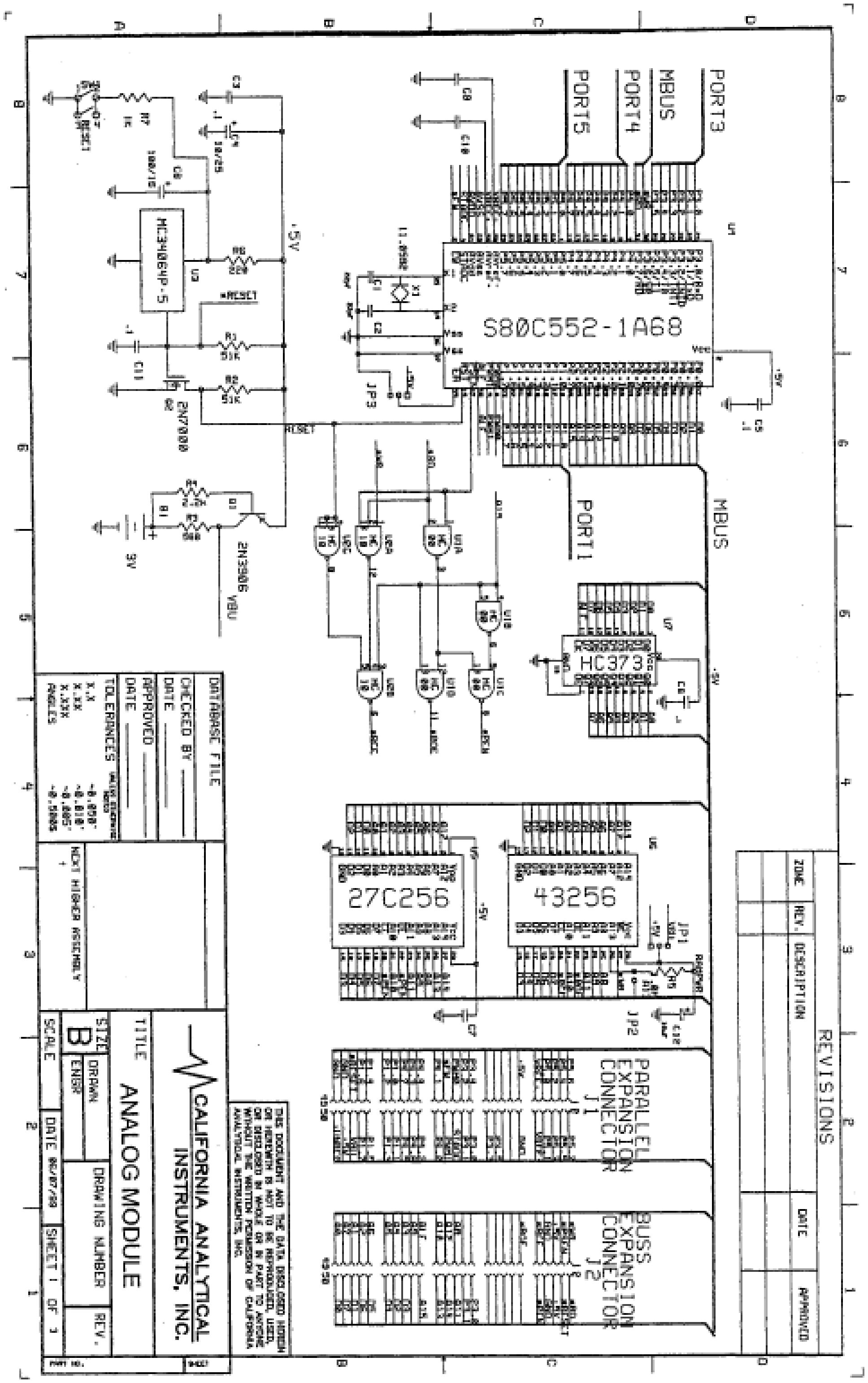
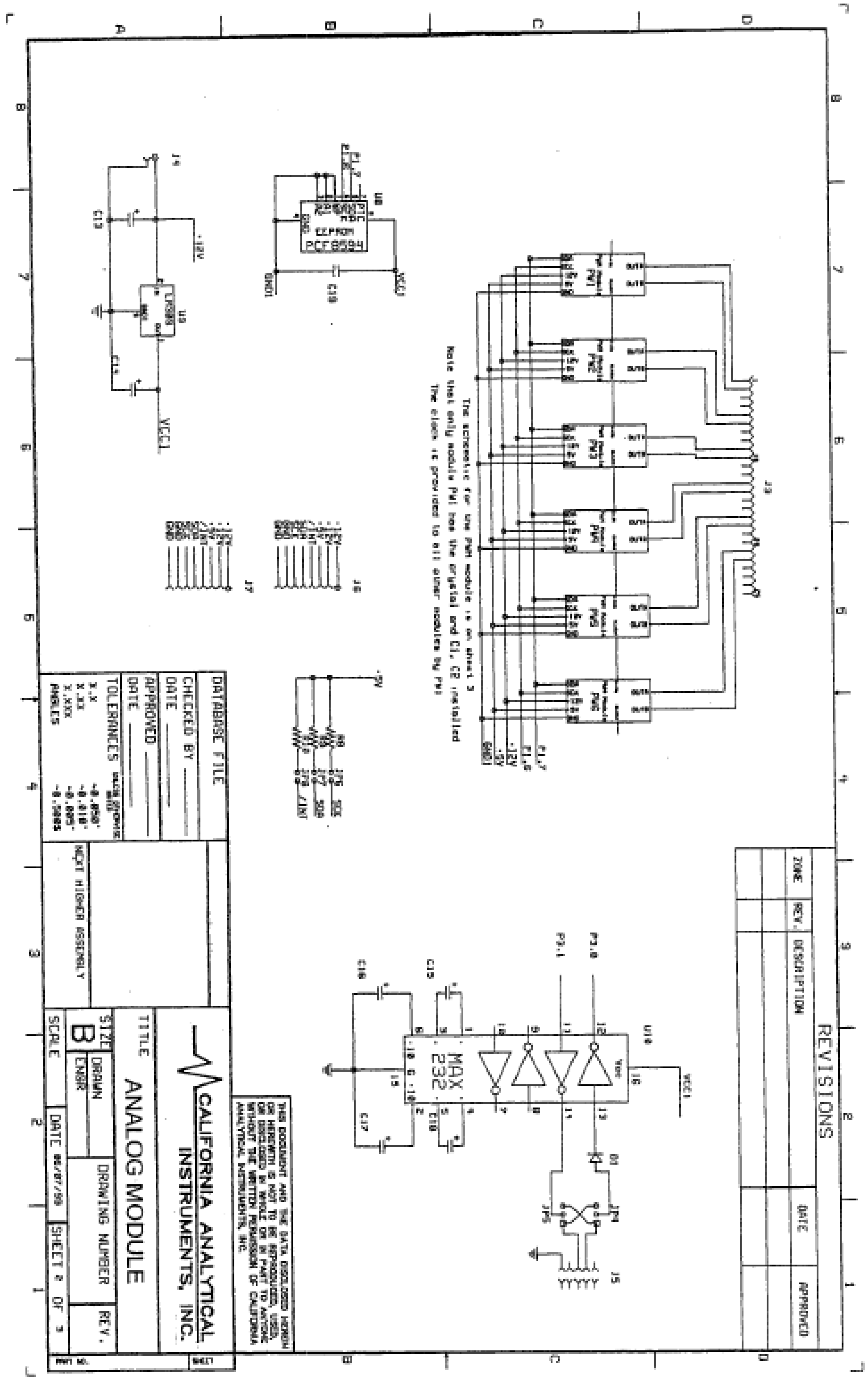
TITLE DB9 & DB25
SIZE A
DRAWN alm
ENGR
DRAWING NUMBER
REV. A
SCALE
DATE 5/5/99
SHEET 1 OF 1


PORT3
MBUS
PORT4
PORT5
S80C552-1A68
U1
11.0592
X1
JP3
+5V
MC34064P-5
U3
2N7000
Q2
RESET
2N3906
9V
B1
PORT1
MBUS
HC373
U7
27C256
43256
U6
JP1
JP2
PARALLEL EXPANSION CONNECTOR J1
BUSS EXPANSION CONNECTOR J2
REVISIONS
ZONE
REV.
DESCRIPTION
DATE
APPROVED
DATABASE FILE
CHECKED BY
DATE
APPROVED
DATE
TOLERANCES
NEXT HIGHER ASSEMBLY
CALIFORNIA ANALYTICAL INSTRUMENTS, INC.
TITLE
ANALOG MODULE
SIZE
B
DRAWN
ENGR
DRAWING NUMBER
REV.
SCALE
DATE 06/07/89
SHEET 1 OF 3


REVISIONS
ZONE
REV.
DESCRIPTION
DATE
APPROVED
The schematic for the PWM module is on sheet 3
Note that only module PW1 has the crystal and C1, C2 installed
The clock is provided to all other modules by PW1
PW1
PW2
PW3
PW4
PW5
PW6
J3
J4
J5
J6
J7
U8
EEPROM
PCF8594
U9
LM309
U10
MAX 232
VCC1
GND1
-12V
-5V
C13
C14
C15
C16
C17
C18
C19
D1
JP4
JP5
P3.0
P3.1
DATABASE FILE
CHECKED BY
DATE
APPROVED
DATE
TOLERANCES
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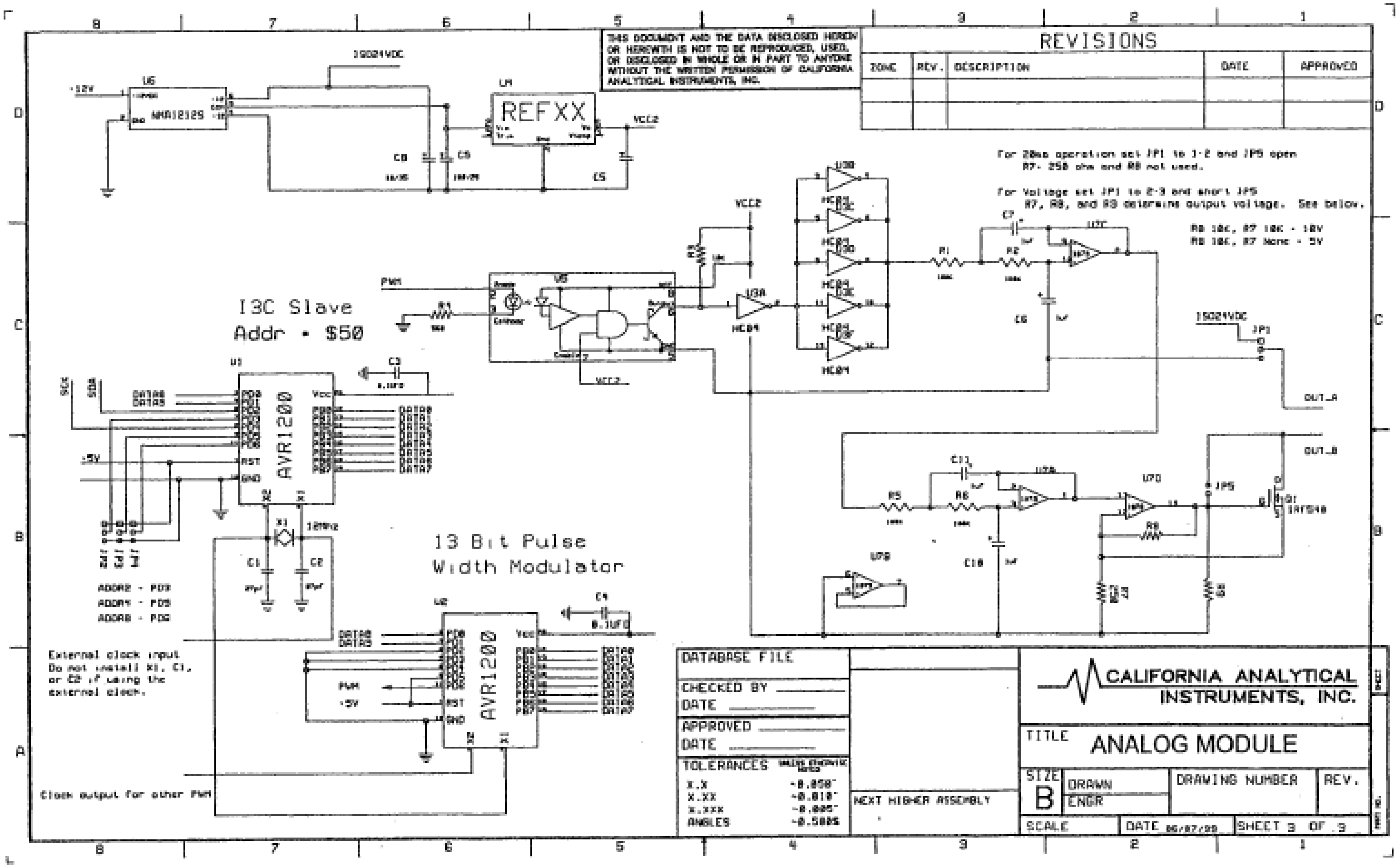
NEXT HIGHER ASSEMBLY
CALIFORNIA ANALYTICAL INSTRUMENTS, INC.
TITLE
ANALOG MODULE
SIZE
B
DRAWN
ENGR
DRAWING NUMBER
REV.
SCALE
DATE
SHEET 2 OF 3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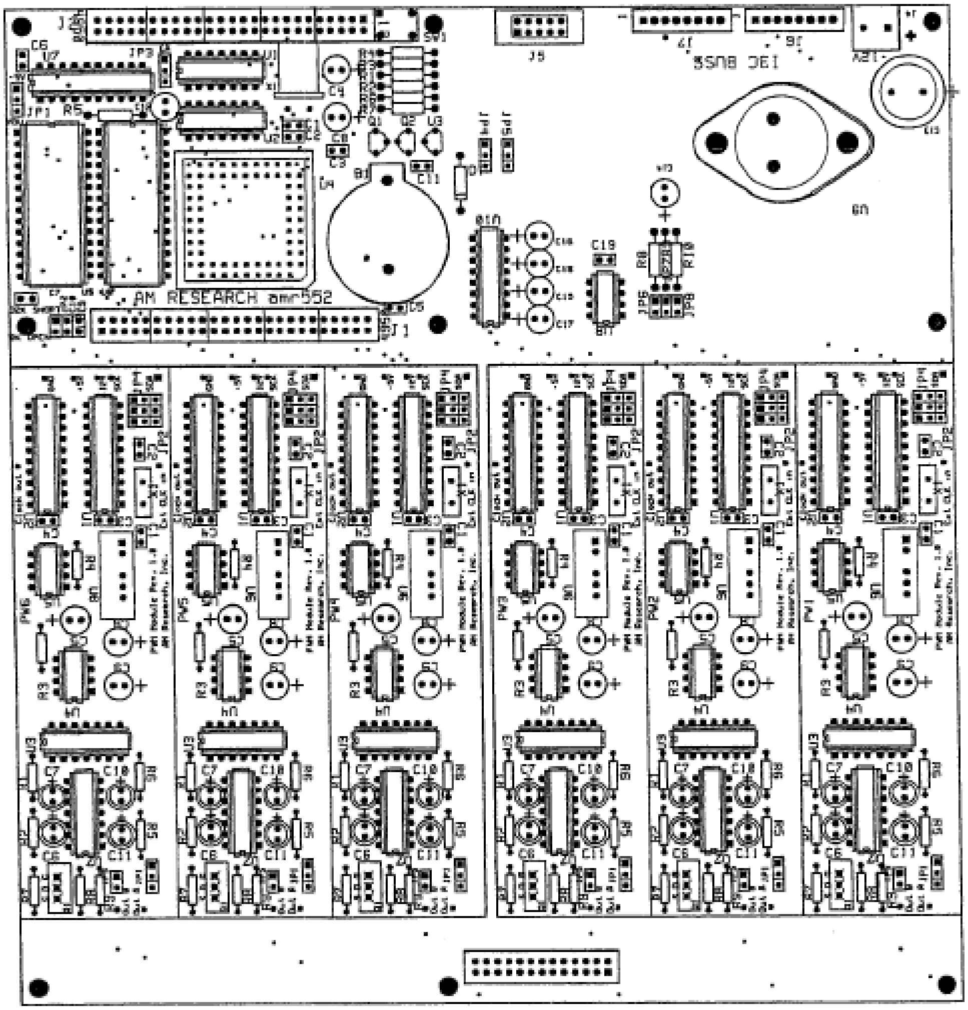
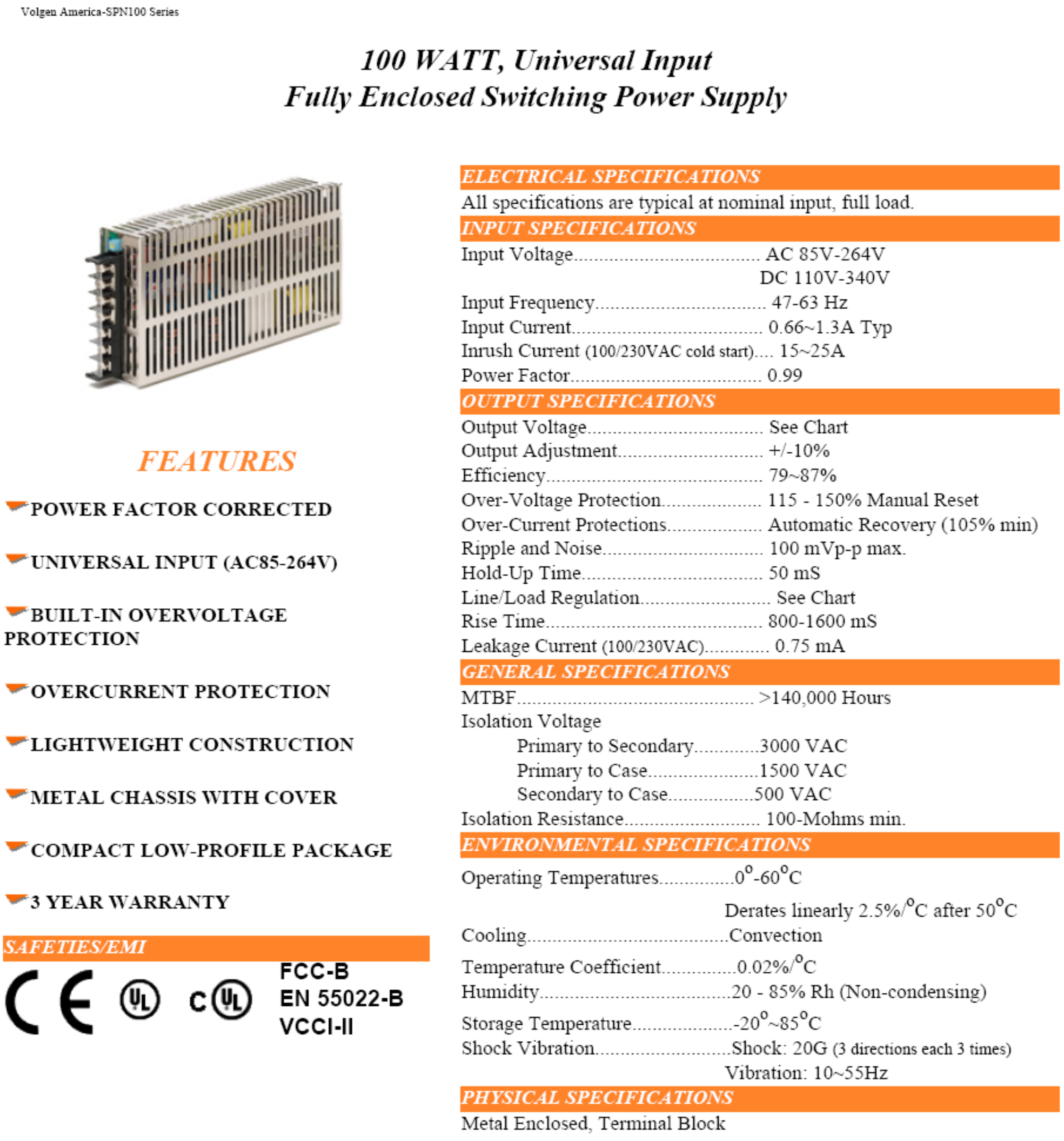
REVISIONS
ZONE
REV.
DESCRIPTION
DATE
APPROVED
For 20ma operation set JP1 to 1-2 and JP5 open
R7- 250 ohm and R8 not used.
For Voltage set JP1 to 2-3 and short JP5
R7, R8, and R9 determine output voltage. See below.
R8 10K, R7 10K - 10V
R8 10K, R7 None - 5V
+12V
U6
NMA1212S
ISO24VDC
U4
REFXX
VCC2
C8
C9
C5
I3C Slave
Addr - $50
U1
AVR1200
SCK
SDA
DATA8
DATA9
+5V
RST
GND
X1
X2
12MHz
C1
C2
C3
0.1UFD
DATA0
DATA1
DATA2
DATA3
DATA4
DATA5
DATA6
DATA7
JP2
JP3
JP4
ADDR2 - PD3
ADDR4 - PD5
ADDR8 - PD6
13 Bit Pulse
Width Modulator
U2
AVR1200
C4
0.1UFD
PWM
+5V
External clock input
Do not install X1, C1,
or C2 if using the
external clock.
Clock output for other PWM
PWM
R4
U5
U3A
HC04
U3B
U3C
U3D
U3E
U3F
R3
R1
R2
C7
U7C
C6
JP1
OUT_A
OUT_B
JP5
Q1
IRF540
C11
R5
R6
U7A
C10
U7D
R8
U7B
R9
R7
DATABASE FILE
CHECKED BY
DATE
APPROVED
DATE
TOLERANCES
X.X -0.050"
X.XX -0.010"
X.XXX -0.005"
ANGLES -0.5005
NEXT HIGHER ASSEMBLY
CALIFORNIA ANALYTICAL INSTRUMENTS, INC.
TITLE
ANALOG MODULE
SIZE
B
DRAWN
ENGR
DRAWING NUMBER
REV.
SCALE
DATE 06/07/99
SHEET 3 OF 3


AM RESEARCH amr552
J5
J6
J7
SW1
JP1
JP3
R5
C4
C8
C9
C11
B1
U4
U6
U9
U10
C19
R8
R10
JP5
JP6
JP8
D5
J1
PW1
PW2
PW3
PW4
PW5
PW6
C6
C7
C10
C11
R3
R5
R6
U3

4. Volgen America Switching Power Supply



Volgen America-SPN100 Series

100 WATT, Universal Input
Fully Enclosed Switching Power Supply

FEATURES

- **POWER FACTOR CORRECTED**
- **UNIVERSAL INPUT (AC85-264V)**
- **BUILT-IN OVERVOLTAGE PROTECTION**
- **OVERCURRENT PROTECTION**
- **LIGHTWEIGHT CONSTRUCTION**
- **METAL CHASSIS WITH COVER**
- **COMPACT LOW-PROFILE PACKAGE**
- **3 YEAR WARRANTY**

SAFETIES/EMI

FCC-B
EN 55022-B
VCCI-II

ELECTRICAL SPECIFICATIONS

All specifications are typical at nominal input, full load.

INPUT SPECIFICATIONS

Input Voltage	AC 85V-264V DC 110V-340V
Input Frequency	47-63 Hz
Input Current	0.66~1.3A Typ
Inrush Current (100/230VAC cold start)	15~25A
Power Factor	0.99

OUTPUT SPECIFICATIONS

Output Voltage	See Chart
Output Adjustment	+/-10%
Efficiency	79~87%
Over-Voltage Protection	115 - 150% Manual Reset
Over-Current Protections	Automatic Recovery (105% min)
Ripple and Noise	100 mVp-p max.
Hold-Up Time	50 mS
Line/Load Regulation	See Chart
Rise Time	800-1600 mS
Leakage Current (100/230VAC)	0.75 mA

GENERAL SPECIFICATIONS

MTBF	>140,000 Hours
Isolation Voltage	
Primary to Secondary	3000 VAC
Primary to Case	1500 VAC
Secondary to Case	500 VAC
Isolation Resistance	100-Mohms min.

ENVIRONMENTAL SPECIFICATIONS

Operating Temperatures	0°-60°C Derates linearly 2.5%/°C after 50°C
Cooling	Convection
Temperature Coefficient	0.02%/°C
Humidity	20 - 85% Rh (Non-condensing)
Storage Temperature	-20°~85°C
Shock Vibration	Shock: 20G (3 directions each 3 times) Vibration: 10~55Hz

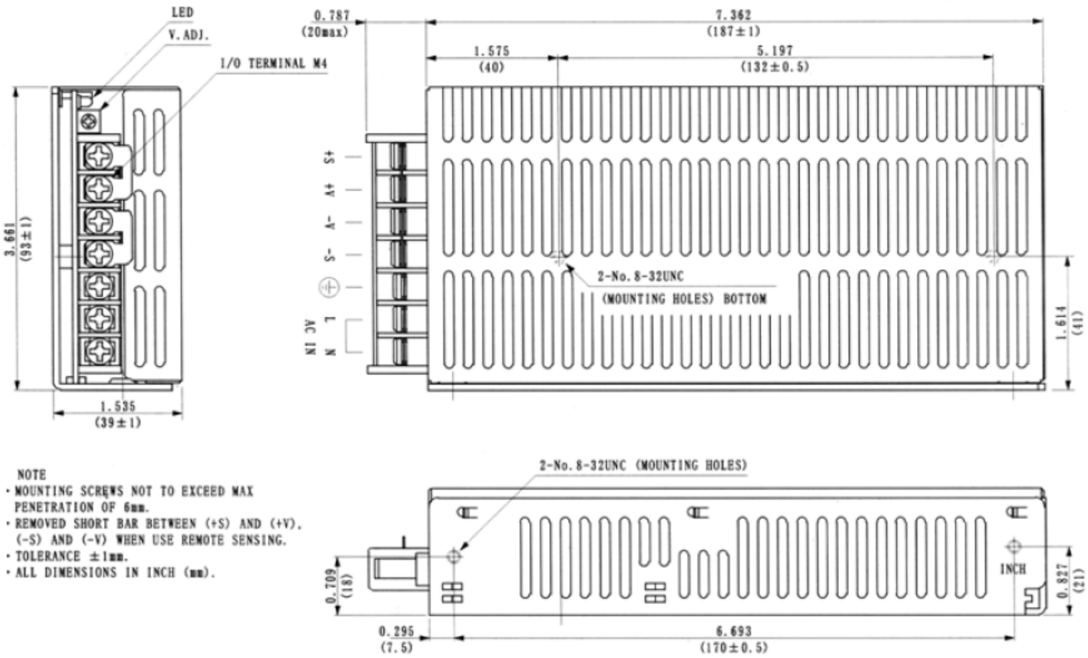
PHYSICAL SPECIFICATIONS

Metal Enclosed, Terminal Block

MODEL	OUTPUT VOLTAGE	CURRENT 85~264 VAC	OUTPUT CURRENT		LINE REGULATION (85~132VAC) (170~264VAC)	LOAD REGULATION (mVmax) (0-100% Load)
			100VAC	230VAC		
SPN100-05S	5V	20.0 A	79%	81%	10	20
SPN100-12S	12V	8.6 A	83%	85%	10	20
SPN100-15S	15V	7.0 A	83%	86%	10	20
SPN100-24S	24V	4.4 A	83%	86%	20	40
SPN100-48S	48 V	2.2 A	84%	87%	20	40

NOTE:

All specifications typical and nominal/full load and 25°C unless otherwise noted.
Avoid sustained operation in overload or dead short conditions.
Specifications subject to changes without notice.



NOTE
- MOUNTING SCREWS NOT TO EXCEED MAX PENETRATION OF 6mm.
- REMOVED SHORT BAR BETWEEN (+S) AND (+V), (-S) AND (-V) WHEN USE REMOTE SENSING.
- TOLERANCE ±1mm.
- ALL DIMENSIONS IN INCH (mm).

***No. 6-32 mounting holes standard**
***Dimensions in mm**
***Terminal block or "pin"**
type connector available

5. Thomas Diaphragm Pump, Model 107CAB18

DIAPHRAGM

Pumps and Compressors

107 Series

MODELS:

Standard models available.

107CAB18, 107CCD18, 107CEF18, 107CGH18
107CDC20

Other models based on availability and minimum purchase.

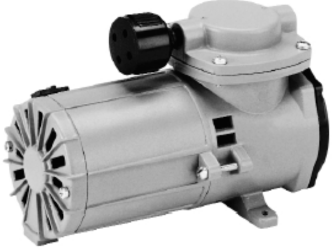
107CAB, CCD

FEATURES (AC& DC):

- Oil-less operation
- Permanently lubricated bearings
- Closed housing and motor vents (107CDC/C only)
- Stainless valves
- Die cast aluminum head, valve plate and diaphragm hold down plate with dichromate conversion treatment
- Balanced for smooth, low vibration operation
- Long-life diaphragm
- Field service capability
- UL® recognized motor and thermal protector (115 Volt, AC only)
- Inlet filter
- CE approval on all standard 220-240/50hz models (Consult factory for non-standard models.)

Consult factory for custom applications

107CEF, CGH



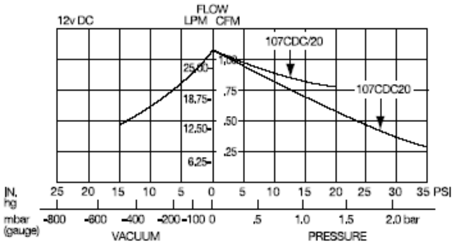
107CDC

ISO 9001 CERTIFIED

THOMAS®
PUMPS & COMPRESSORS

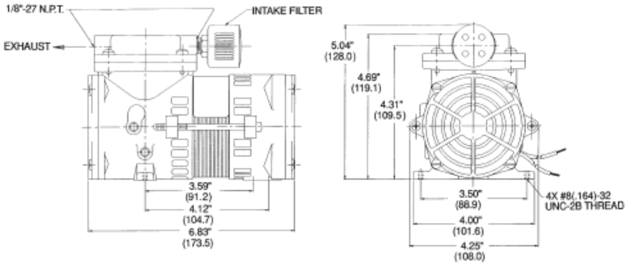
107 SERIES (DC) PERFORMANCE DATA:

		STANDARD			
MODEL NUMBER:		107CDC20		107CDC/C20	
HEAD CONFIGURATION:		Pressure/Vacuum		Pressure/Vacuum	
STROKE:		.200 Inches		.200 Inches	
PRESSURE:		Flow @ 12v		Flow @ 12v	
CFM @ PSI	LPM @ bar				
PSI	bar	CFM	LPM	CFM	LPM
0	0	1.40	39.6	1.40	39.6
5	.5	1.34	35.1	1.34	35.1
10	1.0	1.12	27.1	1.12	27.1
15	1.5	.94	20.2	.94	20.1
20	2.0	.77	14.5	.77	
25	3.0	.61	6.2		
30		.49			
35		.39			
MAX. CONTINUOUS PRESSURE:		35 PSI	2.4 bar	20 PSI	1.4 bar
MAX. INTERMITTENT PRESSURE:		35 PSI	2.4 bar	20 PSI	1.4 bar
VACUUM:		Flow @ 12v		Flow @ 12v	
CFM @ IN. hg	LPM @ mbar (gauge)				
IN. hg	mbar (gauge)	CFM	LPM	CFM	LPM
0	0	1.40	39.6	1.40	39.6
5	-100	1.09	34.4	1.09	34.4
10	-200	.80	29.3	.80	29.3
15	-400	.48	19.3	.48	19.3
20	-600		8.6		8.6
25					
MAX. VACUUM:		22.9" hg	-775 mbar	22.9" hg	-775 mbar
MAX. AMBIENT TEMPERATURE:		104°F	40°C	104°F	40°C
MIN. AMBIENT TEMPERATURE:		50°F	10°C	50°F	10°C
MAX. RESTART PRESSURE:		15 PSI	1.0 bar	15 PSI	1.0 bar
MAX. RESTART VACUUM:		22.9" hg	-775 mbar	22.9" hg	-775 mbar
MOTOR VOLTAGE/FREQUENCY:		12v DC		12v DC	
HORSEPOWER:		1/10		1/10	
MOTOR TYPE:		Permanent Magnet		Permanent Magnet	
CURRENT AT RATED LOAD (AMPS):		8.5		8.5	
POWER AT RATED LOAD (WATTS):					
STARTING CURRENT (LOCKED ROTOR AMPS):		40.0		40.0	
INSULATION CLASS:		A		A	
MIN. FULL LOAD SPEED (RPM):		2970		2970	
THERMAL PROTECTOR:		No		No	
CAPACITOR VALUE:					
NET WEIGHT:		4.5 lbs.	2.0 Kg	4.7 lbs.	2.1 Kg

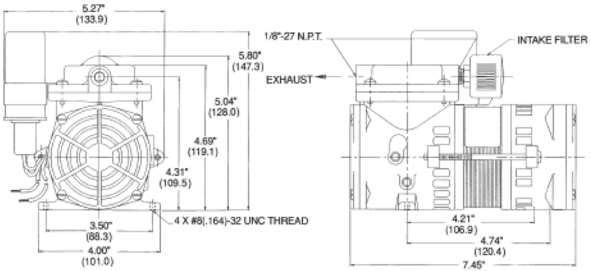


DIMENSIONS:

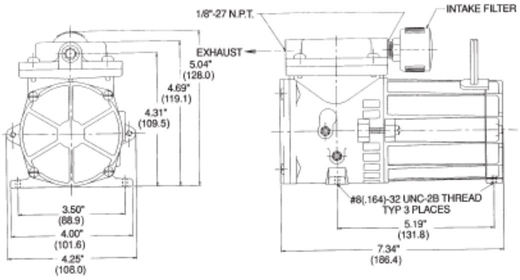
Millimeters are in ( )



107CAB, CCD



107CEF, CGH



107CDC & 107CDC/C

NOTE: 107CDC/C has closed motor vents

The information presented in this material is based on technical data and test results of nominal units. It is believed to be accurate and reliable and is offered as an aid to help in the selection of Thomas products. It is the responsibility of the user to determine the suitability of the product for his intended use and the user assumes all risk and liability whatsoever in connection therewith. Thomas Industries does not warrant, guarantee or assume any obligation or liability in connection with this information.

Note: Models pictured are representative of the series and do not represent a specific model number. Consult factory for detailed physical description.

Printed in U.S.A. Form No. 850-2274 9/01

THOMAS®
PUMPS & COMPRESSORS
1419 Illinois Avenue, P.O. Box 29
Sheboygan, WI 53082-0029 USA
(920) 457-4891 Fax (920) 451-4276
Internet: http://www.thomaspumps.com

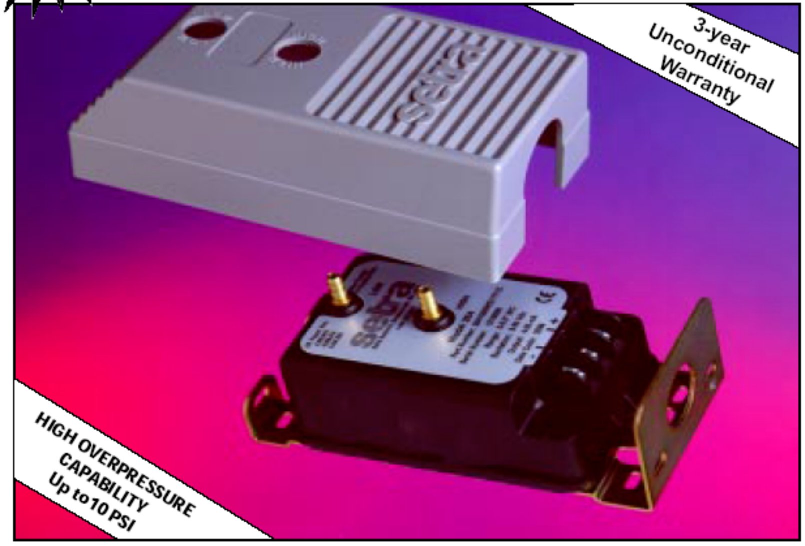
6. Setra Differential Pressure Transducer

GUARANTEED
3 DAY
SHIPMENT
FOR STANDARD PARTS
(less than 10 pieces)

Model 264

Very Low Differential Pressure Transducer

Unidirectional Ranges: 0 - 0.1 to 0 - 100 in. W.C.
Bidirectional Ranges: 0 - ±0.5 to 0 - ±50 in. W.C.
Air or Non-Conducting Gas



Setra Systems 264 pressure transducers sense differential or gauge (static) pressure and convert this pressure difference to a proportional electrical output for either unidirectional or bidirectional pressure ranges. The 264 Series is offered with a high level analog 0 to 5 VDC or 4 to 20 mA output.

Used in Building Energy Management Systems, these transducers are capable of measuring pressures and flows with the accuracy necessary for proper building pressurization and air flow control.

The 264 Series transducers are available for air pressure ranges as low as 0.1 in. W.C. full scale to 100 in. W.C. full scale. Static standard accuracy is ±1.0% full scale in normal ambient temperature environments, but higher accuracies are available. The units are temperature compensated to 0.033% FS/°F thermal error over the temperature range of 0°F to +150°F.

The Model 264 utilizes an improved all stainless steel micro-tig welded sensor. The tensioned stainless steel diaphragm and insulated stainless steel electrode, positioned close to the diaphragm, form a variable capacitor. Positive pressure moves the diaphragm toward the electrode, increasing the capacitance. A decrease in pressure moves the diaphragm away from the electrode, decreasing the capacitance. The change in capacitance is detected and converted to a linear DC electrical signal by Setra's unique electronic circuit.

The tensioned sensor allows up to 10 PSI overpressure (in either direction) with no damage to the unit. In addition, the parts that make up the sensor have thermally matched coefficients, which promote improved temperature performance and excellent long term stability.

NOTE: Setra quality standards are based on ANSI-Z540-1.
The calibration of this product is NIST traceable.

U.S. Patent nos. 4093915; 4358814; 4434203; 6019002; 6014800.
Other Patents Pending.

159 Swanson Rd., Boxborough, MA 01719/Telephone: 978-263-1400/Fax: 978-264-0292

Applications

- Heating, Ventilating and Air Conditioning (HVAC)
- Energy Management Systems
- Variable Air Volume and Fan Control (VAV)
- Environmental Pollution Control
- Lab and Fume Hood Control
- Oven Pressurization and Furnace Draft Controls

Features

- Up to 10 PSI Overpressure on All Ranges
- Installation Time Minimized with Snap Track Mounting and Easy- To-Access Pressure Ports and Electrical Connections
- 0 to 5 VDC or 2-wire 4 to 20 mA Analog Outputs Are Compatible with Energy Management Systems
- Reverse Wiring Protection
- Internal Regulation Permits Use with Unregulated DC Power Supplies
- Meets CE Conformance Standards

When it comes to a product to rely on - choose the Model 264. When it comes to a company to trust - choose Setra.

ISO 9001 Certified

Visit Setra Online:
http://www.setra.com

setra
800-257-3872

Model 264 Specifications

Performance Data

	Standard	Optional	
Accuracy* RSS(at constant temp)	±1.0% FS	±0.4% FS	±0.25% FS
Non-Linearity, BFSL	±0.96% FS	±0.38% FS	±0.22% FS
Hysteresis	0.10% FS	0.10% FS	0.10% FS
Non-Repeatability	0.05% FS	0.05% FS	0.05%FS

Thermal Effects**	
Compensated Range °F(°C)	0 to +150 (-18 to +65)
Zero/Span Shift %FS/°F(°C)	0.033 (0.06)
Maximum Line Pressure	10 psi
Overpressure	Up to 10 psi in Positive or Negative Direction.
Long Term Stability	0.5% FS/1 YR

Position Effect	Range	Zero Offset (%FS/G)
(Unit is factory calibrated at 0g effect in the vertical position.)	To 0.5 in. WC	0.60
	To 1.0 in.WC	0.50
	To 2.5 in.WC	0.22
	To 5 in. WC	0.14

* RSS of Non-Linearity,Hysteresis,and Non-Repeatability.
**Units calibrated at nominal 70°F.Maximum thermal error computed from this datum.

Environmental Data

Temperature	
Operating* °F (°C)	0 to +175 (-18 to +79)
Storage °F (°C)	-65 to +250 (-54 to +121)

*Operating temperature limits of the electronics only. Pressure media temperatures may be considerably higher.

Physical Description

Case	Fire-Retardant Glass Filled Polyester
Mounting	Four screw holes on removable zinc plated steel base (designed for 2.75" snap track)
Electrical Connection	Screw Terminal Strip
Pressure Fittings	3/16" O.D. barbed brass pressure fitting for 1/4" push-on tubing
Zero and Span Adjustments	Accessible on top of case
Weight (approx.)	10 ounces

Pressure Media

Typically air or similar non-conducting gases.

Specifications subject to change without notice.

Electrical Data (Voltage)

Circuit	3-Wire (Com, Exc, Out)
Excitation	9 to 30 VDC
Output*	0 to 5 VDC**
Bidirectional output at zero pressure:	2.5 VDC**
Output Impedance	100 ohms

*Calibrated into a 50K ohm load, operable into a 5000 ohm load or greater.
**Zero output factory set to within ±50mV (±25 mV for optional accuracies).
**Span (Full Scale) output factory set to within ±50mV. (±25 mV for optional accuracies).

Electrical Data (Current)

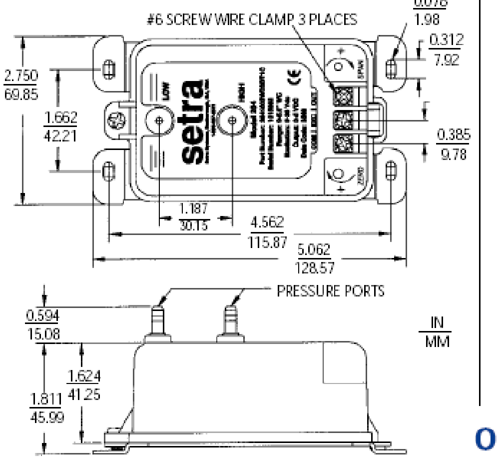
Circuit	2-Wire
Output*	4 to 20mA**
Bidirectional output at zero pressure:	12mA**
External Load	0 to 800 ohms

Minimum supply voltage (VDC) = 9+ 0.02 x (Resistance of receiver plus line).
Maximum supply voltage (VDC) = 30+ 0.004 x (Resistance of receiver plus line).

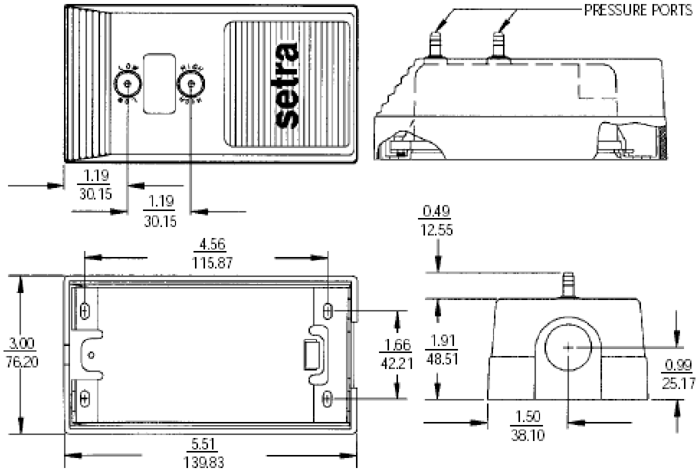
*Calibrated at factory with a 24 VDC loop supply voltage and a 250 ohm load.
**Zero output factory set to within ±0.16mA (±0.08 mA for optional accuracies).
**Span (Full Scale) output factory set to within ±0.16mA (±0.08 mA for optional accuracies).

Outline Drawings

Code T1 Electrical Termination Dimensions



Optional 1/2" Conduit Electrical Enclosure Dimensions



SSP264 Rev.D 04/19/01

ORDERING INFORMATION

Code all blocks in table.

Example: Part No. 26412R5WD11T1C for a 264 Transducer 0 to 2.5 in. WC Range, 4 to 20 mA Output, Terminal Strip Electrical Connection, and ±1% Accuracy.

2 6 4 1 – ☐☐☐☐☐ – ☐☐ – ☐☐ – ☐

Model	Ranges: Differential	Ranges: Bidirectional	Output	Elec. Termination	Accuracy
2641 = 264	**0R1WD** = 0 to 0.1 in.WC	**R05WB** = ±0.05 in.WC	**11** = 4-20 mA	Standard	Standard
	R25WD = 0 to 0.25 in.WC	**0R1WB** = ±0.1 in.WC	**2D** = 0 to 5 VDC	**T1** = Terminal Strip	**C** = ±1% FS
	0R5WD = 0 to 0.5 in.WC	**R25WB** = ±0.25 in.WC		Optional	Optional (w/Cal. Cert.)
	001WD = 0 to 1 in.WC	**0R5WB** = ±0.5 in.WC		**A1** = 1/2" Conduit Enclosure	**E** = ±0.4% FS
	2R5WD = 0 to 2.5 in.WC	**001WB** = ±1 in.WC			**F** = ±0.25% FS
	003WD = 0 to 3 in.WC	**1R5WB** = ±1.5 in.WC			**G** = ±1% FS
	005WD = 0 to 5 in.WC	**2R5WB** = ±2.5 in.WC			
	010WD = 0 to 10 in.WC	**005WB** = ±5 in.WC			
	015WD = 0 to 15 in.WC	**7R5WB** = ±7.5 in.WC			
	025WD = 0 to 25 in.WC	**010WB** = ±10 in.WC			
	050WD = 0 to 50 in.WC	**025WB** = ±25 in.WC			
	100WD = 0 to 100 in.WC	**050WB** = ±50 in.WC			

Please contact factory for versions not shown.

7. Vaisala Humidity and Temperature Sensor

VAISALA

P.O. Box 26, FIN-00421 Helsinki, FINLAND
Tel: +358 9 894 91
Fax: +358 9 8949 2485
Email: industrialsales@vaisala.com
www.vaisala.com

HMW61/71 Humidity and Temperature Transmitter for Industrial/HVAC Applications

Vaisala HUMICAP® Humidity and Temperature Transmitters HMW61/71 are protected against dust and sprayed water.

Features/Benefits

- Full 0...100 %RH measurement
- Accuracy up to ±2 %RH
- True two-wire transmitter with a 4...20 mA loop powered output (HMW61)
- Three-wire transmitter with a selectable signal output of 0...1 V, 0...5 V or 0...10 V (HMW71)
- Optional temperature measurement
- Electronic, on-site, one-point calibration
- Vaisala HUMICAP® Sensor for excellent accuracy and long-term stability, negligible hysteresis and resistance to dust and most chemicals.
- Temperature compensated
- IP65 (NEMA 4) housing
- NIST traceable (certificate included)

The wall mount Vaisala HUMICAP® Humidity and Temperature Transmitters HMW61 and HMW71 are designed for monitoring relative humidity and temperature in demanding environments.

Withstands dust and sprayed water

The transmitters are protected against dust and sprayed water, meeting the IP65 (NEMA 4) requirements. All the materials used have been chosen for excellent corrosion resistance. In addition, the transmitters incorporate Vaisala HUMICAP® Sensor, which is insensitive to dust and most chemicals.

All of these features make the HMW61/71 transmitters especially suitable for humid and wet environments, e.g. greenhouses, live stock farms, indoor swimming pools and other wash down areas.

Measures both humidity and temperature

The HMW61/71 transmitters are available as relative humidity only (U), and as relative humidity and temperature (Y).

Fast, on-site calibration

The accuracy of the transmitters is simple to check using either the Vaisala HUMICAP® Hand-Held Humidity and Temperature Meter HM70 or the Vaisala HUMICAP® Humidity Indicator HMI41. The calibration can be done in seconds with a single potentiometer without disturbing operation, resulting in savings in both maintenance time and costs.

Customized calibration and maintenance contracts for HMW61/71 are available on request.

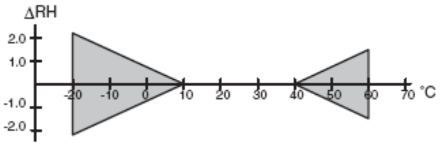
Vaisala HUMICAP® Humidity and Temperature Transmitters HMW61/71 are especially suitable for humid and wet environments.

Technical Data

Relative humidity

Measurement range	0 to 100 %RH
Accuracy at +20 °C (+68 °F)	±2 %RH (0 to 90 %RH) ±3 %RH (90 to 100 %RH)

Temperature dependence



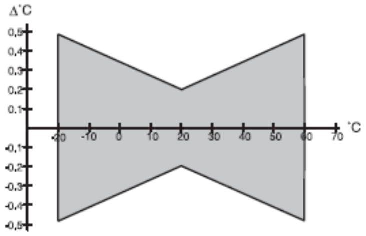
Response time (90%) at +20 °C (+68 °F) in still air	15 seconds (with membrane filter)
Humidity sensor	HUMICAP® 180

Temperature (Y model only)

Measurement range	-20...+60 °C (-4...+140 °F)

Optional temperature scales available on request.

Accuracy



Linearity	better than 0.1 °C (0.18 °F)
Temperature sensor	Pt 1000 IEC 751 class B

General HMW61U/Y

Supply voltage	10...35 VDC (RL = 0 ohms) 20...35 VDC (RL = 500 ohms)
Output signal	4...20mA

Output signal corresponds to 0...100 %RH and -20...+80 °C (-4...+176 °F)

General HMW71U/Y

Supply voltage range depends on the selected output signal. When an AC supply is used, an isolated source is recommended.

	DC	AC
0...1 V	10...35 V	9...24 V
0...5 V	14...35 V	12...24 V
0...10 V	19...35 V	16...24 V

Output signal corresponds to 0...100 %RH and -20...+80 °C (-4...+176 °F)

Factory setting 0...1 V. Other outputs selectable by jumper connections. An output change causes an error, which is less than 0.5 %RH without recalibration.

Power consumption @ 24 VAC	
HMW71U	10 mA typical
HMW71Y	12 mA typical

General

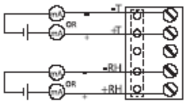
Operating temperature range	-20 °C...+60 °C (-4...+140 °F)
Storage temperature range	-40 °C...+80 °C (-40...+176 °F)
Material:	
Housing	ABS/PC plastic
Probe	ABS/PC plastic
Mounting plate	ABS plastic
Housing classification	IP65 (NEMA 4)
Sensor protection	
Membrane filter	part no. DRW010525
Probe cap	part no. HM47329
Connections	Screw terminals 0.5...1.5 mm²

For field check
HM70 hand-held humidity and temperature meter or HMI41 humidity indicator

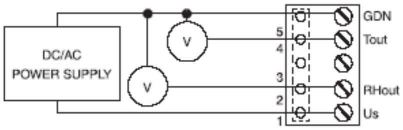
Complies with EMC standard EN61326-1:1997 + Am1:1998 + Am2:2001; Industrial Environment.

Wiring

HMW61 wiring diagram

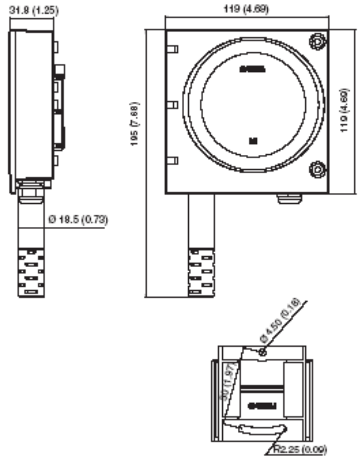


HMW71 wiring diagram



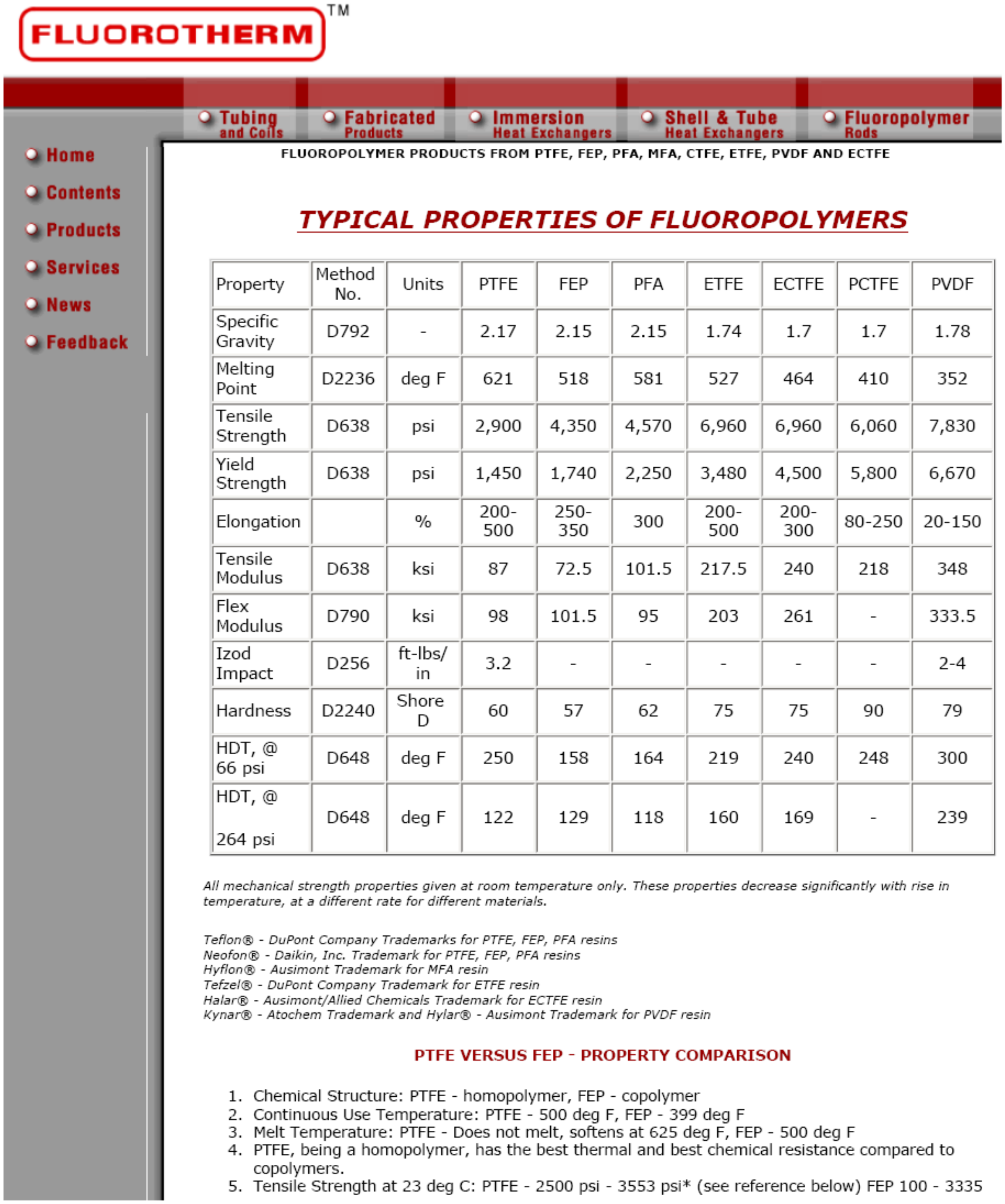
Dimensions

Dimension in mm (inches).



HUMICAP® is a registered trademark of Vaisala.
Specifications subject to change without prior notice.

8. Fluorotherm FEP Tubing



FLUOROPOLYMER PRODUCTS FROM PTFE, FEP, PFA, MFA, CTFE, ETFE, PVDF AND ECTFE

TYPICAL PROPERTIES OF FLUOROPOLYMERS

Property	Method No.	Units	PTFE	FEP	PFA	ETFE	ECTFE	PCTFE	PVDF
Specific Gravity	D792	-	2.17	2.15	2.15	1.74	1.7	1.7	1.78
Melting Point	D2236	deg F	621	518	581	527	464	410	352
Tensile Strength	D638	psi	2,900	4,350	4,570	6,960	6,960	6,060	7,830
Yield Strength	D638	psi	1,450	1,740	2,250	3,480	4,500	5,800	6,670
Elongation		%	200-500	250-350	300	200-500	200-300	80-250	20-150
Tensile Modulus	D638	ksi	87	72.5	101.5	217.5	240	218	348
Flex Modulus	D790	ksi	98	101.5	95	203	261	-	333.5
Izod Impact	D256	ft-lbs/in	3.2	-	-	-	-	-	2-4
Hardness	D2240	Shore D	60	57	62	75	75	90	79
HDT, @ 66 psi	D648	deg F	250	158	164	219	240	248	300
HDT, @ 264 psi	D648	deg F	122	129	118	160	169	-	239

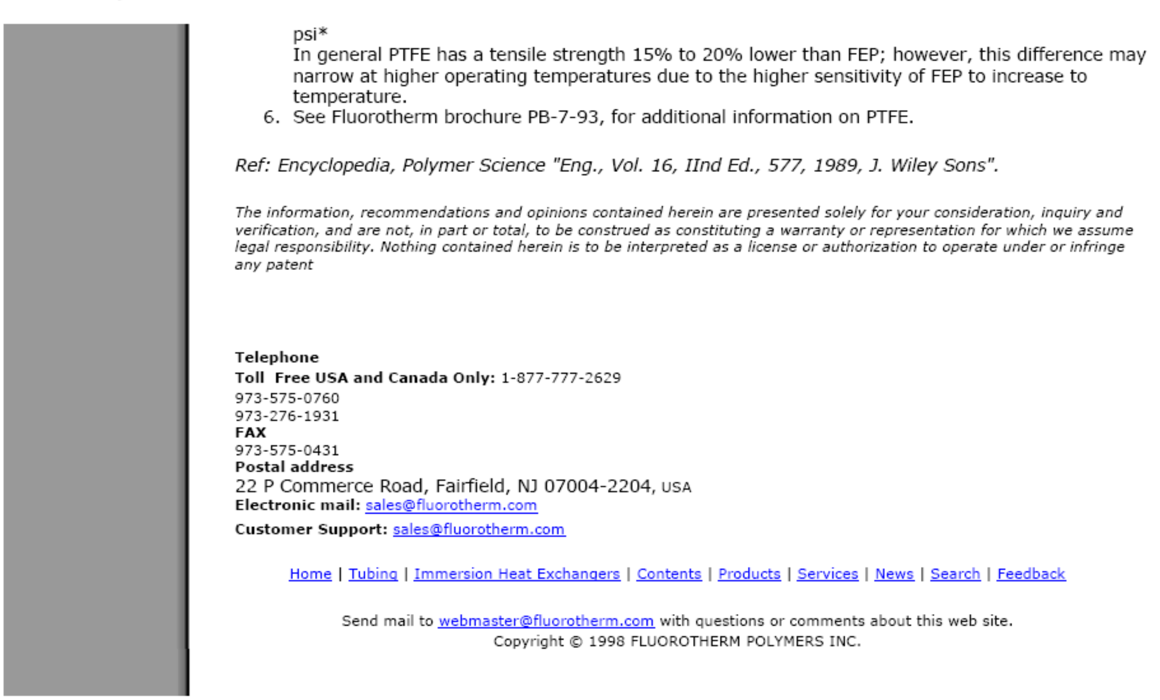
All mechanical strength properties given at room temperature only. These properties decrease significantly with rise in temperature, at a different rate for different materials.

Teflon® - DuPont Company Trademarks for PTFE, FEP, PFA resins
Neofon® - Daikin, Inc. Trademark for PTFE, FEP, PFA resins
Hyflon® - Ausimont Trademark for MFA resin
Tefzel® - DuPont Company Trademark for ETFE resin
Halar® - Ausimont/Allied Chemicals Trademark for ECTFE resin
Kynar® - Atochem Trademark and Hylar® - Ausimont Trademark for PVDF resin

PTFE VERSUS FEP - PROPERTY COMPARISON

1. Chemical Structure: PTFE - homopolymer, FEP - copolymer
2. Continuous Use Temperature: PTFE - 500 deg F, FEP - 399 deg F
3. Melt Temperature: PTFE - Does not melt, softens at 625 deg F, FEP - 500 deg F
4. PTFE, being a homopolymer, has the best thermal and best chemical resistance compared to copolymers.
5. Tensile Strength at 23 deg C: PTFE - 2500 psi - 3553 psi* (see reference below) FEP 100 - 3335

http://www.fluorotherm.com/properties.htm (1 of 2)6/6/2005 8:48:25 AM



psi*
In general PTFE has a tensile strength 15% to 20% lower than FEP; however, this difference may narrow at higher operating temperatures due to the higher sensitivity of FEP to increase to temperature.

6. See Fluorotherm brochure PB-7-93, for additional information on PTFE.

Ref: Encyclopedia, Polymer Science "Eng., Vol. 16, IInd Ed., 577, 1989, J. Wiley Sons".

Telephone
Toll Free USA and Canada Only: 1-877-777-2629
973-575-0760
973-276-1931
FAX
973-575-0431
Postal address
22 P Commerce Road, Fairfield, NJ 07004-2204, USA
Electronic mail: sales@fluorotherm.com
Customer Support: sales@fluorotherm.com

9. API UV Fluorescence Non-methane Hydrocarbon Analyzer

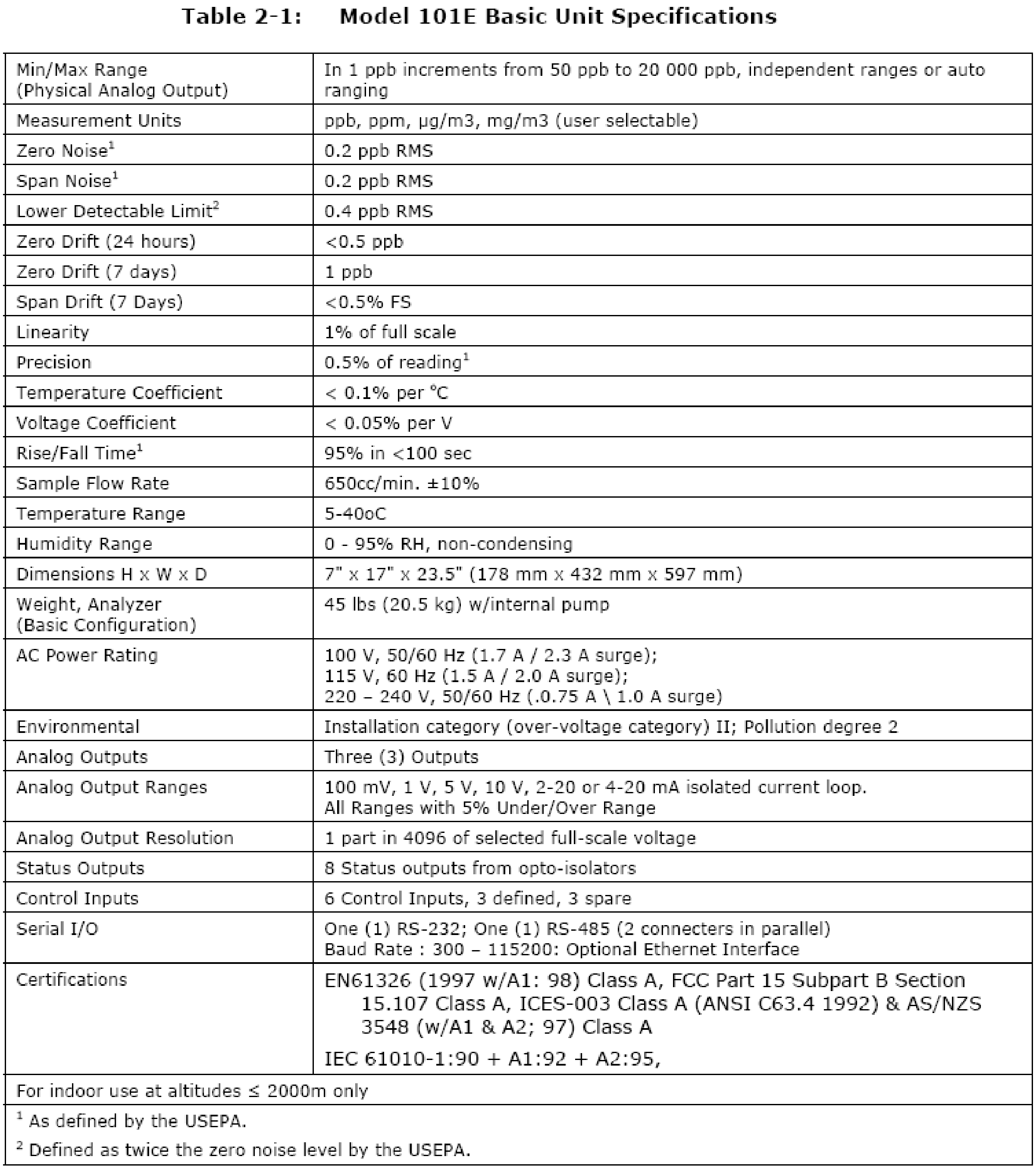


Table 2-1: Model 101E Basic Unit Specifications

Min/Max Range (Physical Analog Output)	In 1 ppb increments from 50 ppb to 20 000 ppb, independent ranges or auto ranging
Measurement Units	ppb, ppm, µg/m3, mg/m3 (user selectable)
Zero Noise[1]	0.2 ppb RMS
Span Noise[1]	0.2 ppb RMS
Lower Detectable Limit[2]	0.4 ppb RMS
Zero Drift (24 hours)	<0.5 ppb
Zero Drift (7 days)	1 ppb
Span Drift (7 Days)	<0.5% FS
Linearity	1% of full scale
Precision	0.5% of reading[1]
Temperature Coefficient	< 0.1% per °C
Voltage Coefficient	< 0.05% per V
Rise/Fall Time[1]	95% in <100 sec
Sample Flow Rate	650cc/min. ±10%
Temperature Range	5-40oC
Humidity Range	0 - 95% RH, non-condensing
Dimensions H x W x D	7" x 17" x 23.5" (178 mm x 432 mm x 597 mm)
Weight, Analyzer (Basic Configuration)	45 lbs (20.5 kg) w/internal pump
AC Power Rating	100 V, 50/60 Hz (1.7 A / 2.3 A surge); 115 V, 60 Hz (1.5 A / 2.0 A surge); 220 – 240 V, 50/60 Hz (.0.75 A \ 1.0 A surge)
Environmental	Installation category (over-voltage category) II; Pollution degree 2
Analog Outputs	Three (3) Outputs
Analog Output Ranges	100 mV, 1 V, 5 V, 10 V, 2-20 or 4-20 mA isolated current loop. All Ranges with 5% Under/Over Range
Analog Output Resolution	1 part in 4096 of selected full-scale voltage
Status Outputs	8 Status outputs from opto-isolators
Control Inputs	6 Control Inputs, 3 defined, 3 spare
Serial I/O	One (1) RS-232; One (1) RS-485 (2 connecters in parallel) Baud Rate : 300 – 115200: Optional Ethernet Interface
Certifications	EN61326 (1997 w/A1: 98) Class A, FCC Part 15 Subpart B Section 15.107 Class A, ICES-003 Class A (ANSI C63.4 1992) & AS/NZS 3548 (w/A1 & A2; 97) Class A IEC 61010-1:90 + A1:92 + A2:95,
For indoor use at altitudes ≤ 2000m only	

[1] As defined by the USEPA.

[2] Defined as twice the zero noise level by the USEPA.

10. Tapered Element Oscillating Microbalance (TEOM)

Series 1400a

TEOM® Automated Ambient Particulate Monitor

Complete Outdoor Enclosure

Streamline Pro™ MultiCal™ Unit for Flow Audit/Calibration

Mass Calibration Verification Kit

Parallel Operation of PM-10 and PM-2.5 TEOM Monitors
Tokyo, Japan

Features

- Continuous *True Mass* Measurement with Unmatched Short-Term (Hourly) Precision and Resolution
- PM-10, PM-2.5, PM-1, TSP Inlets
- Active Volumetric Flow Control Using Advanced Mass Flow Controllers
- No Radioactive Components
- Audit and Calibration Using NIST-Traceable Mass and Flow Standards
- USEPA PM-10 (EQPM-1090-079) and PM-2.5, Worldwide Approvals

Series 8500 FDMS® System

- Measures *Total Atmospheric Aerosol* Mass Concentration
- Accounts for Non-volatile and Volatile PM Components with Innovative Self-Referencing Methodology

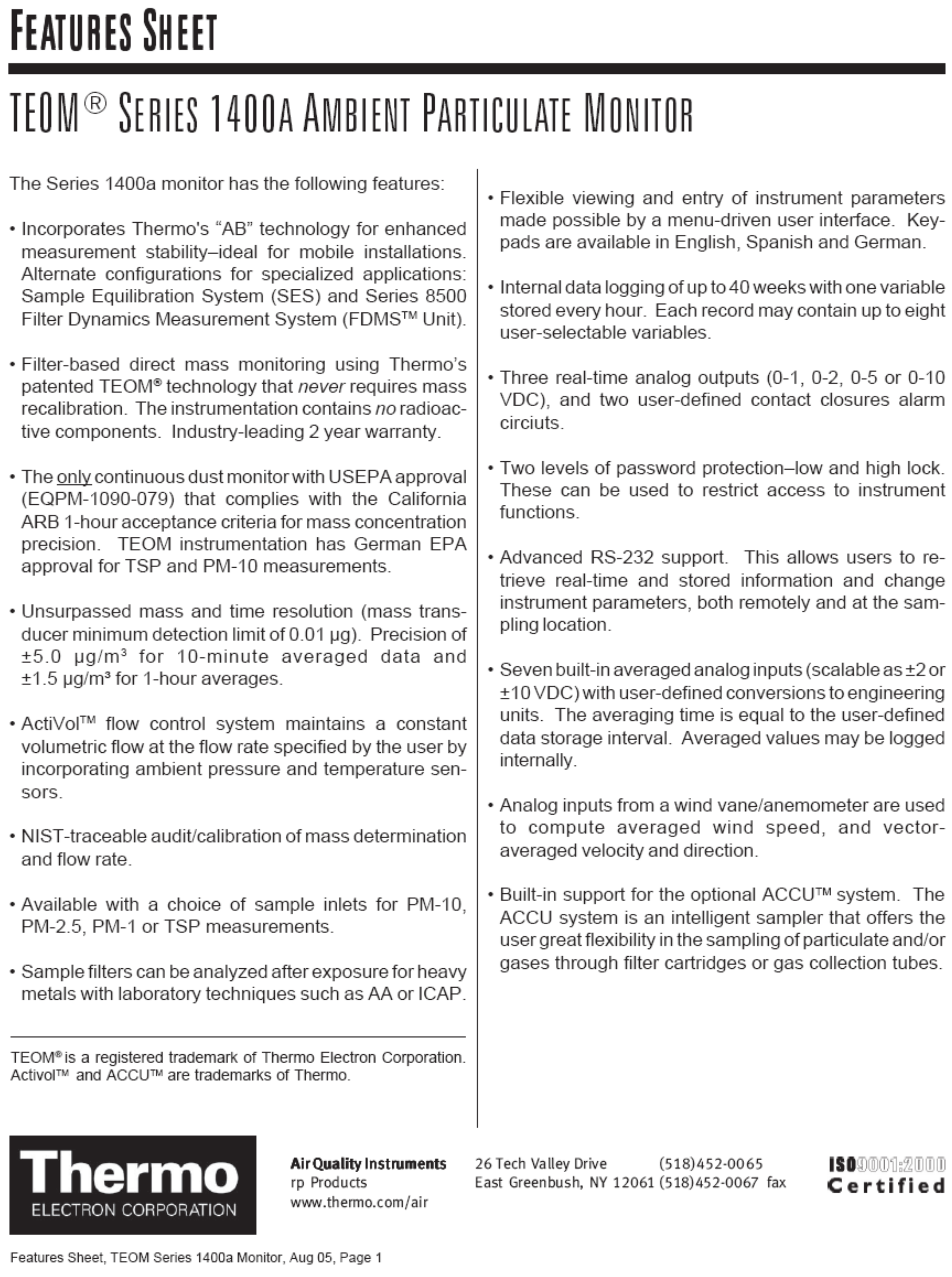
Series 8100 Aethalometer™ Module

- Continuous Black Carbon (BC) Analyzer for the TEOM Monitor

www.rpco.com

Rupprecht & Patashnick Co., Inc.

Feb 06



FEATURES SHEET

TEOM® SERIES 1400A AMBIENT PARTICULATE MONITOR

The Series 1400a monitor has the following features:

- Incorporates Thermo's "AB" technology for enhanced measurement stability–ideal for mobile installations. Alternate configurations for specialized applications: Sample Equilibration System (SES) and Series 8500 Filter Dynamics Measurement System (FDMS™ Unit).
- Filter-based direct mass monitoring using Thermo's patented TEOM® technology that *never* requires mass recalibration. The instrumentation contains *no* radioactive components. Industry-leading 2 year warranty.
- The only continuous dust monitor with USEPA approval (EQPM-1090-079) that complies with the California ARB 1-hour acceptance criteria for mass concentration precision. TEOM instrumentation has German EPA approval for TSP and PM-10 measurements.
- Unsurpassed mass and time resolution (mass transducer minimum detection limit of 0.01 µg). Precision of ±5.0 µg/m³ for 10-minute averaged data and ±1.5 µg/m³ for 1-hour averages.
- ActiVol™ flow control system maintains a constant volumetric flow at the flow rate specified by the user by incorporating ambient pressure and temperature sensors.
- NIST-traceable audit/calibration of mass determination and flow rate.
- Available with a choice of sample inlets for PM-10, PM-2.5, PM-1 or TSP measurements.
- Sample filters can be analyzed after exposure for heavy metals with laboratory techniques such as AA or ICAP.
- Flexible viewing and entry of instrument parameters made possible by a menu-driven user interface. Keypads are available in English, Spanish and German.
- Internal data logging of up to 40 weeks with one variable stored every hour. Each record may contain up to eight user-selectable variables.
- Three real-time analog outputs (0-1, 0-2, 0-5 or 0-10 VDC), and two user-defined contact closures alarm circiuts.
- Two levels of password protection–low and high lock. These can be used to restrict access to instrument functions.
- Advanced RS-232 support. This allows users to retrieve real-time and stored information and change instrument parameters, both remotely and at the sampling location.
- Seven built-in averaged analog inputs (scalable as ±2 or ±10 VDC) with user-defined conversions to engineering units. The averaging time is equal to the user-defined data storage interval. Averaged values may be logged internally.
- Analog inputs from a wind vane/anemometer are used to compute averaged wind speed, and vector-averaged velocity and direction.
- Built-in support for the optional ACCU™ system. The ACCU system is an intelligent sampler that offers the user great flexibility in the sampling of particulate and/or gases through filter cartridges or gas collection tubes.

TEOM® is a registered trademark of Thermo Electron Corporation. Activol™ and ACCU™ are trademarks of Thermo.

Thermo
ELECTRON CORPORATION

Air Quality Instruments
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East Greenbush, NY 12061 (518)452-0067 fax

ISO9001:2000
Certified

11. VIG Industries Hydrocarbon Analyzer

Heated Methane / NonMethane / Total Hydrocarbon Analyzer (NMHC)
Model-200

VIG INDUSTRIES, INC

The VIG Industries, Inc. Model-200 is a microprocessor based, oven heated methane / nonmethane / total hydrocarbon gas analyzer designed for high accuracy, sensitivity and stability. The Model-200 uses two independent flame ionization detectors (FIDs), one to measure total hydrocarbons and the second coupled with a GC Column for the separation of the methane and nonmethane components. A sample is fed to the analyzer via an internal heated pump to the first FID for a real time total hydrocarbon reading. A portion of the sample is trapped and pushed through a column to separate the methane component and then to the second FID. Any remaining sample in the column is back flushed through the column to obtain the nonmethane component. All components that come in contact with the sample through analysis are maintained in a temperature-controlled oven to prevent condensation, and to provide repeatable, reliable performance in the analysis of a wide variety of hydrocarbon concentrations in gaseous mixtures or in ambient air.

Features

- Easy to use software
- Automatic start-up/ignition
- Heated sample pump heads
- Two stage sample filter with exchangeable sintered stainless steel elements
- Teflon isolated detectors (FIDs)
- Automatic fuel shut-off system
- Automatic flame-out indicators
- Adjustable alarm and oven settings
- Precision 1% of full scale
- 19" rack/bench mount

Options

- 4-20mA output - no extra charge
- Zero and calibration solenoids with software
- RS-232 interface
- Internal combustion air supply

Related Available Equipment

- Zero air generator (Reduces bottles)
- Hydrogen generator (Reduces bottles)
- Heated sample lines and controllers
- Strip chart recorders and data loggers
- NEMA rated enclosures

Applications

- *Compliance Monitoring* - U.S. E.P.A. Method 18 and Method 25A
- *Process Monitoring* - Continuous monitoring and alarm or control of: process gas streams utilizing organic solvents, crude oil, and other chemicals containing hydrocarbons.
- *Efficiency Monitoring* - Monitoring effluent of volatile organic compound (VOC) reduction equipment for environmental compliance, efficiency control of incinerators (Thermal or catalytic), scrubbers, carbon absorbers, and other abatement equipment, monitoring of catalytic converters, combustion and diesel engine efficiency.
- *Safety Monitoring* - Lower explosive limit (LEL) monitoring and/or control of ovens/dryers, fugitive emissions monitoring, personnel work area monitoring, leak detection of process equipment or solvent storage areas.
- *Stack Monitoring*

VIG INDUSTRIES, INC.

4051 E. La Palma #C Anaheim, CA 92807 • Toll Free (800)862-7844 • Phone (714)632-8200 • Fax (714)632-8201 • http://www.vigindustries.com

Standard Specifications

Measuring Method - 2 Oven Heated, Flame Ionization Detectors (FIDs)
Separation Method - GC Column
Measurement Range/Standard Ranges - (4 Ranges per amplifier, 2 amplifiers per analyzer, 1 amplifier for total and 1 amplifier for methane and nonmethane)

- 0-10, 0-100, 0-1000, 0-10000ppm (Lower detection limit 0.01ppm) or
- 0-100, 0-1000, 0-10000, 0-100000ppm (Lower detection limit 0.1ppm)
- Other ranges available upon request

Zero & Span Noise - Less than 0.2% of full scale
Zero & Span Drift - +/- 1% full scale per 24 hours
Linearity- Within 1% of full scale through all ranges
Repeatability - Within 1% of full scale through all ranges
Stability - Within 1% of full scale through all ranges
Oxygen Synergism - Within 1% of full scale within selected range
Response Time

- Total - Within 5 seconds to 90% of final reading (Continuous real time reading)
- Methane - Approximately 40 seconds, updated every 3 minutes
- Nonmethane - Approximately 70 seconds, updated every 3 minutes

Ambient Temperature - From 50°F to 120°F
Flow Rate - 4 Liters/Minute (Standard) or 10 Liters/Minute (Upon request)
Physical Dimensions - 19" Wide Front Panel, 16.75" Wide Chassis, 24" Deep Chassis, 27" Deep with fittings and handles, 9" High
Weight - 55 lbs to 65 lbs depending on options
Oven operating temperature - 275°F (Adjustable from 200°F to 300°F)
Safety - Flame-Out indicator lamp, flame-out alarm contacts on back panel, fuel shut-off, calibration and zero solenoid shut-off
Voltage Outputs - One of the following voltage outputs

- 0-10VDC (Standard), 0-1VDC or 0-5VDC (Optional – no extra charge)

Current Outputs - 4-20mA, Sourcing (Optional – no extra charge)
Flame-Out Alarms - Normally open, low current relay contacts (Close on alarm, latching)
Concentration Alarms - Normally open, low current relay contacts (Close on alarm, latching)
Ignition - Automatic (Can be set to manual by operator from front panel)
Glow Plugs - Main and spare glow plugs installed (Selectable by switch on back panel)
Warm-up Time

- Usable in approximately 45 minutes
- Stable in approximately 2 hours

Display - Graphic, backlit, 240W x 64H pixels, high contrast, wide viewing angle

Operation Requirements

Fuel - UHP Hydrogen @ 18psi incoming pressure
Combustion Air - Oil/Water/Hydrocarbon free instrument air @ 18psi incoming pressure
Zero Calibration Gas - UHP zero grade air or nitrogen @ 9psi incoming pressure
Span Calibration Gas - Known concentration of operator selected hydrocarbons balanced in either air or nitrogen @ 9psi incoming pressure (VIG recommends using a mixture of methane and propane balanced in air to save calibration time)
Carrier Gas - UHP nitrogen @ 30psi incoming pressure
Compressed Air - Oil/Water free air @ 50psi incoming pressure for column switching valve
Power Requirements - 115VAC @ 60Hz @ 720Watts or optional 220VAC @ 50Hz

Warranty

All instruments sold by VIG Industries, Inc. are warranted for a period of one (1) year from date of purchase against defects in materials and workmanship. The seller warrants that the product supplied conforms to the specifications assigned thereto. There is no other warranty either expressed or implied. Seller liability is limited specifically to the cost or assigned value of the items sold. Service contracts are available after the warranty expires.

12. Rotem RSC-2 Poultry Scale System

ROTEM

Take Control!

COMPUTERIZED CONTROLLERS

RSC-2

Automatic Live Bird Scale

For Broilers, Breeders, Pullets and Turkeys. Special program that weighs males and females separately, providing separate data on the same platform.

The RSC-2 is a stand-alone live bird scale center. It assures continuous accurate daily data collection of average bird weight, number of weighings, daily weight gain, standard deviation, CV and uniformity.

The RSC-2 can handle up to two bird scale platform placed on the litter in the same or different houses. It is very simple to use. Rotem's unique user-friendly Scale Center uses easy to understand menu.

The sophisticated software can accurately weigh the birds even if more than one bird is stepping on the platform at the same time.

You can link an unlimited number of Rotem bird scale centers to a nationwide communication network, controlled by one central PC via modem, using Rotem's advanced communication program for Windows.

The platforms are made of a high quality stainless steel and are completely sealed to prevent any damage to the excellent load cells installed inside. Rotem uses high quality cables to ensure long life in the harsh litter environment.

Features:

- Up to two bird scales.
- Five digit display.
- Up to 500 days data collection.
- User friendly 3 key programming.
- Weight displayed in Kg. or Lb.
- 115 / 230 VAC operation.
- Local or remote modem PC communication.
- Unerasable memory.
- Power surge protection.
- Water and dust resistant enclosure.
- Simple installation.

ISO 9001:2000 IQC
CE

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Computerized Controllers

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Petach Tikva 49511
ISRAEL
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Fax: +972-3-9249834

www.rotem.com E-mail: rotem@rotem.com

13. Barometric Pressure Sensor

WATER

WE100 Barometric Pressure Sensor

- 4-20 mA output
- Marine grade cable with strain relief

Description

Global Water's highly accurate Barometric Pressure Sensor covers a pressure range from 800 to 1100 mb. The barometric pressure indicator is fully temperature compensated within an operating range of -40° to 65° C. The sensor is mounted on 25' of marine grade cable, with lengths up to 500' available upon request. The sensor output is 4-20 mA with a two wire configuration.

Specifications

Output: 4-20 mA
Range: 800-1100 mb
Accuracy: ±1% of full scale
Linearity/Hysteresis: ± 0.1%
Operating Voltage: 10-36 VDC
Current Draw: Same as sensor output
Warm Up Time: 3 seconds minimum
Operating Temp: -40° to +55°C
Sensor Size: 3"x2"x1"
Weight: 0.13 lb.

Price List

WE100
Barometric Pressure Sensor.......$375

WQEXC Extra Cable
Cable length is measured from end of cable to bottom of sensor.
After 25', up to 500'...........................$1.10/ft

Contact Global Water for all your instrumentation needs:
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- Water Flow
- Water Samplers
- Water Quality
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11390 Amalgam Way
Gold River, CA 95670

Appendix V: Project Team Vitas

Robert Thomas Burns, Ph.D., P.E., CCA

3224 NRSIC
Ames, Iowa 50011
Phone (515)-294-4203

fax: (515)-294-4250
email: rburns@iastate.edu
www: abe.iastate.edu/wastemgmt/

Education:

Ph.D. in Civil Engineering. Environmental Engineering specialization. University of Tennessee, Knoxville. May 1995. GPA: 3.91/4.00. Dissertation title - Impact of Electric Vehicles on Ozone Formation in the Middle Tennessee Area.

M.S. in Environmental Engineering. Air Quality Management/Pollution Control concentration with a minor in mixed waste management. University of Tennessee, Knoxville. May 1992. GPA: 4.00/4.00 Thesis title - Preparation of Air Pollution Emission Inventories for Stationary Sources.

B.S. in Agricultural Engineering. Soil and Water Conservation concentration. University of Tennessee, Knoxville. May 1990.

Professional Experience:

Associate Professor, Iowa State University. Joint appointment between extension (55% appointment) and research (45% appointment). Environmental engineering specialization, including the design of animal waste management systems and nutrient management planning for livestock and poultry operations. August, 2004 - Present.

Associate Professor, University of Tennessee, Knoxville. Joint appointment between The Tennessee Agricultural Extension Service (70% appointment) and The Tennessee Agricultural Experiment Station (30% appointment). Environmental engineering specialization, including the design of animal waste management systems and nutrient management planning for livestock and poultry operations. July, 2000 – July, 2004.

Assistant Professor, University of Tennessee, Knoxville. Tennessee Agricultural Extension Service Water Quality Specialist, 100% Extension service appointment. June 1995 - 1998. Joint appointment (70% extension and 30% research). 1998 - July, 2000.

Research Associate, University of Tennessee, Knoxville. Civil & Environmental Engineering Air Pollution Control Laboratory. Full-time staff position. Worked directly with EPA and State agencies in the preparation of air pollutant emission inventories and computer modeling of ozone formation (EKMA and UAM modeling). 1992 - 1995.

Environmental Engineer, Sverdrup Technology Inc., Tullahoma, Tennessee. Responsible for identifying and classifying waste streams, and monitoring RCRA 90 day hazardous waste storage facility. Maintained Sverdrup air permits at Arnold Engineering Development Center facility. 1992.

Professional Registration:

Registered Professional Engineer in Tennessee (P.E. # 102322)

Certified Crop Advisor (CCA) in Tennessee (CCA # 34046)

USDA - NRCS Certified Technical Service Provider for CNMP Plan Development

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Freeland, R.S., J.C. Regan, R.T. Burns, and J.T. Ammons. 1997. Noninvasive Sensing of Near-Surface Perched Water using Ground Penetrating Radar. *ASAE Paper No. 973073.* ASAE, St. Joseph, MI.

Buschermohle, M.J., R.T. Burns, J.B. Wills, D.L. Coffey, and G.S. Honea. 1997. Mulch Color Effects on Soil Temperature, Soil Moisture and Vegetable Yields. *Proceedings of the 1997 SERA-IEG 4 Meeting*. Tifton, Georgia.

Davis, W.T., A. Early and R.T. Burns. 1995. The Significance of NO_x emissions from Coal-fired Power Plants in the Middle Tennessee Area on Tropospheric Ozone. *Proceedings of the 88th annual Air and Waste Management Association Conference*. San Antonio, Texas.

Burns, R.T.,1995. <u>Impact of Electric Vehicles on Ozone Formation in the Middle Tennessee Area</u>, Dissertation, University of Tennessee, Knoxville.

Burns, R.T., M.A. Kaminski, W.T. Davis, and T.L. Miller. 1994. Interactive Visualization of Urban Airshed Modeling Simulations*. Proceedings of the Air and Waste Management Association Conference, Computing in Environmental Management*. RTP, N.C.

Burns, R.T., W.T. Davis and T.L. Miller. 1995. Potential Air Quality Impact of Electric Vehicles in Southeastern U.S. Urban Area. *Proceedings of the 88th annual Air and Waste Management Association Conference* . San Antonio, Texas.

Davis, W.T., R.T. Burns, M.A. Kaminski, T.L. Miller. 1994. Middle Tennessee Modeling Domain 1996 Urban Airshed Modeling Attainment Demonstration. *U.S. EPA Office of Air Quality Planning and Standards.*

Burns, R.T., A. Early, W.T. Davis, and T.L. Miller.1994. *Significance of NO_x Emissions for Power Plants on Ozone Formation in an Urban Area.* Presented at the 1994 WATTec Meeting.

Burns, R.T., T.L. Miller, and W.T. Davis. 1993. *Emission Inventory Preparation*, APTI Course 519 Training Manual. U.S. EPA Air Pollution Training Institute. Course manual, 411 pp.

Burns, R.T., T.L. Miller, and W.T. Davis, 1992. *Preparation of Emission Inventories*, APTI Course 419 Training Manual. U.S. EPA Air Pollution Training Institute. Course manual, 314 pp.

Burns, R.T.,1992. <u>Preparation of Air Pollutant Emission Inventories for Stationary Sources</u>. Thesis: University of Tennessee.

Publications: Extension Service Publications

Anderson, R, R.T. Burns, L.B. Moody, G. Brann, G. Grandle, F.R. Walker, G. Moore, and D. Tapp. 2002. Comprehensive Nutrient Management Plan for The Barr Dairy Farm; Example CNMP for the UT CNMP Certification Program. UT Agricultural Extension Service.

Burns, R.T. 2001 Alternative Livestock Watering Systems. <u>Conservation Practices for the Farms and Forests of Tennessee</u>. (pp. 45 - 46). The UT Agricultural Extension Service.

Burns, R.T. 2001. Liquid Manure Storage Structures. <u>Conservation Practices for the Farms and Forests of Tennessee</u>. (pp. 49 - 50). The UT Agricultural Extension Service.

Burns, R.T. and C. Goan. 2001. Manure and Litter Land Application. <u>Conservation Practices for the Farms and Forests of Tennessee</u>. (pp. 45 - 46) Knoxville, Tennessee. UT Agricultural Extension Service.

Burns, R.T. 2001. Protected Heavy-Use Areas. <u>Conservation Practices for the Farms and Forests of Tennessee</u>. (pp. 63 - 64) Knoxville, Tennessee. The UT Agricultural Extension Service.

Burns, R.T. 2001. Runoff Management. <u>Conservation Practices for the Farms and Forests of Tennessee</u>. (pp. 65 - 66) Knoxville, Tennessee. The UT Agricultural Extension Service.

Burns, R.T. 2001. Stream Crossings. <u>Conservation Practices for the Farms and Forests of Tennessee</u>. (pp. 67 - 68) Knoxville, Tennessee. The UT Agricultural Extension Service.

Burns, R.T. 2001. Selection of Beef Watering Systems. University of Tennessee Agricultural and Biosystems Engineering Extension Publication. WQS–01-01.

Burns, R.T. and L.B. Moody. 2001. Press Tech Agri-Press 600 solids separator performance test results using The University of Tennessee testing protocol. University of Tennessee Agricultural and Biosystems Engineering Extension Publication. AWM–01-01**.**

Burns, R.T. and L.B. Moody. 2001. *Vincent* KP-6L solids separator performance test results using The University of Tennessee testing protocol. University of Tennessee Agricultural and Biosystems Engineering Extension Publication. AWM–01-02.

Burns, R.T. 2000. Using Incinerators for Poultry Mortality Management. University of Tennessee, Agricultural and Biosystems Engineering, Extension Publication AWM-01-00.

Walker, F.R. and R.T. Burns. 2000. Treating Broiler Litter with Alum. P&SS IS # 318.

Burns, R.T. and M.J. Buschermohle. 1999. Selection of Alternative Livestock Watering Systems. University of Tennessee Extension Publication PB1641.

Buschermohle, M.J. and R.T. Burns. 1999. Solar Livestock Watering Systems. University of Tennessee Extension Publication PB1640.

Burns, R.T., F.R. Walker and H.J. Savoy. 1999. Nutrient Management Plan Assistance Guide for Tennessee Class II Concentrated Animal Feeding Operation Permit. University of Tennessee Agricultural Extension Service Publication PB 1635.

Eash, N.S., J. McClurken and R.T. Burns. 1998. Best Management Practices for Land Application of Biosolids. University of Tennessee Agricultural Extension Publication SP500.

Burns, R.T**.** 1998. Basic Filtration for Micro-Irrigation Systems. University of Tennessee Agricultural and Biosystems Engineering Extension Publication IR-01-98.

Burns, R.T. 1998. Basic Fertigation for Micro-Irrigation Systems. University of Tennessee Agricultural and Biosystems Engineering Extension Publication IR-02-98.

Eash, N.S. and R.T. Burns. Cryptosporidium Contamination of Water. 1996. University of Tennessee Agricultural Extension Publication SP465-A.

Turner, L., R. Bowling, R.T. Burns, M. Buschermohle, W. Crist, G. Grandle, S. Isaacs, P. Scharko, and J. Taraba. 1996. *Farmstead Planning*. Chapter 3 - Sustainable Dairy Systems Manual. SARA / ACE Project. The University of Tennessee AES.

Taraba, J., R. Bowling, R.T. Burns, T. Cross, S. Isaacs and M. Williams. 1996. Manure Management. Chapter 10 - Sustainable Dairy Systems Manual. Southern Region SARA / ACE Project. The University of Tennessee Agricultural Extension Service.

Burns, R.T. and J.B. Wills. 1996. Assessing your Petroleum Product Storage. Tennessee Farm-A-Syst Factsheet. University of Tennessee Agricultural Extension Publication SP484G.

Burns, R.T. and J.B. Wills. 1996. Assessing your Hazardous Waste Management. Tennessee Farm-A-Syst Factsheet. University of Tennessee Agricultural Extension Publication SP484H.

Grantsmanship:

Grants Funded

4/06 – 6/06. Training Workshop on Good Farming Practices to Reduce Environmental Pollution in Bulgaria. *R.T. Burns, R.S. Kanwar and E. Becerra. $35,000 awarded by the USDA.*

4/06 – 12/06. *Development of a Database for Environmental Management Practices Employed at Pork Production Facilities*. R.T. Burns, L. Moody, D. Raman, L. Meyer. $103,002 awarded by the National Pork Board.

03/06 – 02-07. *Laying hen manure characteristics and air emissions as affected by genetic strains.* H. Xin, R.T. Burns & Arthur. $27,160 awarded by MPRP and Hy-Line.

01/06 – 06-07. *Field verification of dietary manipulation on ammonia emission and hen performance in high-rise layer houses.* H. Xin, R. Burns & K. Bregendahal. $150,000 awarded by Eco-Cal Products and Iowa Egg Council.

2/06 – 12/06. *Bio-fuel Production from Bio-Dried Animal Manure to Improve Iowa Livestock Production Economy, Part 2 Farm scale biodrying of bedded back swine manure..* S. Sadaka, R.T.Burns & M. Hanna. 110,000 awarded by the Iowa State University Biotechnolgy Bioproducts Consortium.

10/05 – 10/07. *Total Suspended Particulate, PM10, PM2.5, Hydrogen Sulfide and Hydrocarbon National Consent Agreement Emissions Determination from Broiler Production Systems.* R.T. Burns, H. Xin, R. Gates and S. Hoff. $648,231 awarded by Tyson Foods.

10/05 – 9/07. *Development and Integration of A National Feed Management Education Program and Assessment Tools into a Comprehensive Nutrient Management Plan (CNMP)*. Joe Harrison, Alan Sutton, Galen Erickson, Robert Burns. $425,000 awarded by the USDA-NRCS Conservation Initiative Grant program.

9/05 - 9/09. *A National Learning Center for Animal Agricultural Water Quality Issues.* R. K. Koelsch, Frank Humenik, Mark Risse, Joe Harrison (R.T. Burns is project contributor). $300,000 awarded by the USDA 406 Water Quality Program.

9/05 – 9/06. *Bio-fuel Production from Bio-Dried Animal Manure to Improve Iowa Livestock Production Economy.* S. Sadaka, R.T.Burns & M. Hanna. $80,000 awarded by the Iowa State University Biotechnolgy Bioproducts Consortium.

7/05 – 6/06. *Monitoring of Alternative Technolgy Systems Using Setteling Benches For Beef Feedlot Run-off Control.* R.T.Burns, J.D. Lawrence, L.B. Moody. $100,000 awarded by the Iowa Department of Agriculture and Land Stewardship.

6/05 – 6/06. *Pathogen Monitoring from Alternative Beef Feedlot Run-Off Control Systems*. R.T. Burns, L.B. Moody and J.D. Lawrence. $30,000 awarded by the U.S. EPA.

5/05 – 11/08. Non-basin Technologies For Open Feedlot Runoff: Demonstration, Implementation, And Modeling. R.T. Burns, J.D. Lawrence, L.B. Moody and M.J. Helmers. $632,367 awarded by the Iowa Cattlemen’s Association.

3/05 – 9/06. *Ammonia Emissions Determination from Broiler Production Systems.* R.T. Burns, H. Xin and R. Gates. $399,525 awarded by Tyson Foods.

9/03 - 9/06. *Development of A CNMP Core Training Curriculum.* R.T. Burns, L. B. Moody, N. Rector, A. Sutton and R. Sheffield. $290,000 awarded by the USDA 406 Extension Education Program.

12/03 – 12/06. *Concentration and Extraction of Phosphorus from Swine Manure Slurries.* R.T. Burns, L. B. Moody, F. R. Walker, W. M. Park, and J. R. Buchanan. $168,000. Awarded by USDA/NRI.

05/02 – 12/03. *Control of Ammonia and Litter Pathogen Levels in Broiler Production Facilities Treated with Alum as a Litter Amendment.* R.T. Burns, F.A. Draughon, L.R. Wilhelm and F.R. Walker. $27,914 awarded by the General Chemical Corporation.

07/01 – 06/02. *Animal Waste System Design Workshop.* R.T. Burns. $26,850 awarded by the Tennessee Department of Agriculture.

07/01 – 06/02. *Dairy Waste Management Field Day.* R.T. Burns., F.R. Walker, T. Woods, and J. Goddard. $12,540 awarded by the Tennessee Department of Agriculture.

7/01 – 7/03*. On-farm Demonstration of the Use of Aluminum Sulfate as an in-house amendment for Poultry Litter.* Walker, F.R., and R.T. Burns. $45,030 awarded by the TN 319 Pollution Control Program.

7/01 – 7/03. Control of Ammonia and Litter Pathogen Levels in Broiler Production Facilities Treated with Alum as a Litter Amendment. R.T. Burns., A. Draughon, F.R. Walker, L. Wilhelm. $25,625 awarded by the Food Safety Center of Excellence.

Grants Funded (continued):

11/00 – 01/04. *Agricultural Engineering Water Quality Technical Support.* R.T. Burns. $225,000 awarded by the Tennessee Department of Agriculture.

07/00 – 06/01. *Animal Waste System Design Workshop.* R..T. Burns. $50,608 awarded by the Tennessee Department of Agriculture.

01/00 - 12/00. Walker, F.R., and R.T. Burns. *Demonstration of Phosphorus Binding in Swine Waste using Alum*. $10,000 awarded by the Tennessee Department of Agriculture.

11/99-11/01. Raman, D. R., A.C. Layton, M.D. Mullen, R.T. Burns and G. S. Sayler. *Quantifying and minimizing 17 Beta-estradiol emissions from dairy and swine*. $215,500 awarded by the USDA / NRI.

3/99 B 8/00. Raman, D. R., and R. T. Burns. *High-Rate Anaerobic Pretreatment of Animal Wastewater : Impact on Traditional Anaerobic Animal Waste Treatment System Performance and Economics.* $38,680 awarded by The United States Geological Service Water Resources Research Program.

07/99 - 06/00. R.T Burns and H.H. Dowlen. Dairy Manure Solids Separation project: Animal Waste Management Information & Education Project. $7,000 awarded by The Tennessee Department of Agriculture.

07/98 - 06/99. R.T. Burns, R.E. Yoder, M.J. Buschermohle, and G.S. Honea. *Soil Moisture Measurement of Plasticulture on Tomatoes and Cantaloupes.* UT Vegetable Initiative grant request. $1,800 awarded by the Knox Experiment Station. Work Plan Number TN-050-KES-02.

07/97 - 06/98. R.T. Burns and M.J. Buschermohle. *Alternative Livestock Watering Systems for Limited Access Situations*. $5,000 awarded by The Tennessee Department of Agriculture.

07/97 - 06/98. R.T. Burns and R.E. Yoder. *Soil Moisture Measurement Equipment for Irrigation Scheduling at Knoxville, Crossville, Greenville.* UT Vegetable Initiative grant request. $2,500 awarded by the Knox Experiment Station. Work Plan Number TN-050-KES-01.

07/97 - 06/98. R.T. Burns, R.E. Yoder, and M.J. Buschermohle. *Soil Moisture Data Monitoring in Support of TN-058-KES-01-1 and TN-058-KES-24-1.* UT Vegetable Initiative grant request. $5,400 awarded by the Knox Experiment Station. Work Plan Number TN-050-KES-02.

07/97 - 06/98. R.T. Burns and R.E. Yoder. *Drip Irrigation Filter Demonstration System Plant Sciences Unit - Knoxville.* UT Vegetable Initiative grant request. $5,500 awarded by the Knox Experiment Station. Work Plan Number TN-050-KES-03.

07/97 - 06/98.. R.T. Burns and R.E. Yoder. *Drip Irrigation Fertigation Demonstration System Plant Sciences Unit - Knoxville.* UT Vegetable Initiative grant request. $2,400 awarded by the Knox Experiment Station. Work Plan Number TN-050-KES-04.

10/96 - 09/97. R.T. Burns. Funding to support the Level II Agent In-Service *Animal Waste Management Training. Environmental Education Project*. Course taught in Spring 1997. $5,000 awarded by the U.S. Environmental Protection Agency.

07/96 - 06/97. R.T. Burns. Applied research work in swine waste manure application: *Application of Swine Waste*. $4,000 awarded by the Tennessee Department of Agriculture.

07/95 - 06/97. Yoder, R.E., D.C. Yoder, C.R. Mote, M.J. Buschermohle, R.T. Burns and N.S. Eash. *Cattle Access to Streams: Research and Demonstration.* $22,400 awarded by The Tennessee Department of Agriculture.

Web Site Development:

Iowa State University Animal Waste Management Website co-developed by Lara B. Moody and R.T. Burns. 2004 - Present. Web address: http://www.iastate.edu/

University of Tennessee Animal Waste Management Website co-developed by Lara B. Moody and R.T. Burns. 2001 - 2004. Web address: http://wastemgmt.ag.utk.edu/

Short-Courses Developed:

Training Workshop on Good Farming Practices to Reduce Environmental Pollution in Bulgaria. *May 27-30, 2006. Sofia, Bulgaria. R.T. Burns Course Co-Coordinator.*

Comprehensive Nutrient Management Plan Development Course. Feb. 13-15, 2005. Kansas City, MO. R.T. Burns Course Coordinator.

Comprehensive Nutrient Management Plan Development Course. Nov. 15-17, 2005. Portland, OR. R.T. Burns Course Coordinator.

Anaerobic Treatment of High-Strength Industrial and Agricultural Wastes. September 22-23, 2005 Milwaukee, WI. R.T. Burns course Co-Coordinator with D. Zitomer (Marquette University).

Comprehensive Nutrient Management Plan Development Course. Nov. 16-18, 2004. Indianapolis, IN.. R.T. Burns Course Coordinator.

Comprehensive Nutrient Management Plan Development Course. Feb. 12-14, 2003. Nashville, TN. R.T. Burns Course Coordinator.

Anaerobic Treatment of High-Strength Industrial and Agricultural Wastes. Feb. 19-20, 2004 Nashville, TN. R.T. Burns course Co-Coordinator with D. Zitomer (Marquette University).

Comprehensive Nutrient Management Plan Development Course. Nov. 17-19, 2003. Knoxville, TN. R.T. Burns Course Coordinator.

NRCS Anaerobic Treatment of Agricultural Wastes. Nov. 3-5, 2003 Nashville, TN. R.T. Burns Course Coordinator.

Anaerobic Treatment of High-Strength Industrial and Agricultural Wastes. Sept. 22-23, 2003. Milwaukee, WI. D. Zitomer (Marquette University) course Co-Coordinator with R. T. Burns.

Anaerobic Treatment of High-Strength Industrial and Agricultural Wastes. April 7-8, 2003. Knoxville, TN. R.T. Burns course Co-Coordinator with D. Zitomer (Marquette University).

Comprehensive Nutrient Management Plan Development Course. Feb. 12-14, 2003. Nashville, TN.. R.T. Burns Course Coordinator.

Animal Waste Management Systems: Comprehensive Nutrient Management Plan Development Course. Feb. 20-22, 2002. Nashville, TN. R.T. Burns Course Coordinator.

Manure Utilization Planning for CAFOs. July 28, 2001 Sacramento, CA. Continuing Professional Development Course (CPD) taught at 2001 ASAE meeting. R.T. Burns Course Coordinator.

Animal Waste Management Systems: Comprehensive Nutrient Management Plan Development Course. Feb. 19-21, 2001Nashville, TN Feb. R.T. Burns Course Coordinator.

Animal Waste Management Training: Level II Agent In-Service . March (Taught over a five week period), 1997 Nashville. R.T. Burns Course Coordinator.

Professional Service:

Iowa State University CNMP TSP Certification Program:
Serve as the Designated Technical Leader for the ISU Comprehensive Nutrient Management Plan Technical Service Provider certification program. Iowa State University serves as a national certification program from the United States Department of Agriculture. (2004 - Present).

Tennessee CNMP Third Party Certification Program:
Serve as the Designated Technical Leader for the Tennessee Comprehensive Nutrient Management Plan Technical Service Provider certification program. The University of Tennessee Agricultural Extension Service serves as a national certification program from the United States Department of Agriculture. (2000 - 2004).

Proceedings Chair - ISAAFPW 2003
Served as proceedings chair for The Ninth International Symposium on Animal, Agricultural and Food Processing Wastes held in Raleigh, NC on October 11-14, 2003.

ASAE Committee Service:

T-09 *Environmental Quality Group* member.
SE - 412 *Structures & Environment* committee member, Chair 2004 / 05 Vice Chair 2003 / 04, Secretary 2003 / 04, Session Chair - 2001 ASAE International Meeting
P - 414 *Professional Engineering Licensure* member, Chair for 2003 / 2005 (two -year term)
414 Vice-Chair 2001 - 2003

ASAE Manure Utilization Planning for CAFOs Short-Course:
Coordinated an ASAE national short-course titled "Manure Utilization Planning for CAFOs " held in conjunction with the 94th International ASAE meeting in Sacramento, CA in July, 2001.

2006 Chair - Iowa Section of the ASAE
Served as 2005 Chair of the Iowa Section of ASAE.

2005 Vice Chair for Programs - Iowa Section of the ASAE
Served as 2005 Chair of the Iowa Section of ASAE.

2002 Chair - Tennessee Section of the ASAE
Served as 2002 Chair of the Tennessee Section of ASAE.

Southern Region Chair - National Animal Waste Initiative
Served as the 2001-2002 Southern Region Chair of the National Animal Waste Initiative.

USDA Grant Reviews:

Served as a member of the 2004 USDA Conservation Effects Assessment Program CSREES competitive grant review panels held in Washington, DC.

Panel Manager for the 2002 USDA 406 Water Quality CSREES competitive grant review panel.
Served as a member of the 2000 and 2001 USDA 406 Water Quality CSREES competitive grant review panels held in Washington, DC.

Provide reviews of NRI and SBIR grants within the water quality area on request. 1999 – present.

Preparation of the PE Exam:

Assist with preparation of the national professional engineers exam (Agricultural Engineering exam). 1998 – Present.

Membership on Graduate Degree Candidate Committees: As Major Professor:

Timothy Shepard M.S., Agricultural Engineering In-Progress
Thesis Title: Development of a Pilot-Scale Struvite Recovery System for Phosphorus Recovery from Swine Manure Slurries.

Ishadeep Khanijo M.S., Agricultural Engineering In-Progress
Thesis Title: Modeling and Monitoring of Alternative Technology Beef Feedlot Run-Off Control Systems.

Ipek Celen Ph.D., Biosystems Engineering In-Progress
Dissertation Title: Optimization of Phosphorus Precipitation from Swine Manure Slurries to Enhance Recovery.

Ken Armstrong M.S., Biosystems Engineering Technology Completed 2003.
Thesis Title: Effect of Alum addition to Broiler Litter on Pathogen levels, Soluble Phosphorus and In-house Ammonia Levels on Broiler Production Systems.

Adam Daughtery M.S., Biosystems Engineering Technology Completed 2001
Thesis Title:: Economic Comparison of Animal Waste Transport and Application Methods.

Membership on Graduate Degree Candidate Committees: As Committee Member:
Asli Isci Ph.D. Agricultural Engineering In-Progress
Comparison Of Environmental Impacts Of Biofuel Production From Different Biomasses

Hong Li Ph.D. Agricultural Engineering In-Progress
Dissertation Title: Gaseous Emissions from Stored Poultry Manure

Wei Wu M.S., Animal Science In-Progress
Thesis Title: Influence of Diet on Ammonia and Hydrogen Sulfide Emissions from Laying Hens

Elizabeth Williams M.S., Biosystems Engineering Technology Completed 2003.
Thesis Title: Presence of 17-Beta Estradiol and Estrone in Dairy and Swine Manures.

Alexandra Maria Pinto Ph.D. Biosystems Engineering Completed 2001
Dissertation Title: Fuzzy-Logic Based Toxicity Detector for Upflow Anaerobic Sludge Bed Reactors.

A. Renea Peters M.S., Biosystems Engineering Technology Completed 2001
Thesis Title:: Runoff Masses of 17-Beta Estradiol from Plots Amended with Dairy Manure.

Theresa Louise Ervin M.S., Biosystems Engineering Completed 2001
Thesis Title:: Reservoirs of *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella* species on a Tennessee dairy farm.

Gary Hawkins Ph.D. Biosystems Engineering Completed 2000.
Dissertation Title: Kinetics of High-Rate Anaerobic Digestion of Dairy Waste.

Catherine R. Mayhew M.S., Biosystems Engineering Technology Completed 1999.
Thesis Title: *Mosquito Control and Pollutant removal in Constructed Wetlands: A Mesocosm Study Using Dairy-Wastewater.*

Jeffery Russell Powell M.S., Biosystems Engineering Technology Completed 1998.
Thesis Title: *Water Quality and Ecological Impacts of Watering Cattle Adjacent to a Small Middle Tennessee Stream.*

Joseph Cole Reagan M.S. Biosystems Engineering Technology Completed 1997.
Thesis Title: *An Examination of Methodologies to Assess High-Resolution Noninvasive Sensing of Near-Surface Perched Water.*

International Experience:

Republic of Korea.
Named a Senior Scientist in the Livestock Waste area for a three year term by The National Livestock Research Institute, RDA, South Korea, beginning in 2005. Provide consultation to the Animal Science Research Institute in the Republic of Korea on the development of a 100,000 head swine finish facility.
2004. Seoul National University - Invited Speaker. Presented lectures on Developing Sustainable Animal Production Systems. 2004 and 2005.
Konkuk University - Invited Speaker. Presented lectures on Environmental Engineering Aspects of Animal Production Systems. 2005. Chungju, South Korea.

Zambia. Mpongwe Development Company - Agricultural engineering support in the areas of post-harvest grain drying / storage and irrigation expansion planning for Mpongwe Development Company (MDC). The MDC operates the largest arable farm (60,000 ha) in Africa. The farm is operated in north central Zambia under a partnership between the Commonwealth Development Corporation and the Government of Zambia. 2003.

Consulting: Have provided agricultural and environmental engineering consulting services to various groups including the U.S. EPA, Mopongwe Development Corporation, America's Clean Water Foundation, The Tennessee Department of Environment and Conservation as well as numerous individuals and farming operations.

Membership in Professional and Honorary Societies

Air and Waste Management Association

American Society of Agricultural Engineers

American Society of Engineering Educators

Chi Epsilon (National Civil Engineering Honor Society)

Tau Beta Pi Engineering Honor Society (National member and Alpha Chapter member)

Phi Kappa Phi Honor Society (National Member and UTK Chapter member)

Gamma Sigma Delta (Honor Society of Agriculture)

Honors & Awards:

- **2006 Iowa Section of the ASABE Young Engineer of the Year.** Presented by the Iowa Section of the American Society of Agricultural and Biological Engineers to recognize an outstanding engineer less than 40 years of age in the Iowa Section.
- **2005 Honorary Senior Scientist.** Named a Senior Scientist in the Livestock Waste area for a three year term by The National Livestock Research Institute, RDA, South Korea.
- **2003 Nolan Mitchell Young Extension Worker Award**. Awarded by the American Society of Agricultural Engineers for distinguished educational programming in the areas of water quality and animal waste management.
- **2003 NACAA "Learning Module" National Winner Award**. Presented by the National Association of County Agricultural Agents, R. T. Burns, L. Moody and G. Grandle for the Comprehensive Nutrient Management Plan (CNMP) Certification Program Notebook.
- **2002 ASAE Blue Ribbon Award**. Awarded by the American Society of Agricultural Engineers in the Extension Methods Category for the TN CNMP Certification Program for TSPs. 2002.
- **2001 Outstanding Young Agent**. Awarded by the Tennessee Association of Agricultural Agents and Specialists. 2001.
- **Best Publication.** 1st Place statewide winner for best extension publication recognized

by the Tennessee Association of Agricultural Agents and Specialist for *Solar Livestock Watering Systems*. (PB 1640 Co-authored with M.J. Buschermohle). April, 2000.

- **Outstanding Speaker** by USDA-NRCS for paper *Mass Balance Approach to Long Term Nutrient Management Planning* at the Southeast Animal By-Product Utilization Workshop. September 3, 1999.
- **Epsilon Sigma Phi State Team Award -** Member of the Sustainable Dairy Systems Team that received the 1998 Epsilon Sigma Phi State Team Award. 1998.
- **Tennessee Higher Education Environmental Stewardship Award**. Member of the Extension Environmental Stewardship Priority Team that received the 1998 award.
- **Friend To CFW** - Award given by the Coffee-Franklin-Warren Animal Waste Utilization Association for Continued Support and Interest to the Association’s Dairy and Swine Producers. 1998.
- **Exceptional Service Award**. Presented by The University of Tennessee Department of Civil and Environmental Engineering. 1995.
- **Undergraduate Student with Professional Promise -** Recognition awarded by the faculty of the University of Tennessee Agricultural Engineering Department. 1990
- **ASAE Student Honor Award** - Tennessee Student Engineering Branch. Given in Recognition of Conspicuous Student Activity. 1990.

Hongwei Xin, Ph.D., Professor

Department of Agricultural and Biosystems Engineering
3103 National Swine Research and Information Center
Iowa State University, Ames, Iowa 50011-3080
Phone: 515-294-4240 Fax: 515-294-4250 E-mail: hxin@iastate.edu

Education

Ph.D.	Engineering (Bio-environmental Engineering Field) University of Nebraska-Lincoln (UNL), Lincoln, NE	1989
M.S.	Agricultural Engineering, UNL, Lincoln, NE	1985
B.S.	Agricultural Engineering, Shenyang Agr University, China	1982

Professional Experience

2002 – present	*Professor*, Department of Agricultural and Biosystems Engineering, Iowa State University (ISU), Ames, Iowa
2002 – present	Courtesy appointment, Department of Animal Science, ISU
1998 – 2002	*Associate Professor*, Department of Agricultural and Biosystems Engineering, ISU
1993 – 1998	*Assistant Professor*, Department of Agricultural and Biosystems Engineering, ISU
1990 – 1993	*Post-doctoral Research Associate*, Department of Biological and Agricultural Engineering University of Arkansas, Fayetteville, Arkansas
1990	*Post-doctoral Research Associate*, Department of Biological Systems Engineering, University of Nebraska-Lincoln (UNL), Lincoln, Nebraska
1984 – 1989	Graduate Research Assistant, Department of Agricultural Engineering, UNL
1982 – 1983	Instructor, Department of Agricultural Engineering, Shenyang Agr University, China

Research (70%) and Extension (30%) Activities

Impacts of biophysical factors on production performance, bioenergetics, behavior, physiology, and well-being of livestock and poultry; application of biosensors for enhanced animal well-being and production sustainability; livestock and poultry housing systems; and air quality issues related to concentrated animal feeding operations with emphasis on quantification and mitigation of aerial pollutant emissions.

Selected Awards and Honors

- Chair of the United Egg Producers Environmental Scientific Panel on Air Emissions (July 2004 –)
- Honorary Scientist of the Rural Development Administration of the Republic of Korea (2004-2006)
- Member of EPA National Air Emission Study Advisory Committee (2003-2004)
- New Holland Young Researcher Award of the ASAE (2001)
- Young Member of the Year Award, Mid-Central Section of the ASAE (2001)
- Young Engineer of the Year Award, Iowa Section of the ASAE (2001)
- Research Award for Foreign Specialist, Ministry of Ag, Forestry and Fisheries, Japan (2000)
- Invited member of USDA delegation to China for assessing environmental issues related to intensive animal production (2000)
- Eight ASAE Superior & Honorable Mention Paper Awards (1997 – 2005)
- Newcomer Engineer of the Year Award, Iowa Section of the ASAE (1997)
- Honorary Professor of the Chinese Academy of Agricultural Sciences (1998)
- Honorary Professor of China Agricultural University (1996)
- ASAE Educational Blue Ribbon Award (1995)

- Invited speaker at 20+ national conferences (USDA, ASAS, ASSP, Midwest Poultry Federation, United Egg Producers) and 20+ international conferences/ workshops (Belgium, Brazil, China, Costa Rica, France, Holland and Japan) (since1995)
- Sigma Xi Scientific Research Society Travel Award (1987)
- University of Nebraska Widaman Trust Distinguished Graduate Student Award (1986)

Publications

82 refereed journal articles, 40+ invited talks, 50+ conference proceedings, 120+ technical papers and presentations, 40+ extension publications

Contracts and Grants

Principal investigator (PI), Co-PI or collaborator of over $6.6 millions competitive grants for research, extension and undergraduate education.

Graduate students, post-docs, and visiting professors mentored/hosted

18 graduate students (9 MS, 9 PhD); 6 post-doc/research associates; 12 visiting professors/researchers

Refereed Journal Publications (2000-2006) (in chronological and alphabetical order)

1. Cai, L., J. A. Koziel, J. D. Davis, Y. C. Lo, and **H. Xin**. Characterization of VOCs and odors by *in vivo* sampling of beef cattle rumen gas using solid phase microextraction and gas chromatography-mass spectrometry-olfactometry: implications for gaseous emissions from concentrated animal feeding operations. *Journal of Chromatography* (in review)
2. Cai, L., J. A. Koziel, Y. Liang, A.T. Nguyen, and **H. Xin**. Evaluation of zeolite for control of odorants emissions from simulated poultry manure storage. *Journal of Environmental Quality* (in review)
3. Casey, K.D., R.S. Gates, E.F. Wheeler, **H. Xin**, Y. Liang, A.J. Pescatore, and M.J. Ford. On-farm fan performance: implications for ventilation and operating cost. *Applied Poultry Res.* (in review)
4. Casey, K.D., R.S. Gates, E.F. Wheeler, **H. Xin**, Y. Liang. Quantifying uncertainty in whole-building ammonia emissions from mechanically ventilated broiler houses. *Transactions of the ASAE* (in review).
5. Casey, K.D., R.S. Gates, E.F. Wheeler, **H. Xin**, Y. Liang. Determining whole-building ventilation rate of mechanically ventilated broiler houses. *Transactions of the ASAE* (in review).
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7. Dong, H., Z. Zhu, B. Shang, G. Kang, H. Zhu, and **H. Xin**. 2006. Emissions of greenhouse gases from a typical Chinese swine farrowing house. *Transactions of the ASAE* (in review).
8. Gates, R. S., K.D. Casey, E.F. Wheeler, **H. Xin** and A.J. Pescatore. U.S. broiler ammonia emissions inventory model. *Transactions of the ASAE* (in review).
9. Gates, R.S. and **H. Xin**. 2006. Extracting poultry behavior from time-series weigh scale records. *Computer and Electronics in Agriculture* (accepted for publication)
10. Liang, Y., **H. Xin**, H. Li, R.S. Gates, E.F. Wheeler and K.D. Casey. 2006. Effect of measurement interval on estimation of ammonia emission rates for layer houses. *Transactions of the ASAE* 49(1): 183-186.

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12. Shao, B. and **Xin, H**. 2006. A real-time computer vision assessment and control of thermal comfort of group-housed Pigs. *Computer and Electronics in Agriculture* (accepted for publication)
13. Tao, X., Z. Zhang, H. Dong, H. Zhang and **H. Xin**. 2006. Responses of thyroid hormones of market-size broilers at thermoneutral constant and warm cyclic temperatures. *Poultry Science* (in press)
14. Topper, P.A., E.F. Wheeler, J.S. Zajaczkowski, R.S. Gates, **H. Xin**, Y. Liang, K.D. Casey. Ammonia emissions from two empty broiler houses with built-up Litter. *Transactions of the ASAE* (in review).
15. Wheeler, E.F., K.D. Casey, R.S. Gates, **H. Xin**, J.L. Zajaczkowski, P.A. Topper, Y. Liang, A. J. Pescatore. 2006. Ammonia emissions from twelve U.S.A. broiler chicken houses. *Transactions of the ASAE* (accepted for publication).
16. Gates, R. S., **H. Xin**, K. D. Casey, Y. Liang, and E.F. Wheeler. 2005. A method for measuring ammonia emissions from poultry houses. *Applied Poultry Res.* 14: 622-634.
17. Li, H., H. Xin, Y. Liang, R. S. Gates, E. F. Wheeler, and A.J. Heber. 2005. Comparison of direct vs. indirect ventilation rate determinations in layer barns using manure belts. *Transactions of the ASAE* 48(1): 367-372.
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19. Zhang, Q. and **H. Xin**. 2005. Resting behavior of piglets in farrowing crates equipped with heat mats. *Applied Engineering in Agriculture* 21(6): 1067-1071.
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21. Chepete, H. J. and **H. Xin**. 2004. Heat and moisture production of poultry and their housing systems*: Molting layers*. *Transactions of the ASHRAE* 110(2): 274-285.
22. Chepete, H. J., **H. Xin**, M.C. Puma, and R.S. Gates. 2004. Heat and moisture production of poultry and their housing systems*: Pullets and layers*. *Transactions of the ASHRAE* 110(2): 286-299.
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24. Dong, H. X. Tao, **H. Xin**, and Q. He. 2004. Enteric methane emissions in China estimated with different IPCC methods and production schemes. *Transactions of the ASAE* 47(6): 2051-2057.
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26. Liang, Y., **H. Xin**, S. J. Hoff, and T. L. Richard. 2004. Performance of Single Point Monitor in measuring ammonia and hydrogen sulfide gases. *Applied Engineering in Agriculture* 20(6): 863-872.

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28. Pedersen, S., G. J. Monteny, **H. Xin** and H. Takai. 2004. Progress in research into ammonia and greenhouse gas emissions from animal production facilities. CIGR E-Journal Vol 6. http://cigr-ejournal.tamu.edu/Volume6.html.
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33. Chinkuyu, A.J., R.S. Kanwar, J.C. Lorimor, **H. Xin**, and T.B. Bailey. 2002. Effects of laying hen manure application rate on water quality. *Transactions of the ASAE* 45(2): 299-308
34. Tabler, G. T., I. L. Berry, and **H. Xin**, and T. L. Barton. 2002. Spatial distribution of mortality in broiler flocks. *Applied Poultry Res.* 11: 388-396.
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36. Yanagi, Jr., T., **H. Xin**, and R. S. Gates. 2002. A research facility for studying poultry responses to heat stress and its relief. *Applied Engineering in Agriculture* 18(2): 255-260.
37. Yanagi, Jr., T., **H. Xin**, and R. S. Gates. 2002. Optimization of partial surface wetting to cool caged laying hens. *Transactions of the ASAE* 45(4): 1091-1100 (**Honorable Mention Paper Award**).
38. Dong, H. X. Tao, J. Lin, Y. Li, and **H. Xin**. 2001. Comparative evaluation of cooling systems for farrowing sows. *Applied Engineering in Agriculture* 17(1): 91-96.
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41. Zhang, Q. and **H. Xin**. 2001. Responses of piglets to creep heat type and location in farrowing crate. *Applied Engineering in Agriculture* 17(4): 515-519 (**Honorable Mention Paper Award**).
42. **Xin, H**., I. L. Berry, G. T. Tabler, and T. A. Costello. 2001. Heat and moisture production of poultry and their housing system: *Broilers*. *Transactions of the ASAE* 44(6): 1853-1859.
43. Chepete, H.J. and **H. Xin**. 2000. Alleviating heat stress of laying hens by intermittent partial surface cooling. *Transactions of the ASAE* 43(4): 965-971.
44. Han, T. and **H. Xin**. 2000. Effects of intermittent lighting on limited-fed neonatal chicks. *Transactions of the ASAE* 43(6): 1767-1770.
45. Hu, J. and **H. Xin**. 2000. Image-processing algorithms for swine postural behavior analysis. *Behavior Research Methods, Instruments & Computers* 32(1): 72-85.

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49. Ye, W. and **H. Xin**. 2000. Measurement of surface temperature and postural responses of group-housed pigs to thermal conditions by thermography. *Transactions of the ASAE* 43(6): 1843-1851.
50. Zhang, Q. and **H. Xin**. 2000. Static and dynamic temperature distribution of heat mats for swine farrowing creep heating. *Applied Engineering in Agriculture* 16(5): 563-569.
51. Zhang, Q. and **H. Xin**. 2000. Modeling of heat mat operation for piglet creep heating. *Transactions of the ASAE* 43(5): 1261-1267.

Dr. Steven J. Hoff, Professor

Department of Agricultural and Biosystems Engineering
212 Davidson Hall
Iowa State University
515/294-6180 (voice)
515/294-2255 (facsimile)
e-mail: hoffer@iastate.edu

PERSONAL DATA………………………………………………………………

Born January 16, 1961
Warren, Minnesota USA
Married, 2 Children Ages 20 and 17

Registered Professional Engineer
State of Iowa Certificate No. 14637

EDUCATION……………………………………………………………………

Degree	**Major**	**Institution**	**Date**
Ph.D.	Agricultural Engineering	University of Minnesota	10/90
M.S.	Agricultural Engineering	University of Minnesota	05/87
B.Ag.Eng.	Agricultural Engineering (with **High Distinction**)	University of Minnesota	06/85
B.S.	Agricultural Engineering Technology	University of Wisconsin River Falls	06/83

PROFESSIONAL EXPERIENCE……………………………………………………

Professor, Iowa State University, 2005 to present
Associate Professor, Iowa State University, July 1995 to 2005
Assistant Professor, Iowa State University, November 1990 to June 1995

REFEREED PUBLICATIONS……………………………………………………

Hoff, S.J. and B.C. Zelle. 2006. Hydrogen Sulfide and Ammonia Concentrations in the Community of Multiple Agricultural Sources. (*accepted, Atmospheric Environment*).

Jerez, S.B., Y. Zhang, J.M. McClure, L.D. Jacobson, A.J. Heber, S.J. **Hoff**, J. Koziel, D. Beasley. 2006. Comparison of Measured Total Suspended Particulate Matter Concentration Using Tapered Element Oscillating Microbalance and a TSP Sampler. *J. Air & Waste Management Assoc., 56: 261-270.*

Hoff, S.J., D.S. Bundy, M.A. Huebner, B.C. Zelle, L.D. Jacobson, A.J. Heber, J. Ni, Y. Zhang, J. Koziel, D. Beasley. 2005. Emissions of Ammonia, Hydrogen Sulfide, and Odor Before, During and After Slurry Removal from a Deep-Pit Swine Finisher. *J. Air & Waste Management Assoc., accepted for publication.*

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Alimardani, R. and S.J. **Hoff**. 2005. Development of Multiple Velocity and Temperature Probe Sets for Ventilation Spaces. International *Agrophysics Journal*, 19(1): 1-6.

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Hoff, S.J. 2001. Assessing Air Infiltration Rates of Agricultural-Use Ventilation Curtains. *Applied Engineering in Agriculture, 17(4): 527-531.*

Harmon, J.D., D. Levis, J. Zulovich, S. **Hoff**, and G. Bodman. 2001. Swine Breeding and Gestation Handbook. MWPS-43. Midwest Plan Service, Ames, IA. 103 pages.

Hoff, S.J. 2000. The Environment in Swine Housing. *Pork Industry Handbook, PIH-54.* Purdue University Extension Service.

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Oberreuter, M.E. and S.J. **Hoff**. 2000. Quantifying Factors Affecting Sidewall Air Inlet Performance. *Transactions of the ASAE, 43(3): 707-716.*

Hoff, S.J. and C.G. Wu. 2000. Establishing Criteria for Sidewall Air Inlet Performance and Evaluation of Four Commercial Inlets on this Criteria. *Transactions of the ASAE, 43(3): 735-743.*

Yu, H. and S.J. **Hoff**. 1999. Airflow Pattern Similarity Criteria for Ceiling Slot-Ventilated Agricultural Enclosures Under Isothermal Conditions. *Transactions of the ASAE, 42(2): 459-469.*

Chen, Y., D.S. Bundy and S.J. **Hoff**. 1999. Development of the Relationship Between Odor Intensity and Threshold Dilution Ratio for Swine Units. *J. Air & Waste Manage. Assoc. 49: 1082-1088.*

Hoff, S.J. and P. Sundberg. 1999. Breakage and Deformation Characteristics of Hypodermic Devices Under Static and Dynamic Loading. *American Journal of Veterinary Research, Vol. 60(3):292-298.*

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Chen, Y., D. S. Bundy, and S. J. **Hoff**. 1998. Modeling the Variation of Wind Speed with Height for Agricultural Source Pollution Control. *ASHRAE Transactions. Vol.*104.

Chen, Y., S.J. **Hoff**, and D. S. Bundy. 1998. The Dispersion Parameters Modeling and Evaluation for Odor Control from Agricultural Sources. *Journal of Environmental Systems. 26: 27-39.*

Perez-Munoz, F., S.J. **Hoff**, and T.E. Van Hal. 1998. A Quasi-Adlibitum Electronic Feeding System for Gestating Sows in Loose Housing. *Computers and Electronics in Agriculture. 19: 277-288.*

Buiter, J. and S.J. **Hoff**. 1998. Ammonia Distribution in a Pit-Ventilated Confinement Building: One-Half Scale Model Study. *Transactions of the ASAE*, 41(6): 1817-1827.

Hoff, S.J. and D.S. Bundy. 1996. Comparison of Contaminant Dispersion Modelling Approaches for Swine Housing. *Transactions of the ASAE, 39(3):1151-1157.*

Liu, Q., S.J. **Hoff**, G.M. Maxwell, and D.S. Bundy. 1996. Comparison of Three k-ε Turbulence Models for Predicting Ventilation Air Jets. *Transactions of the ASAE, 39(2):689-698.*

Li, X., S.J. **Hoff**, D.S. Bundy, J.D. Harmon, and H. Xin. 1996. Biofilter- A Malodor Control Technology for Livestock Industry. *J. Environ. Sci. Health, A31(9):2275-2285.*

Hoff, S.J. and J. Li. 1995. Simulated and Measured Effect of Rectangular Obstructions on Carbon Dioxide Gas Dispersion in a Scaled Swine Building. *Transactions of the ASAE, 38(5):1519-1532.*

Hoff, S.J. 1995. Isothermal Airflow Characteristics in the Animal Occupied Zone of a Slot-Ventilated Swine Facility. *Transactions of the ASAE, 38(6):1843-1852.*

Hoff, S.J. 1995. A Simplified Turbulence Model for Describing Airflow in Ceiling Slot-Ventilated Enclosures. *Transactions of the ASAE, 38(6):1853-1862.*

Hoff, S.J., K.A. Janni and L.D. Jacobson. 1995. Evaluating the Performance of a Low Reynold's Number Turbulence Model for Describing Mixed-Flow Airspeed and Temperature Distributions. *Transactions of the ASAE, 38(5):1533-1541.*

Li, Q., D.S. Bundy, and S.J. **Hoff**. 1995. A Study on the Air Flow and Odor Emission Rate From a Simplified Open Manure Storage Tank. *Transactions of the ASAE, 38(6): 1881-1886.*

Hoff, S.J., K.A. Janni and L.D. Jacobson. 1993. Defining the Newborn Piglet's Thermal Environment with an Effective Environmental Temperature. *Transactions of the ASAE, 36(1):143-150.*

Hoff, S.J., K.A. Janni and L.D. Jacobson. 1993. Modelling New-Born Piglet Thermal Interactions with a Surface Energy Balance Model. *Transactions of the ASAE, 36(1):151-159.*

Hoff, S.J., K.A. Janni and L.D. Jacobson. 1992. Three-Dimensional Buoyant Turbulent Flows in a Scaled-Model, Slot-Ventilated, Livestock Confinement Facility. *Transactions of the ASAE, 35(2):671-686.*

Hoff, S.J. and K.A. Janni. 1989. Monte Carlo Technique for the Determination of Thermal Radiation Shape Factors. *Transactions of the ASAE, 32(3): 1023-1028.*

PATENTS AND DISCLOSURES……………….……………………………………..

UNITED STATES PATENT NO. 6,360,955 Received March 26, 2002.

*Method and Means for Automated Variable Heater Control for Agricultural Unit Heaters (**Hoff**, S.J, J.D. Harmon, and D. VanUtrecht)*

Current agricultural heaters use on/off heat control much like a home heating system. This strategy results in significant temperature swings for young animals susceptible to chilling effects. This patent was received for a technique that we developed to provide automated variable output control for LP-gas based livestock housing space heaters. Our design reduced animal level temperature swings from in excess of 14 degrees Fahrenheit to less than 1 degree Fahrenheit.

UNITED STATES PATENT NO. 5,813,599 Received September 29, 1998.

*Automated Controller for Naturally Ventilated Livestock and Poultry Facilities (**Hoff**, S.J.)*

Many livestock housing systems consist of natural ventilation where fans are not used to provide fresh air to livestock and poultry. This strategy can be very cost effective. To control this method of ventilation requires a coordinated strategy between openings used for natural ventilation. This patent was received for the logic developed in controlling ridge vents and sidewall vents using multiple zones and strategic placement of feed-back sensors in a barn. A significant reduction in environmental temperature variation was demonstrated with the developed logic compared to traditional natural ventilation control methods.

UNITED STATES PATENT NO. 5,767,385 Received June 16, 1998.

*Automated Forced-Choice Dynamic-Dilution Olfactometer and Method of Operating the Same (D.S. Bundy, W. Huang, S.J. **Hoff**, Q. Liu, and X. Li)*

Iowa State University has been a national leader in odor measurement and general livestock odor-related topics. This work started in roughly 1990 with Dr. Dwaine Bundy. In 1993 a graduate student under my supervision (Mr. Wen-Yu Huang) developed an olfactometer specific for livestock odors. This work originated with an AE404/504 design project. The olfactometer developed can deliver a diluted odor sample to four panelists simultaneously in 12 dilutions between 2^3 and 2^{15} (fresh-air volume to odor sample volume). The entire system including all electronic hardware and software control along with dynamic dilution theory was developed for which we received a patent.

UNITED STATES PATENT NO. 5,707,283 Received January 13, 1998.
Dual Baffle System in Automatic Air Inlets for Livestock Facilities (Oberreuter, M.E., S.J. ***Hoff****, and F. perez-Munoz)*

Current livestock housing systems utilize fresh-air intakes similar in many ways to diffusers used in office buildings. Many designs utilize an automated baffle inlet control system where the inlet opening changes opening area in response to airflow delivery rates. These automated systems have a weakness in that the inlet area generally increases at a level that is too large relative to the ventilation rate causing low operating pressures and therefore poor air distribution characteristics. This patent was received for a method we developed on baffle control that better adjusted inlet opening area as a function of airflow that allowed higher operating static pressures at low airflow rates thus maintaining better fresh-air distribution characteristics.

UNITED STATES PATENT NO. 5,579,719 Received December 3, 1996.
*Method and Means for Quasi Ad-Libitum Feeding for Gestation Sows in Loose Housing (****Hoff****, S.J., M.S. Honeyman, J.D. McKean, E.J. Stevermer, D.S. Bundy, F. Perez-Munoz, S.E. Bryce, and W.E. Backhaus)*

Housing pigs in bedded situations is a strategy that is gaining popularity. Much of this is in response to animal welfare issues. Gestating sows represent a unique challenge in that control of a sow's growth curve during gestation is beneficial. This can be a very difficult challenge with sows grouped together in a loose housing, bedded situation. The patent that we received was for the electronic sensing and controls, gating design, housing arrangement, and control software to track an individual sow's growth curve and to gate each animal to two specific diets depending upon current growth curve targets. This patent was received eight years ago. Within the past three years, "new" pig sorting systems have been developed and marketed that use many of the features we developed in our patent. I have asked ISURF to determine how much of our strategy is in fact being used with these new systems.

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In addition to the five patents received, software has been disclosed to the Iowa State University Research Foundation for protection for projects that I developed. A summary of these is given below.

ISURF #02478; Submitted and disclosed on September 21, 1998.
*A Community Assessment Model for Site Selection and Odor Management for Swine Operations (****Hoff****, S.J. and D.S. Bundy)*

We have been developing since about 1998 a model to describe the dispersion of odors from swine production systems. This model was initially disclosed to ISURF in 1998 and was recently associated with a current agreement established between ISURF and the Iowa Farm Bureau (August 2002).

ISURF #02714; Submitted and disclosed on July 31, 2000.
Automated Variable Cycling Algorithm for Animal Cooling (S.J. ***Hoff****)*

Pigs do not sweat. As an industry practice, pigs are allowed to artificially sweat through the application of water to their skin. Current practices increase water usage with temperature without regards to current environmental evaporation potential. This disclosure protects logic that I have developed for changing this strategy and significantly reducing water usage for pig cooling.

GRANTS AND CONTRACTS……………………………………………………………………

A total exceeding $6.5 million awarded for projects where I have served as a Co-Investigator or above status. Of this $6.5 million total, I served as PI or Co-PI for $3.5 million.

Richard S. Gates, Ph.D.

Professor and Chair of Department
Biosystems & Agricultural Engineering
University of Kentucky
Email: gates@bae.uky.edu

Administrator for the teaching, research and cooperative extension services of the department.

Teaching undergraduate and graduate courses in probability and statistics, numerical methods, heat and mass transfer, psychrometrics, environment control, data acquisition and control, instrumentation, nonlinear optimization.

Research includes air quality, interior environmental analysis, control and simulation; greenhouse engineering, vapor pressure deficit control systems, livestock production models for real-time economic optimization, and manipulating livestock diets to reduce gaseous emissions and environment impacts.

Extension and **Consulting** related to applications of research, including greenhouse and livestock environment control systems, livestock heat stress reduction, and control systems.

Education

B.S. Agricultural Engineering, University of Minnesota, 1978.
M.S. Agricultural Engineering, Cornell University, 1980.
Ph.D. Biological Engineering, Cornell University, 1984.

Professional Experiences

Senior Systems Analyst, 1983-1984
Assistant Professor, December 1985 – June 1990
Associate Professor, July 1990 – June 1996
Professor, July 1996 to present
Chair, April 2002 to present

Patent

Method for controlling environment conditions based upon time integrated variables. U.S. Patent No. 5,573,199. M.B. Timmons, co-inventor.

Professional and Honor Society Memberships

Registered Professional Engineer: KY PE-14892
United Egg Producers, Environmental Scientific Panel, Research Committee Chair.
Poultry Science Association, Environmental Technical Committee.
Society memberships include:

> American Society of Agricultural and Biological Engineers (ASABE), American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE), Federation of Animal Science Societies (FASS), Poultry Science Association (PSA), World Poultry Association (WPA), Sigma Xi (Research) (1982-present), Alpha Epsilon (Agricultural Engineering) (1977-present), Gamma Sigma Delta

Recent Awards

Henry Giese Structures and Environment Award, ASABE, 2006.
Patriotic Employer Award, National Committee for Employer Support of the Guard and Reserve.
ASABE Outstanding Paper Awards:

1. Feeding behaviors of laying hens with or without beak trimming, 2005. Trans ASAE, 47(2):591-596.
2. A literature review of swine heat production, 2005. Trans ASAE, 47(1):259-270.

Selected Current Extramural Funding

Biosystems and Agricultural Engineering -- Educational Consortium for Sustainable Plant and Animal Production Systems. $204,000 (year 1, $29,850 funded). Project leader. With Iowa State University, and four Brazilian Universities. U.S. Department of Education's Fund for the Improvement of Postsecondary Education (FIPSE), 2003-2007

Kentucky Rural Energy Supply Program, C. Metcalf (University of Louisville, $1,984,000 US Department of Energy). R.S. Gates, S.E. Nokes, D.G. Colliver and M.D. Montross $268,600 (subcontract awarded by University of Louisville for competitive grants administration), 2005-2007

Total Suspended Particulate, PM10, PM2.5, Hydrogen Sulfide and Hydrocarbon National Consent Agreement Emissions Determination from Broiler Production Systems. R.T. Burns, H. Xin, R. Gates and S. Hoff. $648,231 awarded by Tyson Foods.10/05 – 10/07

Ammonia Emissions Determination from Broiler Production Systems. R.T. Burns, H. Xin and R. Gates. $399,525 awarded by Tyson Foods.3/05 – 9/06

Effect of enzyme inhibitors on ammonia emission from broiler houses. $18,000. R.S. Gates, A. Singh, K. Casey and A. Pescatore. North Carolina Animal and Poultry Waste Management Center. 7/04-6/06

Demonstration of Intensive Marine Shrimp Production Using Microbial Floc Based Technology at an In-land Location. Proposal to National Oceanographic and Atmospheric Administration, February 2006. $400,000 per year, 2-years. (Ebeling, Anderson and Boudreau, PI's; Tidwell, Gates, Timmons, Cooperators)

Development of Marine Shrimp Genetic Lines for High Microbial Systems. Proposal to National Oceanographic and Atmospheric Administration, February 2006. $400,000 per year, 2-years. (Boudreau, Anderson and Ebeling, PI's; Tidwell, Gates, Cooperators)

Selected Publications

Publications in Refereed Journals 91
In Review: 6
In Preparation: 9

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- Purswell, J.L., R.S. Gates, L.M. Lawrence, J.D. Jacob, T.S. Stombaugh and R.J. Coleman. 2006. Air exchange rate in a horse trailer during road transport. Transactions of the ASAE accepted for publication.
- Liang, Y., H. Xin, E.F. Wheeler, R.S. Gates, H. Li, J.S. Zajaczkowski, P. A. Topper, K.D. Casey, B.R. Behrends, D.J. Burnham and F.J. Zajaczkowski. 2005. Ammonia emissions from U.S. laying houses in Iowa and Pennsylvania. Transactions of the ASAE. 48(5):1927-1941.
- Gates, R.S., H. Xin, Y. Liang, K.D. Casey, E.F. Wheeler and. 2005. Method for measuring ammonia emissions from poultry houses. J Appl Poult Res. 14:622-634.
- Green, A.R., R.S. Gates and L.M. Lawrence. 2005. Measurement of horse core body temperature. J. Thermal Biol. 30(1):370-377.

Dr. Douglas G. Overhults, P. E.

Associate Extension Professor
University of Kentucky
Biosystems & Agricultural Engineering Department

Registered Professional Engineer
State of Kentucky

Professional Specialty:

Planning, analysis, and engineering design for animal production facilities, environmental control systems, and manure management

Educational Background:

B. S. and M. S. in Agricultural Engineering from the University of Kentucky

Ph.D. in Bio-environmental Engineering from the University of Nebraska

Experience

7/88 – present	Associate Extension Professor, Agricultural Engineering, U. of KY
4/82 – 6/88	Assistant Extension Professor, Agricultural Engineering, U. of KY
6/78 – 4/82	Instructor & Research Asst., Agricultural Engineering, U. of NE
11/72-5/78	Extension Specialist, Agricultural Engineering, U. of KY
1/71-10/72	Research Assistant, Agricultural Engineering, U. of KY

Current Assignment:

University of Kentucky, Cooperative Extension Service

Located at the UK Research & Education Center in Princeton, KY

Professional Activities

Local arrangements chair for 2001 International Livestock Environment Symposium

- Past Chairman of ASAE SE-302, Environment of Animal Structures Committee
- Past Chair – ASAE SE-02 (Structures & Environment Division Steering Committee)
- Member – ASAE SE-404 (Swine Housing) and SE-405 (Poultry Housing) committees
- Technical reviewer for articles published in 2 ASAE peer reviewed journals
- Instructor for 3 ASAE continuing professional development sessions
- Previously served as Chairman of the Swine Housing and Animal Environment committees and the Structures and Environment Division of the American Society of Agricultural and Biological Engineers
- Served on Planning Committee for the 2001 International Livestock Environment Symposium

Consulting

- Consultant to Lewis-King, Attorneys at Law , Nashville, TN. Litigation involving dairy cattle facilities, Defendant. 1999-2000.
- Court appointed expert for a special judge in litigation regarding the construction of broiler production houses. 1997.

Awards and Honors

- ASAE Blue Ribbon Awards for Educational Aids (6)
- American Society of Agronomy “Certificate of Excellence,” Extension publication
- “Outstanding Service Award” from the Kentucky Pork Producers Association, 1997

Current Extension Education/Training Programs

Livestock and Poultry Facilities

- Environmental modification and control systems with emphasis on mechanical ventilation, cooling systems, and energy use in swine and poultry barns
- Testing fans as installed in broiler barns to determine ventilation rates under field operating conditions
- Engineering design and analysis related to swine and poultry production systems, including structures, equipment, manure management, and feed processing

Swine & Poultry Manure Management

- Providing technical information to assist with the development of design and construction information for poultry litter storages, liquid manure storages, lagoons, and composters.
- Part of research team measuring gaseous and particulate emissions from broiler barns

Hay Storage Structures

- Providing educational program support for the Kentucky Ag. Development Board's model program on hay storage facilities

Recent Publications

Overhults, Douglas G. 2004. Measuring hay temperatures. In 24th Kentucky Alfalfa Conference Proceedings, p 12-17. University of Kentucky Cooperative Extension Service.

Bridges, T.C., L. W. Turner, R. S. Gates, D. G. Overhults. 2003. Assessing the benefits of misting–cooling systems for growing/finishing swine as affected by environment and pig placement date. Applied Engineering in Agriculture 19(3): 361–366.

McNeill, S. G. and D. G. Overhults. 2002. Moisture and handling shrink factors for grain. Electronic publication at URL: http://www.bae.uky.edu/ext/GrainStorage/shrink_factors.htm

Coffey, R.D., G. R. Parker, K. M. Laurent, and D. G. Overhults. 2000. Sampling Animal Manure. University of Kentucky, Cooperative Extension Service. No. ID-148.

Bridges, T.C., L. W. Turner, R. S. Gates and D. G. Overhults. 2000. Swine performance enhancement with cooling as influenced by summer growth period and weather. In Swine Housing, Proc. First Int. Conf. (October 9-11, 2000, Des Moines, Iowa), pp. 348-356, ASAE, St. Joseph, MI.

Animal Waste Focus Group. 1999. Assessment of the Potential for Livestock and Poultry Manure to Provide the Nutreints Removed by Crops and Forages in Kentucky. University of Kentucky Cooperative Extension Service. No. IP-56.

Lara Beal Moody, P.E.

Iowa State University
3165 NSRIC
Ames, IA 50011
515-294-7355
lmoody@iastate.edu

Education

M.S. Biosystems Engineering, The University of Tennessee, Knoxville. Thesis: Laboratory Scale Testing of an Anaerobic Waste Treatment System for a Confectionery Wastestream. August 1998. GPA: 3.6/4.0
B.S. Agricultural Engineering, The University of Tennessee, Knoxville. December 1996.
GPA: 3.2/4.0

Employment History

Department of Agricultural & Biosystems Engineering, Iowa State University, Ames, IA
- Extension Program Specialist, October 2004 - Present

America's Clean Water Foundation, Washington, D.C.
- Consulting Engineer, April 2004 – March 2005

Department of Agricultural & Biosystems Engineering, The University of Tennessee, Knoxville
- Extension Associate, Water Quality Engineer, June 2001 – August 2004
- Research Associate, September 1998 – May 2001
- Graduate Research Assistant, January 1997 – August 1998
- Undergraduate Research Assistant, June 1995 - December 1996

Research Areas
- Alternative technologies for beef feedlot runoff control
- Forced precipitation of phosphorus for soluble nutrient reduction in swine waste
- Chemical amendment to manure for increased performance of mechanical solids separators
- Field-testing of solids separation equipment for dairy wastewater
- Quantification and minimization of estrogen discharges to the environment from dairy waste
- Feasibility of confectionery waste treatment using high rate anaerobic digestion

Professional Registration
- Registered Professional Engineer in Tennessee, 2002
- Registered Professional Engineer in Iowa, 2006

Professional Service
- SE-412. Agricultural Waste Management. ASAE. 2003 – 2007
- FPE-707. Food Processing Waste Management and Utilization. ASAE. 2002 - 2006

Honors & Awards
- NACAA Communication Award, Learning Module Competition, 2003
- The ASAE Blue Ribbon Award, Educational Aids Competition, 2002
- Agricultural Engineering Undergraduate Student with Professional Promise, 1996
- First place, Padnos Team Engineering National Design Competition, 1996
- Agricultural Engineering Scholarship, 1995 & 1996
- Jo Mac Alphin Scholarship, 1994 & 1995
- Joe and Margaretta Wheeler Scholarship, 1994

Grants

- 09/03 – 09/06. *Development of a CNMP Core Training Curriculum*. R.T. Burns, L.B. Moody, N. Rector, A. Sutton, R. Sheffield. **$290,000. Awarded by USDA 406 Extension Education Program**.

- 12/03 – 12/06. *Recovery and Agronomic Recycling of Phosphorus from Swine Manure Slurries*. R.T. Burns, **L.B. Moody**, F.R. Walker, W. Park, J. Buchanan. **$168,000. Awarded by USDA NRI.**

- 05/05 – 05/08. *Non-Basin Technologies for Open Feedlot Runoff: Demonstration, Implementation, and Modeling*. R. Burns, J. Lawrence, L. Moody, M. Helmers. **$631,000. Subcontract from Iowa Cattleman's Association via the U.S.EPA.**

- 6/05 – 6/06. *Pathogen Monitoring from Alternative Beef Feedlot Run-Off Control Systems*. R.T. Burns, L.B. Moody and J.D. Lawrence. **$30,000 awarded by the U.S. EPA.**

- 4/06 – 12/06. *Development of a Database for Environmental Management Practices Employed at Pork Production Facilities*. R. Burns, L. Moody, D. Raman, L. Meyer. **$103,002 awarded by the National Pork Board**.

Publications

Refereed:

Oh, I., R.T. Burns, **L.B. Moody**, J. Lee. 2005. Optimization of phosphorus partitioning in dairy manure using chemical additives with a mechanical solids separator. *Transactions of ASAE*. 48(3).

Burns, R.T.; **L.B. Moody**; I. Celen; J.R. Buchanan. 2003. Optimization of phosphorus precipitation from swine manure slurries to enhance recovery. *Water Science Technology*. 48(1): 139-146.

Raman, D.R.; A.C. Layton; **L.B. Moody**; J.P. Easter; G. Saylor; R.T. Burns; M.D. Mullen. 2001. Degradation of estrogens in dairy waste solids: effects of acidification and temperature. *Transactions of ASAE*. 44(6): 1881-1888.

Burns, R.T.; **L.B. Moody**; F.R. Walker; D.R. Raman. 2001. Laboratory and in-situ reductions of soluble phosphorus in swine waste slurries. *Environmental Technology.* 22(11): 1273-1278.

Moody, L.B. and D.R. Raman. 2001. A dual reactor anaerobic system for complete treatment of a food processing waste. *Journal of Agricultural Engineering Research*. 80(3): 293 – 299.

Beal, L.J. and D.R. Raman. 2000. Sequential two-stage anaerobic treatment of confectionery wastewater. *Journal of Agricultural Engineering*. 76(2), 211-217. doi:10.1006/jaer.2000.0555.

Beal, L.J., F.H. Moody, J.T. Wesner, T.L. Ogle, B.A. Peters, M.L. Orr, J.A. Crouch, D.R. Raman, and R.E. Yoder. 1997. Feasibility of an Alternative Dairy Waste Management System. *Technology: Journal of the Franklin Institute. 334A*.

Extension Publications:

AWM-01-01, *Press Tech Agri-Press 600* Solids Separator Performance Tests Results Using the University of Tennessee Testing Protocol. R.T. Burns and **L.B. Moody**.

AWM-01-02, *Vincent KP-6L* Solids Separator Performance Tests Results Using the University of Tennessee Testing Protocol. R.T. Burns and **L.B. Moody**.

Sampling Dairy Manure for Nutrient Management, in Comprehensive Nutrient Management Planning for Your Dairy, field day proceedings (pp 77-79). **L.B. Moody**.

Non-refereed:

Burns, R.T., **L. B. Moody**, G. Considine, B. Gramig, T. Hebert, J.K. Meeker and A. Stokes. 2005. Developing the Model of Animal Waste System Risk (MAWSR) for Livestock Waste Storage Facilities. *Proceedings of the 98th Annual Air & Waste Management Association Conference*. Paper # 1305.

Burns, R.T. and **L.B. Moody**. 2003. Tennessee comprehensive nutrient management plan third party element writer certification program. Proceedings of the Ninth International Symposium on Animal, Agricultural and Food Processing Wastes, Raleigh, NC.

Grandle, G.F., **L.B. Moody**, R.T. Burns. 2003. Experiences in preparing a CNMP Emergency Response Plan for a Tennessee Dairy Farm. Proceedings of the Ninth International Symposium on Animal, Agricultural and Food Processing Wastes, Raleigh, NC.

Burns, R.T and **L.B. Moody**. 2003. CNMP certification for third party technical service providers. ASAE # 038027. ASAE St. Joseph, MI.

Burns, R.T. and **L.B. Moody**. 2003. Development of a standard method for testing mechanical manure solids separators. *ASAE Paper # 034131*. ASAE St. Joseph, MI.

Oh, I.; **L.B. Moody**, I. Celen, J. Lee; R.T. Burns. 2003. Optimization of phosphorus partitioning in dairy manure using aluminum sulfate with a mechanical solids separator. *ASAE # 032266*. ASAE St. Joseph, MI.

Burns, R.T. and **L.B. Moody**. 2001. Performance testing of screw-press solid separators: comprehensive solids analysis and nutrient partitioning. Presented at the International Symposium addressing animal production and environmental issues, Oct. 3-5, Raleigh, North Carolina.

Dyer, A.R.; D.R. Raman; M.D. Mullen; R.T. Burns; **L.B. Moody**; A.C. Layton; G.S. Saylor. 2001. Determination of 17b-estradiol concentrations in runoff from plots receiving dairy manure. ASAE Paper #012107. ASAE St. Joseph, MI.

Pinto, A.M.; D.R. Raman, **L.B. Moody**. 2000. Using fuzzy logic to determine failure modes in a biological sensor for UASB reactors. *ASAE Paper # 006127*. ASAE St. Joseph, MI.

Beal, L.J., R.T. Burns, K.J. Stalder. 1999. Effect of anaerobic digestion on struvite production for nutrient removal from swine waste prior to land application. *ASAE Paper # 994042*. ASAE St. Joseph, MI.

Beal, L.J. and D.R. Raman. 1998. Comparison of high-rate anaerobic processes for confectionery wastewater treatment. *ASAE Paper #986109*. ASAE St. Joseph, MI.

Raman, D.R., **L.J. Beal**, S.W. Rye, A.C. Stiles, R.E. Yoder, and N.S. Eash. 1997. Kinetics of COD and N removal from a highly loaded constructed wetlands. *ASAE Paper #975025.* ASAE St. Joseph , MI.

John Walter Earnest, Jr.

206 Cherry Lane
Princeton, KY 42445-2325
(270) 365-6273

EDUCATION:

- B.S. in Electrical Engineering (Power; Optoelectronics) Pennsylvania State University, 1978.
- A.S. in Electrical Technology, Williamsport Area Community College, 1976

BACKGROUND:

- 1978 to 2004, Major US Army, Status Retired. Significant positions included:
    - Survey Recon Commander
        - Commanded a topographic survey and reconnaissance 20 man platoon in support of a combat Field Artillery Battalion
        - Responsible for tactical deployment, equipment maintenance, and operations associated with the platoon
        - Supervision of the maintenance operations of a 210 man Headquarters Battery and all associated tactical equipment.
    - Battery (Unit) Commander
        - Commanded a 200 man capable combat Field Artillery Battery
        - Responsible for tactical deployment, equipment maintenance, personnel management and operations of a nuclear capable unit deployed in Western Europe.
    - Deputy Installation Coordinator (Equivalent to a position of a small City Manager)
        - Supervised both the coordination between and operations of eighteen major staff directorates and ten assigned tactical units. Ensured the effective, cohesive execution of the objectives of the community.
        - Supervised the maintenance and operation of facilities and all construction projects of large military community. Ensured that both the needs and requirements of the community were satisfied and that the objectives of the Community Commander were met.
        - Supervised the implementation of a community Master Development Program which will effectively meet all requirements until Fiscal Year 1999. Plan was fully supported by utility upgrades, both major and minor construction projects, beautification plans and traffic management studies at a total program cost of $36.2 million.
- 1989 to 1990, Assistant Water Superintendent
    - Supervised the successful construction of a major sewer collection project and water main distribution project built for the City of Princeton, Kentucky.
- 1989 to Present, Police Officer (Part time), Princeton Police Department, Princeton KY.
    - As a Kentucky Certified Police Officer, duties include those of

    - Collision Reconstructionist Level V
    - School Extracurricular Activities Officer
    - Information Technology Coordinator

- 1990 to Present, Technical Engineer, Biosystems and Agricultural Engineering, University of Kentucky
    - Designed and built specialized agricultural equipment to include ATV Towed Plot Boom Sprayer,
    - Designed and installed specialized electrical and motor control projects. Significant projects included fruit sorting facility, cattle processing and weighting facilities, automated water pumping facility, and swine mature pump and spray facility.
    - Provided technical support to an extensive, multi-year energy study of a chicken broiler houses over a period of 72 barn months. Results of the study provided the basis for temperature and energy control procedures which are used throughout the poultry industry.
    - Developed and maintain a detailed Geographic Information Database that is used as an example for Precision Agriculture databases.
    - Provided technical support in a multi-University research project which developed insect and environment control guidelines for use in grain storage facilities.
    - Demonstrated skills include operation and utilization of electrical test, power generation, light and heavy construction and material handling, automotive diagnostic, hand and power tools, automated motor control, pneumatic, hydraulic, geographical and topographical survey, geographical positioning systems, geographical information systems, semi-automatic and arc welding, automated data recoding equipment, and computer/automated data collection and processing equipment.
    - Served as an elected representative of the University Staff on the University Staff Senate.
    - Serve as a Information Technology advisor to the University of Kentucky Research & Education Center

HONORS:

- Outstanding Staff Award, College of Agriculture, University of Kentucky – 2005
- Army Meritorious Service Medal – 1985; 1989
- Army Commendation Medal – 1982; 1985
- Dean’s List – Pennsylvania State University and Williamsport Area Community College.

Hong Li, Ph.D.

Department of Agricultural and Bioenvironmental Engineering

1242 NSRIC, Iowa State University, Ames, IA 50011
Phone: (515) 294-8633 Fax: (515) 294-4250 E-mail: lwblue@iastate.edu

EDUCATION

Ph.D. in Agricultural and Biosystems Engineering, Iowa State University, USA
August 2002 – May 2006

M.S in Agricultural and Bioenvironmental Engineering, China Agricultural University, China,
September 1998 – July 2001

B.S in Agricultural and Bioenvironmental Engineering, China Agricultural University, China,
September 1994 -- July 1998

PROFESSIONA EXPERIENCES

Present	*Post-doc Research Associate,* Department of Agricultural and Bioenvironmental Engineering, Iowa State University, Ames, Iowa
2005- 2006	*Pre-doctoral Research Associate,* Department of Agricultural and Bioenvironmental Engineering, Iowa State University, Ames, Iowa
2002- 2005	*Research Assistant*, Department of Agricultural and Bioenvironmental Engineering, Iowa State University, Ames, Iowa
2001- 2002	*Engineer*, Jingwei Textile Machinery Co., Ltd., Jinzhong, Shanxi, China
1998- 2001	*Research Assistant*, China Agricultural University, Beijing, China

PROFESSIONAL MEMBERSHIPS

American Society of Agricultural and Biological Engineers (ASABE)

Air and Waste Management Association (AWMA)

Association of Overseas Chinese Agricultural, Biological and Food Engineers (AOCABFE)

AWARDS AND HONORS

First Place in 2004 AOCABFE paper competition

China Agricultural University Scholarship from 1995-1998

SERVICE ACTIVITIES

ITF-10 section chair, AWMA annual meeting (2006)

Graduate student organization of Horticulture (Chair, ’00; Vice Chair, ‘99)

University graduate student Senate at China Agricultural University (1998-2000)

REFEREED PUBLICATIONS

Li, H., H. Xin, Y. Liang, R. S. Gates, E. F. Wheeler, and A.J. Heber. 2005. Comparison of direct vs. indirect ventilation rate determinations in layer barns using manure belts. Transactions of the ASAE 48(1): 367-372

Y. Liang, H. Xin, **H. Li**, R. S. Gates, E. F. Wheeler and K. D. Casey. 2006. Effects of Measurement Intervals on Estimation of Ammonia Emissions from Layer Houses. Transactions of the ASABE 49(1): 183-186

Y. Liang, H. Xin, E. F. Wheeler, R. S. Gates, **H. Li**, J. S. Zajaczkowski, P. A. Topper, K. D. Casey, B. R. Behrends, D. J. Burnham, F. J. Zajaczkowski. 2005. Ammonia emissions from U.S. laying hen houses in Iowa and Pennsylvania. Transactions of the ASAE 48(5): 1927-1941

Chen, Q. Y., **H. Li**. 2001. Study on the Expert System of Cucumber Culture Management in Greenhouse. Transactions of the CSAE 17(6):142-146

Wang, Y. X., D.S. Chen, T.Z. Zhang, **H. Li**. 1999. Double Skin Inflated Greenhouse Inner Local Climate Control Characteristics in Higher Cold Area. Transactions of the CSAE 15(4):167-171

CONFERENCE PROCEEDINGS

Li, H., Hongwei Xin, Robert T. Burns, Yi Liang. 2006. Reduction of Ammonia Emission from Stored Poultry Manure Using Additives: Zeolite, Al$^+$clear, Ferix-3 and PLT. 2006 ASABE Annual Meeting, Portland, Oregon, American Society of Agricultural and Biological Engineers, St. Joseph, MI: ASAE

H. Xin, **H. Li**, R. T. Burns, R. S. Gates, D. G. Overhults, J. W. Earnest, L. B. Moody, and S. J. Hoff. 2006. Use of CO_2 Concentrations or CO_2 Balance to Estimate Ventilation Rate of Modern Commercial Broiler Houses. 2006 ASABE Annual Meeting, Portland, Oregon, American Society of Agricultural and Biological Engineers, St. Joseph, MI: ASAE

R. T. Burns, H. Xin, **H. Li**, R. S. Gates, D. G. Overhults, J. W. Earnest, Z. Zhu, J. Davis and C. Peterson. 2006. Measurement of TSP, PM_{10} and $PM_{2.5}$ Emissions from Commercial Broiler Houses. 2006 ASABE Annual Meeting, Portland, Oregon, American Society of Agricultural and Biological Engineers, St. Joseph, MI: ASAE

Li, H., R. Burns, H. Xin, L. Moody, R. Gates, D. Overhults, J. Earnest. 2006. Development of a Continuous NH_3 Emissions Monitoring System for Commercial Broiler Houses. Paper #485, Air and Waste Management Association

Burns, R. T., H. Xin, **H. Li**, S. Hoff, L. Moody, R. S. Gates, D. Overhults and J. Earnest. 2006. Monitoring system design for the southeastern broiler gaseous and particulate matter air emissions monitoring project. Symposium on Air Quality Measurement Methods and Technology, May 9 - 11, 2006, Durham, NC.

Moody, L.B., **H. Li**, R. T. Burns, H. Xin, and R. S. Gates. 2006. AWMA QAPP paper. Quality Assurance Project Plan (QAPP) implementation for the southeastern broiler gaseous and particulate matter air emissions monitoring project. Symposium on Air Quality Measurement Methods and Technology, May 9 - 11, 2006, Durham, NC.

Muhlbauer, R. V., T. A. Shepherd, **H. Li**, R. T. Burns, H. Xin. 2006. Development and Testing of a Fan Monitoring System using Induction Operated Current Switches. ASABE Technical Paper, St. Joseph, MI: ASABE

Li, H., H. Xin, and Y. Liang. 2005. Effects of stack surface to volume ratio and air exchange rate on ammonia emission of laying hen manure storage. Paper #1157, Air and Waste Management Association

Li, H., H. Xin, and Y. Liang. 2005. Moisture production of commercial manure-belt laying hen houses. Proc of the 7th International Livestock Environment Symposium, May 18-20, 2005, Beijing, China. St Joseph, MI: ASAE

Li, H., Hongwei Xin, Yi Liang , Comparison of Direct vs. Indirect Ventilation Rate Determination for Manure Belt Laying Hen House, Paper number 044177, 2004 ASAE/CSAE Annual International Meeting ,Ottawa, Ontario, Canada, American Society of Agricultural Engineers, St. Joseph, MI: ASAE

Li, H., H. Xin, Y. Liang, R.S. Gates and E.F. Wheeler. Determination of Ventilation Rates for a Manure-Belt Laying Hen Housing Using CO_2 Balance. Mid-Central Conference of the ASAE, St. Joseph, Missouri, March 25-26, 2004. American Society of Agricultural Engineers, St. Joseph, MI: ASAE

Liang, Y. H. Xin, **H. Li**, J. Koziel, L. Cai. 2005b. Evaluation of treatment agents and diet manipulation for mitigating ammonia and odor emissions from laying hen manure. Paper # 054160. American Society of Agricultural and Biological Engineers, St. Joseph, MI: ASABE

Liang, Y., H. Xin, A. Tanaka, S. H. Lee, **H. Li**, E. F. Wheeler, R. S. Gates, J. S. Zajaczkowski, P. Topper and K. D. Casey. 2003. Ammonia Emissions from U.S. Poultry Houses: Part II – Layer Houses. In Proc. Third International Conference on Air Pollution from Agricultural Operations. Oct 12-13, 2003, Raleigh, NC, pp147-158

Xin, H., Y. Liang, A. Tanaka, R.S. Gates, E. F. Wheeler, K. D. Casey, A. J. Heber, J. Ni, and **H. Li**. 2003. Ammonia emissions from U.S. poultry houses: Part I - Measurement system and techniques. Proceedings of the 3rd International Conference on Air Pollution from Agricultural

Operations, Raleigh, NC, October 2003. American Society of Agricultural Engineers, St. Joseph, MI: ASAE

Liang, Y., H. Xin, A. Tanaka, S. H. Lee, **H. Li**, E. F. Wheeler, R. S. Gates, J. S. Zajaczkowski, P. Topper and K. D. Casey. 2003. Ammonia emissions from layer houses in Iowa. Proc of the Gaseous and Odor Emissions from Animal Production Facilities, Scandic Hotel Bygholm Park, Horsens, Denmark, June 1-4, 2003

EXTENSION PUBLICATIONS & POPULAR PRESS ARTICLES DERIVED FROM RESEARCH

Li, H., H. Xin, and Y. Liang. 2004. Indirect Measurement of Building Ventilation Rate for Manure-belt Laying Hen House Using CO_2 Balance. College of Agriculture Research Report, ASL # 520, Iowa State University

Liang, Y., H. Xin, and **H. Li**. 2004. Dietary manipulation to reduce ammonia emission from high-rise layer houses. College of Agriculture Research Report, ASL # 517, Iowa State University

Liang, Y., H. Xin, **H. Li**, and E. F. Wheeler. 2004. Ammonia emissions from layer houses. College of Agriculture Research Report, ASL # 518, Iowa State University

APPENDIX B

SMP CA1B
SITE MONITORING PLAN FOR BROILER RANCH IN CALIFORNIA

SMP CA1B
SITE MONITORING PLAN FOR BROILER RANCH IN CALIFORNIA

Site Description

The University of California-Davis (UCD), with assistance from Purdue University, will measure emissions from two broiler barns at a 16-barn broiler ranch in Stanislaus County, California. The overall layout of the site is provided in Fig. 1. The broiler site is located 163 km (102 mi) driving distance from the UCD and 3,565 km (2,228 mi) driving distance from Purdue.

The barns are oriented E-W and spaced 12.2 m (40 ft) apart (Fig. 1). The barn roofs have a 4:12 slope. Each barn is 125 m (410 ft) long x 12.2 m (40 ft) wide and houses 21,000 birds that grow from 0.05 to 2.41 kg (1.1 to 5.3 lb). Six to seven batches of birds are raised in each barn every year, and all barns are on the same growth cycle.

Average monthly climatic data for the site is presented in Table 1. Average daytime high temperatures range from the mid-50’s (°F) (~12°C) in the winter to mid-90’s (~35°C) in the summer. Average overnight lows (°F) range from the mid-30’s (~3°C) in winter to the low 60’s (~16°C) in summer. Prevailing winds are from the SE in the winter, and W to WNW during the rest of the year.

Birds are fed a pelleted diet consisting of 62% corn, 22% soybeans, 19.5% protein, and 3% poultry fat. Feed is delivered by auger. All litter is removed from the barn after three batches, and is taken off-site (to a fertilizer plant) within 2-3 d on average. Prior to being removed from the site, manure may remain in piles by the road (to the W of the barns) for 2-3 days. Between each batch, the top 20 to 25% of the litter is removed the entire length of the barn in a decaking operation using a Lewis Brothers Housekeeper. After decaking, the remaining litter at the front of the barn is moved to the back of the barn and 34.4-m^3 (45-yd^3) of rice hulls are placed in the front using a 3.8-m^3 (5-yd^3) Carry-All Soil Mover.

Ventilation air enters the barn through pressure-adjusted baffled air inlets at the eaves (Fig. 2). The air is exhausted out the W end of the barn where there are ten, 1.2-m. (48-in) diameter belted exhaust fans (Model 48318-235, Chore-Time, Milford, IN) located in banks of five fans on the north and south sidewalls. The fans on the N and S walls are 0.2 m (8 in) apart. The fan motors for the 1.2-m (48-in) fans are 1 Hp (Model # 5KCR49UN0462AT). The five fans located on the north sidewall (Fig. 3) are numbered 3 thorough 7 (Fig. 4), and the five fans located on the S wall (Fig. 5) are numbered 8 thorough 12 (Fig. 4). In addition, there is one 0.9-m (36-in) diameter belted exhaust fan (Model AT365Z1CP, Aerotech, Mason, MI) located on the W wall at the back of the barn. This fan is designated as Fan #2, and has a 1/2-Hp motor (Model # 177509-01). Finally, there is one other 0.9-m (36-in) diameter belted exhaust fan (Model AT365Z1CP, Aerotech, Mason, MI), designated Fan #1, located on the E wall; however, this fan is inactive, and will remain so throughout the study. The barn has six temperature sensors. Fan relay control regimes are dependent upon the age of the birds; a total of 8 different schemes are used (Table 2), depending on two factors – namely, the age of the birds and the maximum temperature (with 75°F being the transition point between schemes). Eight of the 10 fan relays control single fans, while two (relays 6 and 10) each control two of the 48-in fans (Fig. 4).

During cooler weather, the front half of the barn is heated by 14 LP Radiant Brooders (42,000 Btu/h), while the rest of the barn is heated by 3 LB White Convection LP heaters (180,000 Btu/h). During warmer conditions, supplemental cooling is provided by evaporative pads, which are located at the E ends of the barns (Fig. 6). These are Munters pads made of a paper product, and are four feet high, eight inches deep, and 12 inches wide. The lights are shut off for several hours each night. Water consumption is recorded by an automatic water meter. Daily mortalities are recorded manually.

The farm follows a strict biosecurity policy, which requires that visitors not have been on another broiler or layer farm for at least 48 h prior to coming onsite. Persons are required to shower and wear clean protective clothing (bodysuits, hairnets, and boots), and instruments and equipment are required to be disinfected before being brought onsite. Access to the farm by outside vehicles is restricted; the farm requires personnel and equipment to be brought onsite using the farm's golf cart. Advance notice of site visits is thus required.

Other potential pollution sources near the farm include a hatchery just over one mile W of the ranch, another 10-house broiler ranch approximately ¾ mi to the NNW, and a large dairy about ½ mi to the NW.

This site was selected for monitoring for the National Air Emissions Monitoring Study for the following reasons:

1. It is owned by Foster Farms, the top broiler producer in California.
2. The site represents the type of barns that Foster Farms uses in California.
3. The site meets the criteria for site selection.

Monitoring Plan

The barns selected for measurement are barns 10 and 12, which are part of a complex of 16 barns (Fig. 1) that was built in the 1960s and remodeled in 2002. Figs. 7 and 8 show schematics of the monitoring plan for the barns, and Table 3 lists the locations at which the various samples will be collected. It is intended that data collection will commence at the beginning of one of the growth cycles that is started after a full removal of litter from the barn. The on-farm instrument shelter (OFIS, SOP U1) will be positioned at the far W end of the space (Fig. 9) between barns 10 and 12 (Fig. 7), with a N/S orientation to minimize interference with vehicle traffic along the driveway W of the barns. The OFIS will be positioned somewhat off-center in the space between the barns, so as to leave enough space to one side for vehicle access (note that positioning the OFIS on-center in the space would have left approximately 2.5 m (8 ft) on either side, which was judged to be insufficient to allow access). Heated raceways (SOP U3) will be used to connect the OFIS with each barn, to avoid condensation in the sampling lines during cold weather.

Three gas sampling probes will be placed in the W end of each barn, near the exhaust fans at a height equal to the fan hubs (Fig. 7). One gas sampling probe (A) is located in front of the inlet of fan 2, and between fans 5 and 10. Gas sampling probes B and C are located 3 m (10 ft) from each sidewall, in a cross-sectional plane that is 1 m (3 ft) E of fans 7 and 12. Each sampling location will be sampled individually with one tube using a PAAQL gas sampling system (GSS, SOP G1). The inlet air sampling location will be located at approximately the midpoint (lengthwise) of the barns, near one of the two barns. Except for the 2-3 day stockpiling of litter just outside the far end of the barns, there are no outdoor manure storages or lagoon to contribute to inlet contaminant concentrations, and these are expected to be relatively low and stable.

All sampling locations will be connected to the GSS using Teflon tubing. The control sequence for the six barn locations during each 60-min sampling cycle is given in Table 4. The ambient location will be monitored for 30 min twice daily. Thus, there will be 23 samples taken per location every day, unless calibration or other interruption of sampling occurs.

One set of gas analyzers in the OFIS will be used to sequence through all the GSLs. A TE Model 450C fluorescence-based analyzer (SOP G5) will be used to measure H_2S. Ammonia and CO_2 will be measured with an INNOVA Model 1412 Photoacoustic IR multi-gas monitor (SOP G7). The INNOVA Model 1412, will also measure methane, methanol, and non-methane VOC concentrations, the last of these by measuring total VOC and subtracting methane and methanol.

Continuous inlet PM measurements will be taken using a Beta-Gage monitor (SOP P4), which will be located at the inlet gas-sampling location of barn 10 (Fig. 7), enclosed in a protective outdoor enclosure. This location for the inlet PM monitor is very close to the ventilation inlet air entrances, and the closest possible contaminant sources – the exhaust fans at the W end of the barns – are more than 60 m (200 ft) away, although they will be downwind approximately ¾ of the time (Table 1). The driveway around the complex is paved, so vehicle traffic should not stir up much dust; however, the area between the barns is neither paved nor vegetated. Vehicle traffic through this area could cause "spikes" of dust to the inlet PM monitor; however, such traffic is infrequent. TEOMs will continuously sample exhaust PM_{10} (SOP P1), and will be located about 6 m (19 ft) in front of fan 7, which is denoted as the primary representative exhaust fan (PREF) for each barn, as shown in Fig. 7. This places the TEOM at approximately the midpoint of a line connecting fans 7 and 12. The PM_{10} inlet head on the TEOMs and Beta-Gage will be replaced with $PM_{2.5}$ heads for two, two-week periods over the course of the study. The first of these is scheduled for December 5-20, 2007; the second, for June 15-30, 2008. TSP inlet heads will be placed on the TEOMs and Beta-Gage for one week every 8 weeks, beginning with the first week of data collection.

Capacitance-type relative humidity and temperature probes (SOP E2) will be located at the W end of each barn, near the TEOM (Fig. 7). A solar radiation shielded (SOP E3) RH/temperature probe (SOP E2) and a wind anemometer (SOP E4) will be attached to a 1-m (3-ft) aluminum tower (SOP E5) located on the ridge of Barn 10 near the OFIS.

Thermocouples (TC) will be used to measure temperatures (SOP E1) at each sampling point, and will also be distributed with equal spacing along the center of each barn. These will be attached to the 4″x 4″ support posts which run down the center of the barn at 10′ intervals (Fig. 10). Two TC will be located next to the two brooders closest to the OFIS, and two will be located at the center of the evaporative pads (Fig. 7). Thermocouples will also be located in the heated raceway between the barn and OFIS (SOP U3). Two TC will be located in the OFIS; one will measure the temperature of the OFIS, and one will measure the temperature of the instrument rack.

Barn static pressure will be measured (SOP A5) in the barn across the N, S, and W walls (Fig. 7). The outside port will be located against the outside wall near the ventilation fans of the north, south, and west walls. These pressures will be different with northerly, southerly, and westerly winds. Static pressure in the OFIS will also be measured, to ensure that positive pressure is maintained.

Fan operation will be monitored using RPM sensors mounted on the 11 active fans in each barn. No sensors will be mounted on the inactive fan #1 at the E end of the barns. The Hall-effect RPM sensors will be mounted to detect the rotational speed (RPM) of either the fan shaft, a fan blade, or the fan pulley. The digital signal from the RPM sensor will be converted into a frequency measurement with a counter module in the data acquisition system. Impeller anemometers (SOP A3) will be mounted on the PREF (fan 7) in each barn, and on one of the infrequently-used 36-in fans (fan #2 in Barn 12).

The FANS analyzer (SOP A2) will be used to test fans in the barns. If there are any fans that are inaccessible to the FANS analyzer, the traversing method (SOP A8) will be used to test these fans.

Relays that control lights, brooders and feeders will also be monitored in each barn, using auxiliary contacts in 5-VDC circuits, in conjunction with the digital inputs of the data acquisition system (SOP S4). Activity sensors (SOP S3) will be located to monitor movement of birds and workers in the barn (Fig. 7); as with the thermocouples, these will be mounted to the support posts along the center axis of the barn (Fig. 10). Activity sensors will also be used to monitor researcher presence in the OFIS.

An initial characterization study of barn VOCs will be conducted on one day during the first month of data collection. While total VOC emissions are continuously monitored using the INNOVA 1412, along with building airflow rate, VOCs will be sampled with duplication at fan 7 (the primary representative exhaust fan) in each barn, using sorbent tubes (SOP V1) and Silcosteel canisters (SOP V2) for phenols and volatile fatty acids (VFAs), and all-glass bubblers (SOP V3) for linear and cyclic amines. Each phenol/VFA sample (sorbent tubes or canisters) will be evaluated using gas chromatography – mass spectrometry (GC-MS) (SOP V4 or V6, respectively, for sorbent tubes and canisters), while amines collected in the bubblers will be analyzed by ion chromatography (IC) (SOP V5). Any single analyte that contributes more than 5% of the total VOC mass (as determined by the PIR) will be identified during this initial characterization study. Whichever individual sampling method(s) (sorbent tubes, canisters, and/or bubblers) best captures these analytes will be employed for the remainder of the study. VOC samples will be collected through the GSS, and will be collected from GSL-C at fan 7 (1 m

E of fan 7 and 3 m from the S wall of he barn – Table 3) in each of the two barns. This subsequent VOC sampling will be conducted on a quarterly basis.

Litter on the floor of the barns will be sampled (SOP M1) six times per year; one sampling run will be conducted each season, and will be timed to take place near the middle of a brood cycle. At each time point, 16 samples will be collected from each of the two barns; collection points will be chosen such that 8 are taken in the portion of the barn with relatively fresh litter (the front), and 8 from the portion with the older litter (the back). Apart from this specification, sample locations will be randomly selected. Thus, the two groups together will give a representative picture of the barn as a whole. At each sampling point, all litter in a 2-ft radius will be brought to the center of the sampling location and mixed for a composite sample. These samples will be analyzed for pH (SOP M2) and solids content (SOP M3), and will provide the primary data for correlating these manure (litter) properties with emissions.

The material removed from the barn during each full cleanout (those after each second or third brood) will also be sampled. Three of these events would occur in the first year of the study, and two or three in the second, with the last occurring near the conclusion of the two-year data collection period). During each of these events, 12 samples will be taken from the blended litter pile before it is removed from the site, and 4 samples of the new incoming bedding will be collected. To compare the composition of the litter removed during the full cleanouts with litter removed after the decaking operations, three of these events will also be sampled. Six samples will be taken from the blended pile. Analysis of samples taken from the litter removed during the full cleanout and from litter removed during decaking will provide data for the N mass balance for the facility (SOP S5). The samples will be analyzed for total (Kjeldahl) nitrogen (SOP M4), ammoniacal nitrogen (SOP M5), pH (SOP M2) and solids content (SOP M3). Incoming bedding and feed will be analyzed for Kjeldahl N (SOP S6). Analytical data for feed will be compared with that provided by the producer (SOP S1). Manure production per barn (for the full cleanouts and the decaking operations) will be estimated by determining the total volume of manure removed off-site from cleanout or decaking operations, and dividing by the number of barns (16).

Data on animal inventory, mortalities and weight will also be provided by the producer, and will be verified quarterly by the study personnel (SOP S2). Hatchery and slaughterhouse counts (SOP S2) will also be obtained as additional checks on the accuracy of the counts. Water will be evaluated with several samples of the water provided to the animals. The producer also records daily mortalities (SOP S2), and will provide this data (SOP S1). Nitrogen content of the animals themselves (mortalities, birds sent to slaughter) will be determined from the literature.

OFIS Electrical Power Supply

The OFIS will be supplied with 3-wire, single-phase, mid-point neutral, 120/240-volt, 100 A at 240 V (SOP U1) power by the farm. The electrical lines will be run from the power supply control box situated on the W side between Barns 8 and 10, across Barn 10 to reach the external pullout switch at the OFIS. The outdoor section of power line will be protected by electric PVC conduit. The section run through the open ground will be buried. A copper ground rod will be installed at the location of the OFIS and connected to the OFIS ground.

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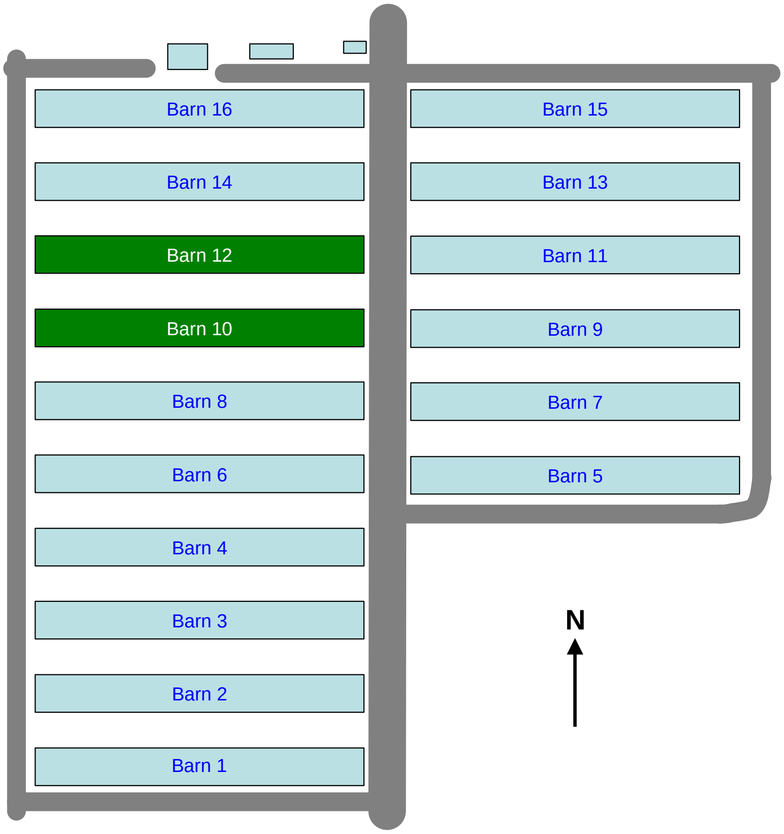

Figure 1. Layout of the facility. Continuous emissions will be measured at barns 10 and 12.

Table 1. Monthly averages for weather conditions at the site*.

	Temperature		**Precipitation**		**Wind Speed**	**Wind Direction**
Month	**High (ºF / ºC)**	**Low (ºF / ºC)**	**Rain (in / mm)**	**Snow (in / cm)**	**Mph / kmh**	**(From)**
January	53 / 12	37 / 3	2.84 / 72.1	0.0 / 0.0	8 / 13	SE
February	61 / 16	40 / 5	1.97 / 50	0.0 / 0.0	8 / 13	SE
March	65 / 19	43 / 6	2.17 / 55.1	0.0 / 0.0	9 / 15	WNW
April	73 / 23	46 / 8	1.08 / 27.4	0.0 / 0.0	10 / 15	WNW
May	82 / 28	52 / 11	0.26 / 6.6	0.0 / 0.0	11 / 17	W
June	89 / 32	58 / 14	0.08 / 2.0	0.0 / 0.0	11 / 18	W
July	94 / 35	61 / 16	0.06 / 1.5	0.0 / 0.0	10 / 16	WNW
August	93 / 34	61 / 16	0.07 / 1.8	0.0 / 0.0	9 / 15	WNW
September	88 / 31	58 / 14	0.35 / 8.9	0.0 / 0.0	9 / 14	WNW
October	78 / 26	51 / 10	0.79 / 20.1	0.0 / 0.0	7 / 12	WNW
November	63 / 17	43 / 6	2.17 / 55.1	0.0 / 0.0	7 / 12	SE
December	53 / 12	37 / 3	2.11 / 53.6	0.0 / 0.0	8 / 13	SE

*http://www.weatherunderground.com

Figure 2. Air inlet in the eave of the barn.

Figure 3. The bank of 48-in fans in the N sidewall of barn 10.

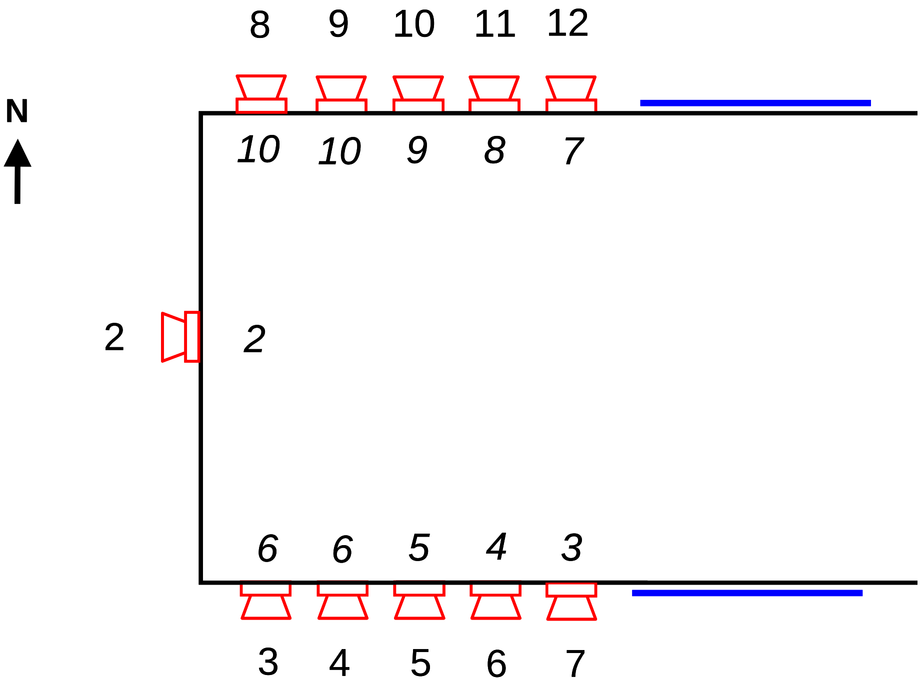

Figure 4. Fan assignments to control relays. Fan numbers are on the outside; relay numbers are on the inside. Note that relays 6 and 10 each control two adjacent fans.

Figure 5. The bank of 48-in fans in the S sidewall of barn 10, as seen from the outside.

Table 2. Fan relay control for the various stages of the 8 temperature control regimes used at the California broiler farm site.

Fan relays running	Timer relays	% on	Scheme[1] 1	2	3	4	5	6	7	8	Fan relays running (proposed)[2]
Tunnel Ventilation											
3,4,5,6,7,8,9,10										■	3,4,5,6,7,8,9,10
3,4,5,6,7,10										■	3,4,5,6,7,10
3,4,5,6,7,8										■	3,4,5,6,7,8
3,4,5,7,8,9									■	■	3,4,5,7,8,9
3,4,5,7,8								■	■	■	3,4,5,7,8
3,4,7,8							■	■			3,4,7,8
3,4,7							■				3,4,7
3,7						■					3,7
3,2						■					3,2
Power Ventilation											
3,4,5,7,8					■					■	3,4,5,7,8
3,4,5,6					■						3,4,5,6
3,4,7,8							■	■	■	■	3,4,7,8
3,4,7,2							■				3,4,7,2
3,4,7							■	■	■	■	3,4,7
3,4,5					■						**3,7,5**
3,4,2					■						**3,7,2**
3,7,2							■	■	■		3,7,2
3,7							■	■	■	■	3,7
3,4	3,4	100		■	■						**3,7**
3,4	3,4	80			■						**3,7**
3,7	3,7	80								■	3,7
3,7	3,7	60							■		3,7
3,2	3,2	100	■	■	■	■	■	■			3,2
3,2	3,2	80					■	■			3,2
3,2	3,2	75			■						3,2
3,2	3,2	50			■		■	■			3,2
3,2	3,2	35			■		■	■			3,2
3,2	3,2	20			■						3,2
3,2	3,2	10			■						3,2
3,2	2	50	■	■							3,2
3,2	2	30	■	■							3,2
3	3	100	■	■		■					3
3	3	75	■	■		■					3
3	3	50	■	■		■					3
3	3	35	■	■		■					3
3	3	20	■	■		■					3
3	3	10	■	■		■					3

[1] Scheme numbers: 1 = Days 1-9, 2 = Days 10-28, 3 = Days 28-ship, 4 = Days 1-9 (T>75), 5 = Days 10-14 (T>75), 6 = Days 15-24 (T>75), 7 = Days 25-29 (T>75), 8 = Days 29-ship (T>75).

Figure 6. Evaporative cooling pads in the sidewall near the E end of one of the barns.

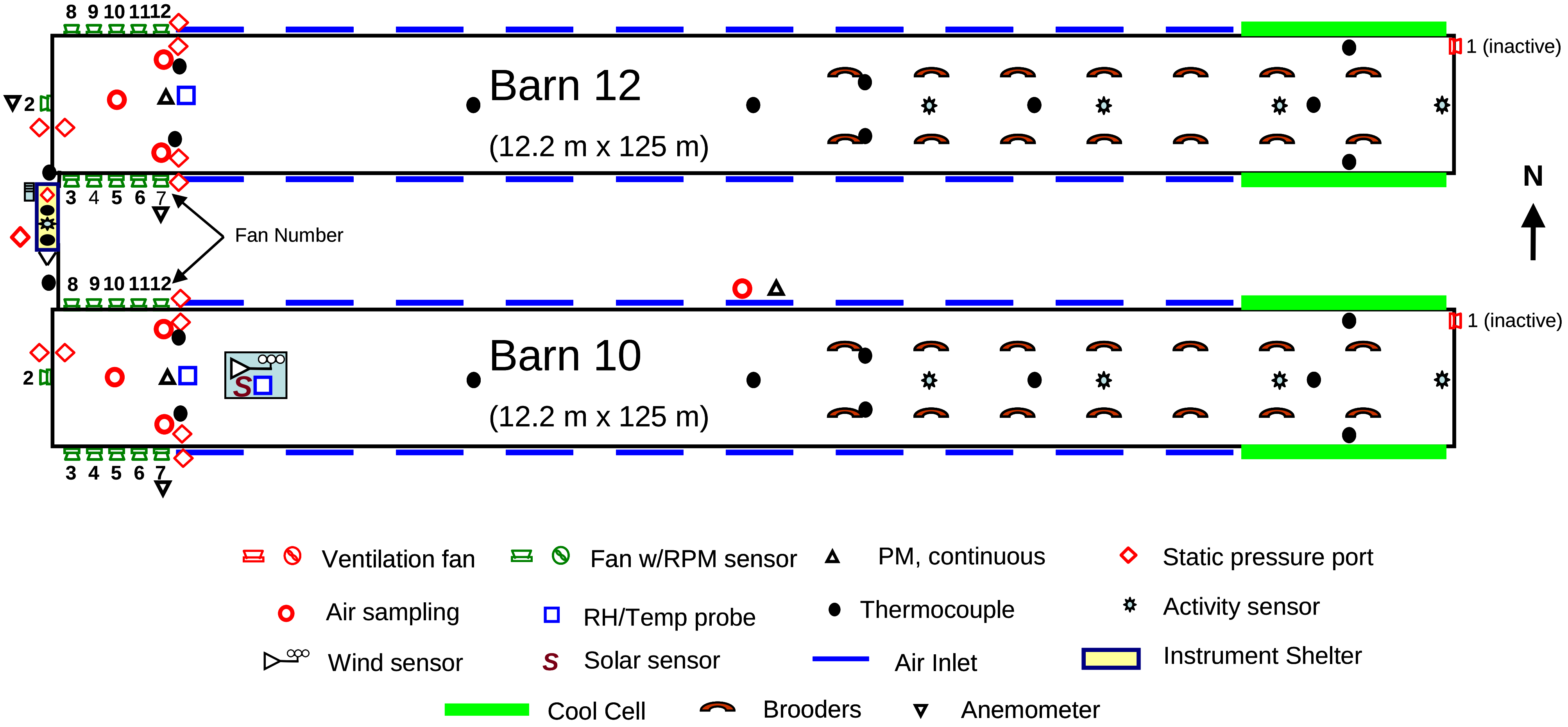

Figure 7. Overhead view of the barn schematics, showing the site monitoring plan for continuous air emission testing at barns 10 and 12.

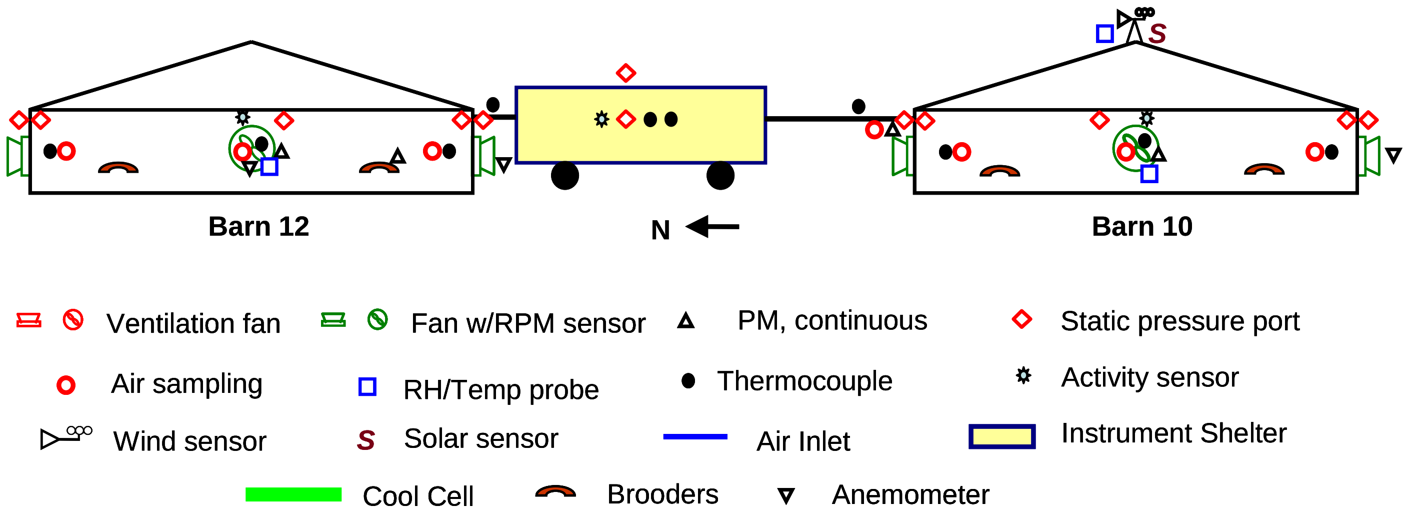

Figure 8. End (W) view of the barn schematics, showing part of the site monitoring plan for continuous air emission testing at barns 10 and 12.

Table 3. Analyte sampling locations at the CA1B site.

Analyte	Barn	Sampling Location*	#Locations**
Gases (NH_3, H_2S, NMHC, CO_2)	10, 12	GSL-A: Directly in front of the inlet of fan 2, along a line connecting fans 5 and 10	2
	10, 12	GSL-B: 1 m E of fan 12 and 3 m from N wall	2
	10, 12	GSL-C: 1 m E of fan 7 and 3 m from S wall	2
	10, 12	**INLET:** In front of the 5th ventilation inlet from the E end of barn 10 on N sidewall	1
PM ($PM_{2.5}$, PM_{10}, TSP)	10, 12	TEOM located 2 m in front of Fan 7	2
	10, 12	**INLET:** Beta-Gage in front of the 5th ventilation inlet from the E end of barn 10 on N sidewall	1
VOC (canister, sorbent tubes, and/or impingers)	10, 12	1 m E of fan 7 and 3 m from S wall, at fan hub level (GSL-C)	2

*Gas sampling probes will be located at fan hub height, suspended from the ceiling.
**Total for entire site
GSL: Gas sampling location
PREF: Primary representative exhaust fan (fan #7).
GSS: Gas sampling system

Figure 9. California Broiler Site 1, barns 10 and 12, as viewed from their E end. The OFIS will be located in the space between the two barns, at the far end in this view.

Table 4. Exhaust air stream control sequence during gas sampling cycle. Solenoids 1 to 7 direct air streams to bypass manifold or sampling manifold (when "open"). Location 7 samples inlet air twice daily.

Solenoid #	Location	Sampling period						
		1	2	3	4	5	6	
1	B10: F7	open						
2	B10: F12			open				
3	B10: F2					open		
4	B12:F7		open					
5	B12:F12				open			
6	B12:F2						open	

Figure 10. The row of center posts to which thermocouples and activity sensors will be mounted.

Table 4. Characteristics of barns at the California broiler ranch site.

Parameter	Description
Livestock type	Broilers
Inventory per barn, nominal	21,000
# barns at site	16
Year of construction	1960s/2002
Barn type	Mechanically Ventilated
Orientation	E-W
Distance to site, km	163 (UCD)
Type of birds (genetics)	60% Cobb, 40% Ross
Average mass, kg	1.14 (2.5 lb)
Animal occupation, d	42
Type of floor	Rice hulls on dirt
Shower in/out?	No
Barn width, m	12.2 (40 ft)
Barn length, m	125 (410 ft)
Barn area, m^2	1,524 (16,400 ft^2)
Ridge height, m	4.2 (13.8 ft)
Sidewall height, m	2.3 (7.5 ft)
Barn spacing, m	12.2 (40 ft)
Basement depth, m	N/A
Manure collection	Housekeeper, Carry-All Soil Movers
Manure storage in barn, d	46 (brooder area), 155 (back)
Number of air inlets	60 sidewall/2 tunnel
Inlet type, m	Baffled eave inlet, 0.18 x 1.32 (0.6 ft x 4.3 ft)
Tunnel inlet type, m	Curtain, 18 x 1.92 (59 ft x 6.3 ft)
Inlet adjustment method	Vent machine
Inlet control basis	Static pressure
Controls vendor	Choretime (48), Aerotech (36)
Number of exhaust fans	12
# variable speed fans	0
Largest fan dia., m	1.22 (48 in)
Smallest fan dia., m	0.91 (36 in)
Fan spacing, m	0.2 (8 in)
Fan manufacturer	Choretime (48), Aerotech (36)
# ventilation stages‡	17
# temperature sensors†	6
Emergency ventilation	Generator
Artificial heating	LP Radiant brooders (14), 42,000 Btu/h Convection LP heaters (3), LB White, 180,000 Btu/h
Summer cooling	Tunnel/EP
Internet service type	Wireless DSL

Appendix C

SOPs

LABORATORY TESTING OF VENTILATION FAN PERFORMANCE
Standard Operating Procedure (SOP) A1

LABORATORY TESTING OF VENTILATION FAN PERFORMANCE
Standard Operating Procedure (SOP) A1

Prepared by
Steve E. Ford (Univ. of Illinois Urbana-Champaign) and Bill W. Bogan

Reviewed by
Yuanhui Zhang (Univ. of Illinois at Urbana-Champaign), Steve J. Hoff (Iowa State Univ.),
and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This SOP describes performance testing of ventilation fans that are used on mechanically-ventilated barns and livestock buildings, including manure sheds.
1.2. Fan testing determines performance in terms of airflow rate, pressure, speed of rotation, power and ventilation efficiency.
1.3. The methodology described in this SOP is suitable for the testing of wall-mounted, constant- or variable-speed ventilation fans, including manure storage pit fans. It does not apply to the testing of air circulating fans.
1.4. Testing is performed in accordance with two industry standards:
  1.4.1. American Society of Agricultural and Biological Engineers (ASABE) Standard S565 (“Agricultural Ventilation Constant Speed Fan Test Standard”)
  1.4.2. Air Movement and Control Association (AMCA) Standard 210-99 (“Laboratory Methods of Testing Fans for Rating”) – Equivalent to American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) Standard 51-1999
1.5. Testing of the fans is conducted using a stationary laboratory fan test facility located in the Bioenvironmental and Structural Systems (BESS) Laboratory, Agricultural Engineering Sciences Building, University of Illinois at Urbana-Champaign.

2. Summary of Method

An airflow test chamber was designed and constructed according to AMCA 210-99/ASHRAE 51-1999 standard format (Fig. 15 of AMCA 210-99, included as Fig. 1 at the end of this SOP). The airflow test chamber measures airflow in the range of 100 - 28,000 ft^3/min (accuracy ±2%). The fan being tested is mounted in the chamber, and the volume of air handled is measured at up to six distinct static pressures by varying the air supplied by the chamber’s variable supply system. This is done by measuring the pressure differential across the nozzle in the center of the chamber, which is proportional to the volume of air moved by the fan. Electrical measurements (voltage and current) are made with a Valhalla Scientific 2100 power analyzer (for single-phase testing) or a Valhalla Scientific 2300 power analyzer (for three-phase testing). The rotational speed of the fan impeller is measured with either a digital stroboscope (Nidec-Shimpo Model DT-301) or a fiber-optic photoelectric sensor (Banner Model SM312FMHS). Wet and dry bulb temperature and barometric pressure are measured so that air density may be calculated. Fan ventilation efficiency ratio (VER) is calculated in units of ft^3/min-W.

3. Definitions

3.1.	BESS	Bioenvironmental and Structural Systems
3.2.	Manure pit fan	A ventilation fan used to remove harmful gases from a manure pit, and which is designed to resist corrosion caused by these gases.
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	Variable-speed fan	A fan whose speed can be modulated, usually based on temperature.

3.5.	Ventilation efficiency ratio (VER)	Airflow volume per unit of power consumed by the operation of the fan. Units used for VER in this SOP are ft^3/W.
3.6.	Ventilation fan	An un-ducted, axial-flow fan system used for air exchange (as opposed to air circulation) purposes. Generally consists of an impeller, housing, motor, shutter or damper, and guard.

4. Health and Safety

4.1. Fans should not be plugged in until the test and warm-up period is started.
4.2. Wear safety glasses while the fan is operating.

5. Cautions

5.1. Since the air chamber is under negative pressure, any leaks between the flow nozzles and the fan will cause a negative bias in fan airflow results. Make sure that there are no leaks in the chamber, or in the mounting seal. Ensure all joints around the fan assembly and the chamber are sufficiently tight. Test for leaks in the chamber by sealing up the fan opening (no fan installed) and pressurizing the chamber while introducing smoke into the chamber. Leaks are readily identified by visualizing the smoke.
5.2. Fans should be mounted for testing in the same configuration as they are installed or deployed in the field. All protective screens or guards, hoods or other wind-deflecting attachments, or discharge cones should be in-place during testing. Failure to do so may produce data which are not truly applicable to the field performance of the fan.

6. Interferences

6.1. In order to avoid inaccurate airflow data due to blockage, the exhaust area of the fan being tested should be kept clear (to a distance of at least three times the fan diameter).

7. Personnel Qualifications

7.1. Personnel should be trained in the operation of all instruments listed in Sections 8.1 through 8.6.1. The training will be provided by PAAQL and UIUC BESS Laboratory personnel.
7.2. Personnel must read and understand all applicable instrument manuals and this SOP before operating any of the equipment. These documents will be kept at the UIUC BESS.

8. Equipment and Supplies

8.1. Airflow test chamber as specified in AMCA 210/99 (See Fig. 1)
8.2. Variable voltage transformer capable of delivering 230 V with a precision of ±0.5 V
8.3. Manometer (Model 40HE35WM, Meriam Process Technologies, Cleveland, OH)

8.4. Micro-manometer (Model 1430, Dwyer Instruments, Michigan City, IN)
8.5. Mechanically aspirated psychrometer (Model Series 37210, Oakton Instruments, Vernon Hills, IL)
8.6. Barometer (Model 469, Princo Instruments, Southampton, PA)
8.7. Power analyzer (Model 2100 or 2300, Valhalla Scientific, San Diego, CA)
8.8. Fan impeller rotational speed monitor (two options)
  8.8.1. Digital stroboscope (Model DT-301, Nidec-Shimpo America Corp, Itasca, IL)
  8.8.2. Fiber-optic photoelectric sensor (Model SM312FMHS, Banner Engineering, Minneapolis, MN)

9. Procedures

9.1. Fan Performance Test
  9.1.1. Instrument checks (To be performed prior to each series of tests)
    9.1.1.1. Manometer
      9.1.1.1.1. Check fluid level according to instrument manual.
      9.1.1.1.2. With high and low pressure manifolds shunted, zero the instrument by adjusting the level until the micromanometer reads zero.
    9.1.1.2. Psychrometer
      9.1.1.2.1. Turn instrument on and observe the wet bulb temperature reading.
      9.1.1.2.2. Replace batteries if it takes more than 2 min for the wet bulb temperature to stabilize.
    9.1.1.3. Barometer
      9.1.1.3.1. Check the white zero pointer in the cistern and adjust to zero according to the instrument manual.
  9.1.2. Test procedure
    9.1.2.1. Mount the fan in the test chamber, with the fan inlet facing the main chamber, as shown in Fig. 1. All joints between the fan assembly and the chamber itself must be sufficiently tight that air leakage does not occur during the test. Leaks can be detected with a tufted wand while the chamber is pressurized with the chamber air supply.
    9.1.2.2. Check and zero the manometers before the fan is turned on.
    9.1.2.3. Turn the fan motor on and ensure that the input voltage is 230 V. Allow the fan motor to operate 20 min before proceeding with test.
    9.1.2.4. Measure and record wet-bulb and dry-bulb air temperature of the lab with the psychrometer.
    9.1.2.5. Measure and record the barometric pressure.
    9.1.2.6. Turn on the chamber air supply fan.
    9.1.2.7. Set the fan static pressure at free air (0" static pressure), which is to equalize the pressure in the chamber immediately upstream of the test fan with the pressure in the lab area surrounding the chamber. This is conducted by adjusting the operating static pressure point of the test fan by adjusting the supply fan blade pitch and by-pass door. Large changes in static pressure should be performed by blade pitch adjustment. Adjust the by-pass door for small changes.

9.1.2.8. The pressure drop (ΔP) across the measurement nozzles should remain above 0.5 inches of water gauge (iwg). The number of nozzles open must be lowered if the measurement falls below 0.5 iwg. If only one nozzle is open and the pressure differential drops below 0.5 iwg, select a smaller nozzle size.

9.1.2.9. Record the number of flow nozzles open, nozzle diameter (in.), pressure drop across the flow measurement nozzles (in. of water), fan speed (rpm), voltage (V), current (A), and power (W). A sample data sheet is included in Appendix A of this SOP.

9.1.2.9.1. Take readings when the system is at equilibrium. Equilibrium can be recognized by observing the stable pressure and other variable readings, or by taking trail measurements of the various variables until constant values are obtained. Equilibrium is usually reached within one to five minutes when the system is warmed-up. Note any test conditions (static pressures) under which equilibrium cannot be reached.

9.1.2.10. Increase the fan static pressure by 0.05 iwg, and repeat steps 9.1.2.7 through 9.1.2.9. The fan should be tested for at least 5 points, from 0.0 iwg up to 0.25 iwg static pressure, or airflow cut-off, whichever comes first. The former of these would result in a total of six static pressure points being tested (0, 0.05 iwg, 0.10 iwg, 0.15 iwg, 0.20 iwg, and 0.25 iwg).

10. Data and Records Management

10.1. Appendix A of this SOP contains a sample data sheet to be used for recording the data collected in these tests.

10.2. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.3. Manage all data according to SOP B5.

10.4. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance

11.1. Equipment manuals & certification

11.1.1. Master copies of instruction manuals and calibration certificates (when applicable) for all instruments described herein are kept in a specific file drawer, and made available to the users during training and measurement.

11.1.2. The fan test data will be kept at the UIUC BESS and delivered to PAAQL. The PAAQL will distribute the data to the trailer at the respective farm.

11.2. Equipment performance checks and calibration

11.2.1. Manometer

11.2.1.1. Calibrate with the micro-manometer annually according to manufacturer's procedures. Perform the following steps on the micro-manometer before using:

11.2.1.1.1. Check fluid level.

11.2.1.1.2. Remove needle tip. Clean and reinstall.

11.2.1.1.3. Check battery and replace (AA) if necessary.

11.2.2. Psychrometer

11.2.2.1. Calibrate thermometers annually. Calibrate four points between 32ºF and 100ºF in a water bath with either a NIST-traceable thermometer or a block calibrator (Model DB-35L, Techne Incorporated, Burlington, NJ).

11.2.3. Power analyzer

11.2.3.1. Cross check performance of the Valhalla Scientific 2100 or 2300 power analyzer with a power transducer (Model EW5–20B, Ohio Semitronics, Hilliard, OH). Voltage and current should be calibrated against a multimeter (Model 75 or Model 77, Fluke Corp., Everett, WA). Both of these checks should be done annually.

12. References

12.1. AMCA Standard 210-99. 1999. Laboratory Methods of Testing Fans for Rating. Air Movement and Control Association, Inc., Arlington Heights, IL.

12.2. ASABE Standard S565. 2005. Agricultural Ventilation Constant Speed Fan Test Standard. American Society of Agricultural and Biological Engineers, St. Joseph, MI.

12.3. Barometer Manual. Operations Manual for Model 469 Barometer. Princo Instruments, Southampton, PA.

12.4. Manometer Manual. Operations Manual for Model 40HE35WM Manometer. Meriam Process Technologies, Cleveland, OH.

12.5. Micro-Manometer Manual. Operations Manual for Model Model 1430 Micro-Manometer. Dwyer Instruments, Michigan City, IN

12.6. Power Analyzer Manual. Operations Manual for Model 2100 or 2300. Valhalla Scientific, San Diego, CA.

12.7. Psychrometer Manual. Operations Manual for Model Series 37210 Mechanically Aspirated Psychrometer. Oakton Instruments, Vernon Hills, IL

12.8. Stroboscope Manual. Operations Manual for Model DT-301 Digital Stroboscope. Nidec-Shimpo America Corp, Itasca, IL

12.9. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

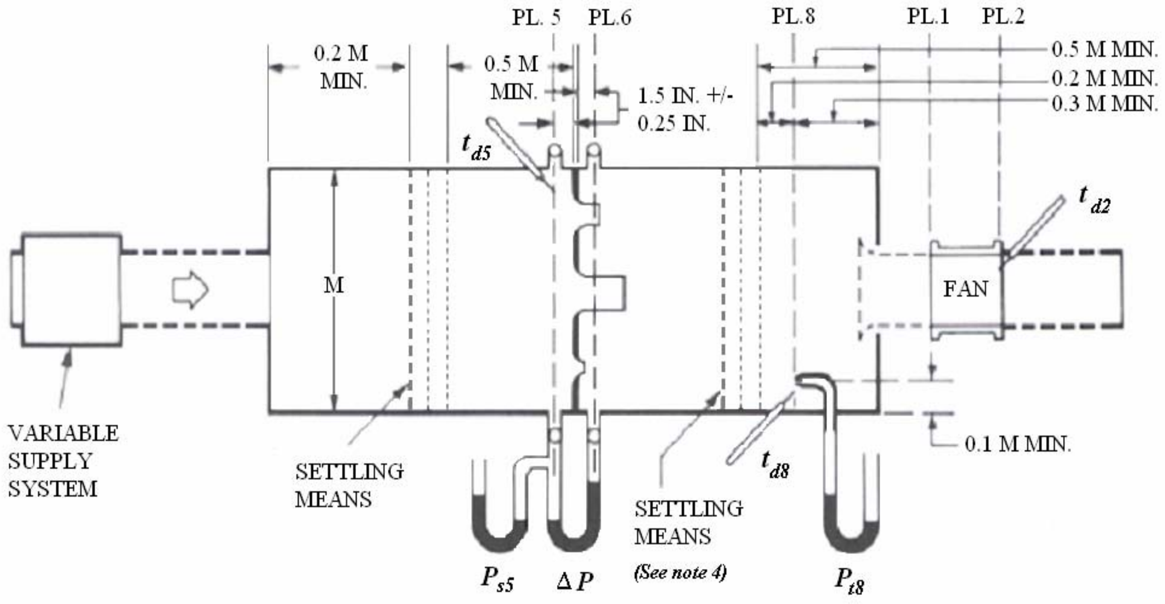

Figure 1. Configuration of the fan testing chamber, as adapted from AMCA210-99 Figure 15. M = Main chamber dimension (ft); PL. = Plane; P_s = Static pressure; t_d = Dry-bulb temperature; ΔP = Pressure differential; Settling means = mesh screen to create uniform flow.

Notes:

1. Dotted lines on fan inlet indicate an inlet bell (bell-mouth inlet that is fabricated of steel or alloy with flange) and one equivalent duct diameter which may be used for inlet duct simulation. The duct friction shall not be considered.
2. Dotted lines on fan outlet indicate a uniform duct 2 to 3 equivalent diameters long, and of an area within ± 0.5% of the fan outlet area and a shape to fit the fan outlet. This may be used to simulate an outlet duct. The outlet duct friction shall not be considered.
3. Variable supply system may be an auxiliary fan or throttling device.
4. The distance from the exit face of the largest nozzle to the downstream settling means shall be a minimum of 2.5 throat diameters of the largest nozzle.

Appendix A – Fan test datasheet including all data to be collected. Entries denoted by "*" must be calculated using the primary data.

Test Date		Fan is from	
Fan Manufacturer		Motor Manufacturer	
Fan Model		Motor Model	
Fan Size		Motor Amps/Volts/RPM	
Attachments			
Test Conditions			
Temperature (Wet Bulb), ºF		Barometric Pressure, in Hg	
Temperature (Dry Bulb), ºF		Corrected Pressure, in Hg	

Time Started	Time Read	# Nozzle	Nozzle Dia. (inch)	Pressure Drop (In. H_2O)	Static Pressure (In. H_2O)	Airflow (ft^3/min)	Fan Speed rpm	Voltage (V)	Current (A)	Power (W)	VER (ft^3/min /W)
					0.00	*					*
					0.05	*					*
					0.10	*					*
					0.15	*					*
					0.20	*					*
					0.25	*					*

MEASUREMENT OF VENTILATION FAN FLOWRATE

USING THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)

Standard Operating Procedure (SOP) A2

MEASUREMENT OF VENTILATION FAN FLOWRATE USING THE FAN ASSESSMENT NUMERATION SYSTEM (FANS)

Standard Operating Procedure (SOP) A2

Prepared by
Sam M. Hanni and Bill W. Bogan

Reviewed by
Teng-Teeh Lim, Albert J. Heber, and Kenneth D. Casey (Texas A&M Univ.)

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. A method is needed to spot-measure actual fan capacities in the field, as the performance of a fan deteriorates over time due to dust buildup, belt wear and shutter degradation. This renders published performance curves for new fans unsuitable for accurately determining airflow of fans operating in barns.

1.2. This SOP describes the in-situ measurement of ventilation fan flow rate using the Fan Assessment Numeration System (FANS).

1.2.1. The maximum diameter of fan that can be measured with the FANS depends on the size of the analyzer. The FANS that are currently available can test fans up to 30″, 48″ and 54″.

1.2.2. About 30 in. of free space in front of the fan is needed to provide access for the FANS analyzer.

2. Summary of Method

A device for *in situ* fan airflow capacity measurement, called the FANS, previously developed at the USDA-ARS Southern Poultry Research Laboratory, was refined and constructed by University of Kentucky (Gates et al., 2004). It is designed to measure the total airflow rate of a ventilation fan by measuring the air speed across the entire fan cross-section. The FANS incorporates an array of five impeller anemometers to perform a real-time traverse of the airflow entering or exiting an exhaust fan. The five anemometers supply an average airflow velocity across a known cross-sectional area, allowing calculation of the total airflow rate.

3. Definitions

3.1.	BESS	Bioenvironmental and Structural Systems
3.2.	dP	Differential pressure
3.3.	FANS	Fans Assessment Numeration System
3.4.	PAAQL	Purdue Agricultural Air Quality Laboratory

4. Health and Safety

4.1. Be careful when working with electrical power connections. Instrument repair should only be carried out by trained personnel.

4.2. Be careful when working near operational ventilation fans. The high-speed fan blades can be a hazard, especially if they are not protected by fan shutters.

4.3. Wear safety glasses when working near operational fans. Avoid wearing loose-fitting or baggy clothing, or dangling jewelry near an operational fan, and tie up long hair.

5. Cautions

5.1. Prevent damage by rodents and livestock, especially if the analyzer is stored at the measurement site, by storing it off of the ground, in areas which livestock do not enter.

5.2. Store the analyzer away from moisture, manure and mechanical vibration.

5.3. Protect instrument from adverse weather, especially precipitation.

5.4. Ensure that adequate power is available at the measurement site. Lack of a stable power source can result in the loss of data because of power interruptions. The system requires measurement to start from the top or bottom positions for a complete measurement cycle. If the anemometers are stopped before completing a measurement cycle, use the manual button or program to bring the anemometers to either the top or bottom position before starting another measurement cycle.

6. Interferences

6.1. When the field measurement of FANS data covers only a narrow range of static pressures, determining the full fan performance curve is not possible. This can result in greater uncertainty of the calculated airflows, because the degraded fan curve will be estimated based on shape of the undegraded fan curve rather than measured.

6.1.1. To measure the airflow of the exhaust fan over the operating range of dPs, take three measurements, at approximately the minimum, middle and maximum of the static pressure range of the barn. Do this by increasing or decreasing the number of fans that are running, and/or by adjusting the opening(s) of the barn air inlets (baffles, curtains, etc.).

6.1.2. Unless the barn is empty or proper ventilation airflow can be ensured for the comfort of the animals, avoid intervening with the barn’s environmental control system to adjust barn static pressure to desired values.

6.2. In order to avoid inaccurate airflow data due to blockage, keep all objects, livestock and personnel from moving in front of the fan being tested, to a distance at least two (2) times the fan diameter.

6.3. Use of the FANS unit upstream or downstream of a ventilation fan could add pressure drop to the working fan, and hence may reduce performance. However, laboratory test of the FANS at the BESS facility (Gates et al., 2004) suggest that the pressure drop was insignificant.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument and associated software before initiating the procedure.

7.2. Personnel should possess a basic understanding of barn ventilation systems, and be able to identify the normal ranges of barn pressure and fan performance.

7.3. Personnel should be able to lift 50 lbs.

7.4. Each analyst must read and understand Reference 12.1 (Gates et al., 2004) and this SOP before operating the FANS analyzer.

8. Equipment and Supplies

8.1. FANS, including appropriate hardware and software (Biosystems and Agricultural Engineering Department, University of Kentucky, Lexington, KY)

8.2. Laptop computer for operating the FANS unit and logging the measurement data. The computer must have enough memory (>20 Mb) for data storage, and a CD drive.
8.3. RS232 cable – standard 9-pin
8.4. Model 27106RS Propeller Anemometer (R.M. Young Company, Traverse City, MI).

9. Procedures

9.1. Installing software
  9.1.1. Before using the FANS Analyzer for the first time, set up the laptop computer with the necessary software to link with the FANS Analyzer, to control the analyzer and record data. Close down all background applications and programs of the computer.
  9.1.2. Insert Purdue Calibration Data 2007 Control Interface CD, and install the program by clicking the auto-start program or using the command “setup.exe”.
    9.1.2.1. Installation may require an internet connection if the Microsoft.Net framework hasn’t already been installed as part of regular updates.
  9.1.3. The software will automatically install, and an icon (“FANS Interface Application”) will appear on the computer’s desktop.
9.2. FANS cart
  9.2.1. The FANS cart is a metal frame that provides an easy way to move the analyzer from one fan to another.
  9.2.2. The cart has four trailer jacks (one at each corner) that can be adjusted up and down, and that help in adjusting the height of and leveling of the analyzer (Fig. 1a).
  9.2.3. Use of the FANS cart is optional; other means (Fig. 1b) can be used to support the analyzer, provided it is kept level.

(a) (b)

Figure 1. Measuring fan airflow rate using a FANS analyzer positioned on the outlet side of a fan with the aid of the FANS cart (a) and on the fan inlet, supported by cinderblocks (b).

9.3. Operation

- 9.3.1. Supply power to the FANS and laptop computer with stable 110 VAC power source.
  - 9.3.1.1. Switch on the unit by turning the power switch to the on position.
  - 9.3.1.2. Operate the unit manually by toggling the up and down switch to make sure the motor is moving the anemometers upward or downward freely.
- 9.3.2. Install impellers onto the anemometers.
  - 9.3.2.1. The impellers cannot be installed at the bottom position due to limited space; the holder must be at least six inches from the bottom.
  - 9.3.2.2. Make sure that the numbers on the impellers match those on the anemometers.
  - 9.3.2.3. Reposition the anemometer holder back to either the top or bottom position.
- 9.3.3. Center the FANS, both horizontally and vertically, in front of the desired fan, either at the exhaust (Fig. 1a) or inlet (Fig. 1b) side. If possible, enclose the entire cross-sectional area of the fan to make sure all airflow goes through the FANS for accurate measurement. Use the cart’s wheels to adjust position horizontally, and the jacks to adjust vertically.
- 9.3.4. Connecting the computer and FANS.
  - 9.3.4.1 Double click on the “FANS Interface Application” icon.
  - 9.3.4.2 Find the serial number on the FANS Analyzer (ex. FANS 48-0015)
  - 9.3.4.3 In the FANS Interface Application software, click “Edit” then “Serial Number”.
    - 9.3.5.3.1 This will give a pull-down list of serial numbers. Select the number of the analyzer that is being used.
    - 9.3.5.3.2 Once the serial number is selected, the FANS Interface Settings and BESS Calibration Information will be automatically set.
  - 9.3.4.4 Data acquisition and automated control are provided through the RS232 interface.
    - 9.3.4.4.1 Use a standard 9-pin serial cable to connect the unit to the computer.
  - 9.3.4.5 In the FANS Interface Application software, click “Edit” then “Communication Port”.
    - 9.3.4.5.1 This will give a pull-down list of communication ports. Select the proper port.
  - 9.3.4.6 In the FANS Interface Application software, click “File” then “Connect to FANS”.
    - 9.3.4.6.1 Data will not be read unless the FANS Analyzer has power and is turned on.
    - 9.3.4.6.2 If the FANS is connected, the “Status” should read “Connected”.
- 9.3.5. Bring the anemometer bar back to either the top or bottom position.
- 9.3.6. Start the measurement by clicking “Run Test”.
  - 9.3.6.1. It will take 186 s to complete one airflow measurement. Data will scroll as it is being collected, and will automatically save to a file when the measurement is complete.
  - 9.3.6.2. Record the sampling location, barn and fan numbers, date and time, and other details such as fan operating dP, weather, and other observations in the field sampling data sheet (Appendix A).
  - 9.3.6.3. Record the measurement data (speed and flow rate) output by the program.
  - 9.3.6.4. Repeat the measurement. If the difference between the two measurements is >5%, despite a constant dP, repeat measurement until the difference (standard deviation) of all measurements is ≤ 5%.

9.3.7. It is important to note all observations and changes that could affect the fan dP, including changes in number of fans operating, changes in wind direction and velocity, and any other factors that could affect the fan airflow.

9.4. When measurements are completed at a particular fan and the computer and power must be disconnected from the FANS, make sure to click “File” then “Disconnect Fans”. Move the equipment to the next fan, and repeat Steps 9.3.3 through 9.3.7.

9.4.1. Apply silicone grease to the chain, bearings, all-thread support, and other mechanical parts of the FANS to make sure they are well lubricated. The necessary lubrication frequency will depend on several factors, including dust levels, relative humidity, and how the FANS is used. The grease should be added at the operator’s discretion.

9.4.2. When sampling is completed for the day, disconnect the power, and place all items in a protected location, such as the OFIS (On-Farm Instrument Shelter).

10. Data and Records Management

10.1. Maintain all field sampling records in a worksheet of the electronic field notes spreadsheet that is designated for this method. Supplement this electronic record with a bound record book designated for the method, which should also contain bound copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all of the data and information on field data sheets, and site logbooks with permanent ink, or in electronic field notes. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. At the beginning and end of each set of field measurements, perform a “zero airflow” measurement to make sure the program reads an insignificant zero value. Do this by operating the FANS with no impellers attached. The zero reading should be less than 3 m^3/min (106 ft^3/min).

11.2. Back up the FANS folder at the end of each day on which field measurements are performed, to ensure an extra copy of the measurement data. The measurement data logged by the Anemometer2 program contains the date and time, mean velocity and flow rate for each of the measurement run, and mean values for each anemometer.

11.3. Calibrate each FANS unit annually at the UIUC (University of Illinois at Urbana-Champaign) BESS Lab.

12. References

12.1. Gates, R.S., K.D. Casey, H. Xin, E.E. Wheeler, and J.D. Simmons. 2004. Fan Assessment Numeration System (FANS) design and calibration specifications. Transactions of ASAE 47(5): 1709-1715.

12.2. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

Appendix A. Field Data Sheet for FANS Measurement.

Project ____________________

FANS Measurement Field Sheet

Date ____________________

Operator ____________________

Weather ____________________

Fan location ____________________

Site/Building ____________________

Run	Time start	Time stop	Flow rate	Speed	Notes

Fan location ____________________

Run	Time start	Time stop	Flow rate	Speed	Notes

Fan location ____________________

Run	Time start	Time stop	Flow rate	Speed	Notes

VENTILATION FAN AIR VELOCITY MEASUREMENTS USING OPEN IMPELLER ANEMOMETRY

Standard Operating Procedure (SOP) A3

VENTILATION FAN AIR VELOCITY MEASUREMENTS USING OPEN IMPELLER ANEMOMETRY

Standard Operating Procedure (SOP) A3

Prepared by

Sam M. Hanni and Bill W. Bogan

Reviewed by

Teng-Teeh Lim and Albert J. Heber

Effective Date: November 6, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This SOP describes monitoring of wall and pit ventilation fan air speeds and operational status using an impeller anemometer.

1.2. This method applies to the measurement of air velocities in locations where cyclonic flow conditions exist and temperatures range from 10°C and 40°C (barn exhaust air)

1.3. This SOP is specific to the R.M. Young Company's Model 27106RS Impeller Anemometer.

  1.3.1. This anemometer will be used for monitoring ventilation fans ranging from 18 to 54 in. in diameter.

  1.3.2. The diameter of this anemometer is 7 in.; thus, it will measure airflow velocity of a small fraction of the fan's cross–sectional area, ranging from 16% on an 18-in. fan to 2% on a 54-in. fan.

  1.3.3. The anemometer can be placed upstream or downstream of the fan.

  1.3.4. With the specifications in this SOP, this anemometer has a lower threshold of 1 m/s, and an upper threshold of approximately 45 m/s.

  1.3.5. Measurements are taken continuously.

2. Summary of Method

The Model 27106RS anemometer is equipped with a four-blade helicoid impeller, which drives a miniature tach-generator transducer. The generator converts the rotation of the impeller into a DC voltage. Output voltage from this generator is directly proportional to the axial component of the air speed. Signal polarity indicates direction of impeller rotation. The instrument should be oriented with the impeller facing the predominant flow of air being measured. The tachometer generator output is set at the factory for 500±2 mV at 1800 rpm. The pitch of the impeller is 0.00478 m/s per rpm, with an accuracy of ±1%. Data collected from anemometers is logged by the AirDAC software program (SOP B2). While the method in this SOP measures air velocity directly, the fan airflow rate is calculated based on a velocity vs. airflow curve for the anemometer and the fan. To develop this curve, the anemometer is installed within a fan, and tested with a low-turbulence wind tunnel (SOP A1). The curve is then verified in field with a calibrated portable fan tester (Fans Assessment Numeration System, FANS) that consists of multiple traversing impeller anemometers (SOP A2). Sections 9.1 through 9.4 of this SOP describe procedures for using the anemometer to measure airflow velocity on-site, while Section 9.5 covers use of the anemometers in generating the velocity vs. airflow curve. Procedures for initial ("benchmarking") performance testing of anemometers, and for periodic performance audits are also included.

3. Definitions

3.1.	AirDAC	Data Acquisition and Control Software
3.2.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.3.	QAPP	Quality Assurance Project Plan
3.4.	rpm	Revolutions per minute
3.5.	SOP	Standard operating procedure

3.6. Transfer function — The ratio of air speed to anemometer rotation rate (in rpm)

4. Health and Safety

4.1. Make sure that the ventilation fan in which the anemometer is being placed is turned off manually before anemometer installation, and during all maintenance.

4.2. Be careful when working with electrical power connections. Repair of instruments should only be carried out by trained personnel, and in accordance with procedures detailed in the instrument manual.

5. Cautions

5.1. Connecting the wires to cable connectors on the impeller anemometer improperly could cause a positive signal when the impeller rotates counterclockwise, which is not desired (Section 9.6.2.2.1).

5.2. Avoid placing the anemometer too close to the center (hub) of the ventilation fan. The region is often characterized by very low air velocity, and sometimes even reverse flow. Placing the anemometer close to this region will reduce the rotational speed of the anemometer. Previous experience has shown that the ideal location on most fans is approximately ⅓ the distance from the fan housing wall to the outer edge of the fan hub.

5.3. When using anemometers to monitor multiple fans of the same size and model, position the anemometer at the same spot on each fan, and the same distance from the fan. Record this position and distance for each anemometer.

5.4. Worn or improperly functioning fan shutters can change the velocity profile of the fan, which will affect the readings of the anemometer.

5.5. Cleaning and maintaining the shutters can affect fan capacity and velocity profile.

5.6. Damage to the fan housing can change the velocity profile.

5.7. Before conducting any maintenance on a fan that is being monitored by an anemometer, remove the anemometer to avoid damage.

5.8. Avoid installing an anemometer too far away from the fan on the inside of the barn, as this could affect worker activity in the barn, or result in the anemometer being damaged or knocked out of alignment.

5.9. The most common problem with the Model 27106RS is partial or complete bearing failure. The bearing failure usually leads to increased friction, which results in reduced signal output and an underestimation of airflow speed. This problem is diagnosed through the torque test described in Section 11.1.1.

5.10. When the tach-generator output becomes erratic (usually due to brush failure) or begins to show signs of bearing failure (high torque), the entire generator assembly should be removed and replaced

6. Interferences

6.1. Dust collected on the anemometer could reduce its rotational speed. Check for dust accumulation, and clean anemometers as necessary.

6.2. Make sure the signal wires from the anemometer are firmly attached to the anemometer support and tidy to avoid being blown loose over time.
6.3. Wind speed and wind currents around the barn can affect rotation of impeller. Therefore locate the impeller anemometer close to the ventilation fan and make sure that the outside wind cannot affect the direction or speed that the impeller is turning.
6.4. Moisture can cause the bearings to rust, and can lead to a bad connection between the impeller anemometer and the DAQ (Data acquisition) hardware.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument, including the associated calibration equipment, before initiating the procedure.
7.2. Each analyst must read and understand the entire instrument manual and this SOP before operating the instrument.

8. Equipment and Supplies

8.1. Impeller anemometer (Model 27106RS, R.M. Young Company, Traverse City, MI)
8.2. Anemometer torque disc (Model 18310, R.M. Young Company, Traverse City, MI)
8.3. Anemometer rotational calibration unit (Model 18802, R.M. Young Company, Traverse City, MI)
8.4. Voltage & resistance meter
8.5. Stop watch
8.6. 5-ft. steel fencing post and post driver
8.7. Hose clamps
8.8. Level
8.9. Screwdriver
8.10. Pocket knife
8.11. Flange bearings (part # 27122)
8.12. Tach generator
8.13. Soldering kit

9. Procedures

9.1. Siting
  9.1.1. Always place the anemometer shaft parallel to the ventilation fan shaft. For example, if the fan is mounted into the wall with a downward angle, the anemometer should be mounted facing upwards if it is mounted outside the fan, or downwards if it is mounted inside the fan.
  9.1.2. When placing the anemometer on the inlet side of ventilation fan, face the impeller toward the fan blades. The impeller should be at least 4 in. away from the fan blades.
  9.1.3. When placing the anemometer on the exhaust side of the fan, face the impeller towards the fan blades, with the anemometer impeller at least 4 in. away from the ventilation fan blades.

9.1.4. Record the distance and direction of the anemometer from the fan blades and the shaft of the fan. If necessary, include a drawing detailing the location in the site monitoring plan. See Section 5.3 if monitoring more than one fan of the same size and model.
9.1.5. If possible, protect the anemometer from wind by placing it within the fan housing.
9.1.6. Depending on the location of the fan guards, the anemometer can be placed upstream or downstream of the fan guard.
9.2. Installing anemometer at outlet side of ventilation fan
9.2.1. Turn off the ventilation fan before any work is started.
9.2.2. Using a post driver, drive a steel post into the ground until the stabilizing blades of the post are completely buried (Fig. 1).

Figure 1. Model 27106RS Impeller Anemometer installed on a post on the exhaust side of a ventilation fan (Hoff et. al. 2004)

9.2.3. Place the anemometer at the proper monitoring location. If the impeller is to be positioned between the fan guard and fan blades, remove the impeller from the anemometer shaft and housing. Do not place the anemometer in line with the hub of the fan (Section 5.2).
9.2.4. Secure the shaft housing and generator housing to the steel post using hose clamps.
9.2.5. If the impeller was removed, replace it onto the shaft.

9.2.6. Restart the ventilation fan.

9.3. Installing anemometer at inlet side of ventilation fan

9.3.1. Shut off the ventilation fan before any work is started.

9.3.2. Many ventilation fans have a fan guard or shutters on the inlet side.

9.3.3. If there are shutters, remove and replace with a fan guard if the ventilation fan is kept running throughout the year.

9.3.4. If the fan is not a winter fan and the shutter cannot be replaced, cut a small section (1 in.) out of one of the shutter blades, and install the anemometer. The objective is to minimize the leakage of the shutter when the anemometer is installed through the shutters.

9.3.5. Connect the anemometer shaft to the fan guard or shutter if one of these is located such that it would place the anemometer in the desired location, If not, install an additional supporting pole. Use hose clamps or similar rigid means to attach the anemometer to the support.

9.3.6. Make sure that the anemometer shaft is parallel with the fan shaft (Section 9.1.1). Do not place the anemometer directly in line with the fan hub (Section 5.2).

9.3.7. Restart the ventilation fan.

9.4. Operation and data collection

9.4.1. The anemometer analog signals (voltages) are recorded by the data acquisition system, as specified in SOP B2. Data will be one-minute averaged for recording purposes.

9.4.2. The DAS (Data acquisition software) will also convert the output signal into air velocity.

9.5. Estimating fan airflow rate based on anemometer air velocity measurement

9.5.1. If possible, remove used fan(s) from the measurement site and test their performance with a low-turbulence wind tunnel (SOP A1). If this is not possible, use a new fan of the same manufacturer and model.

9.5.2. When testing fan performance, install the anemometer within the fan housing and record velocity readings. It is very important that the anemometer position is carefully chosen as discussed above, and is the same as that which will be used in the field.

9.5.3. Correlate the measured anemometer velocities and wind tunnel flow rates to develop fan performance curves based on anemometer velocity data (Fig. 2).

9.5.4. Measure *in-situ* fan airflow capacities with a calibrated portable FANS analyzer (SOP A2). Use these measured values, together with the anemometer velocities obtained at the same time, to update the relationship in Fig. 2. This field spot-check is necessary because differences exist for each ventilation fan, and their capacities can change over time.

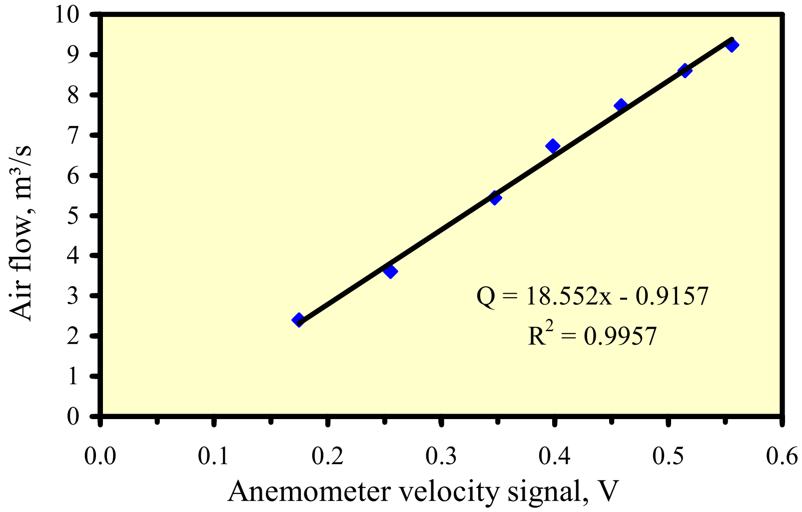

Figure 2. Anemometer velocity vs. fan airflow rate, based on wind tunnel measurements.

9.5.5. Based on the comparison of field spot-checks and wind tunnel data, develop an individual fan performance curve (anemometer velocity vs. airflow rate) for each fan that is monitored by a vane anemometer, to determine airflow rate based on the single-spot velocity measurement.

9.6. Maintenance
- 9.6.1. Replacement of bearings
  - 9.6.1.1. Removing old bearings
    - 9.6.1.1.1. Remove impeller from anemometer.
    - 9.6.1.1.2. Unthread and separate shaft housing assembly from generator housing.
    - 9.6.1.1.3. Loosen set screw on shaft collar/coupling disk, and remove from impeller shaft.
    - 9.6.1.1.4. Slide impeller shaft through both bearings and out of housing.
    - 9.6.1.1.5. Remove front bearing dust shield from housing.
    - 9.6.1.1.6. Gently pry front and rear bearings out of housing using the edge of a pocket knife or a sharp screw driver.
  - 9.6.1.2. Installing new bearings
    - 9.6.1.2.1. Gently insert front bearing into housing.
    - 9.6.1.2.2. Install front bearing dust shield through front bearing and into housing.
    - 9.6.1.2.3. Carefully slide impeller shaft through front bearing and into housing.
    - 9.6.1.2.4. Slide rear bearing over impeller shaft and gently push it into housing.
    - 9.6.1.2.5. Place shaft collar/coupling disk on impeller shaft.
    - 9.6.1.2.6. Thread shaft housing assembly into generator housing and tighten firmly.
    - 9.6.1.2.7. Check bearing torque to confirm it is within specifications.
- 9.6.2. Tach-generator replacement
  - 9.6.2.1. Removing old generator assembly
    - 9.6.2.1.1. Remove impeller from anemometer.

- 9.6.2.1.2. Unthread generator housing collar. Remove generator housing from sensor connector and generator assembly.
- 9.6.2.1.3. Note position of generator wires on sensor connector pins. Unsolder wires from pins and remove old generator assembly.

9.6.2.2. Installing new generator assembly

- 9.6.2.2.1. Solder wires of new generator assembly onto proper connector pins. Verify correct polarity: Counterclockwise (CCW) rotation should produce a negative output voltage.
- 9.6.2.2.2. Slide generator housing over generator assembly. Tighten housing collar onto connector threads.
- 9.6.2.2.3. Check bearing torque to confirm it is within specifications.

10. Data and Records Management

10.1. Maintain laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance

11.1. Initial inspection

11.1.1. Torque test

11.1.1.1. Keeping anemometer in the horizontal orientation, remove impeller, and replace with Model 18310 torque disc (Fig. 3).

Figure 3. Model 18310 Impeller Torque Disc (R.M. Young 2000).

11.1.1.2. Use torque disc to measure anemometer torque in both directions (clockwise and counterclockwise). Using a combination of black nylon screws (0.1 g) and pan-head stainless steel screws (1.0 g), establish weights at the various radii on the torque disc (see figure on Pg.7 of RM Young Manual 18860-90) to create the desired torque. Hold torque disc with the weights in a horizontal line (as in Fig. 3), then release the disc. Disc should rotate freely downwards.

11.1.1.2.1. This provides a check of the anemometer's bearing conditions. Failure to freely rotate downwards indicates degraded bearings

11.1.1.2.2. The torque disc allows verification of the anemometer bearing torque with 0.1 g-cm resolution.

11.1.1.2.3. The torque disc can also be used for simple and accurate pass/fail checks.

11.1.1.2.4. For a new anemometer, the acceptable threshold is 1.5 g-cm. This corresponds to a stainless steel screw at the 1-cm radius, plus a nylon screw at the 5-cm radius. For a used anemometer, in order to maintain a threshold of 1.0 m/s, the acceptable maximum torque value (from Pg. 9 of the manual) is 2.5 g-cm, which corresponds to a stainless steel screw at the 2-cm radius, plus a nylon screw at the 5-cm radius.

11.1.2. Measurement of transducer output

11.1.2.1. Attach the Model 18802 Anemometer Drive unit (Fig. 4) to the anemometer, and connect a voltmeter to the "A" and "B" output pins of anemometer. The Model 18802 is a selectable-speed unit which can be run at any speed between 100 and 10,000 rpm.

11.1.2.2. Run the Model 18802 at the following speeds, and record its voltage output:

- 300 rpm
- 1800 rpm
- 3600 rpm

11.1.2.3. Repeat for the opposite rotational direction.

Figure 4. Model 18802 Anemometer Drive (R.M. Young 2000).

11.1.2.4. Factory-specified voltage outputs for the Model 27106RS are as follows:

Rate of Rotation (rpm)	Signal Output (mV)
300	83.3
1800	500
3600	1000

11.1.2.4.1. Deviation of more than ± 6 mV at any rate of rotation indicates possible problems with the unit's signal conditioner, transmitting system, averaging system and/or recording system. A unit in this condition should be returned to the manufacturer for repair.

11.2. Periodic inspection and maintenance

11.2.1. Perform torque tests according to the frequency specified in the QAPP for the study.

11.2.1.1. Replace the bearings if the measured torque is greater than the maximum allowed, and repeat the torque test.

11.2.2. Measure transducer output according to the frequency specified in the QAPP.

11.2.2.1. Deviation(s) of more than ± 6 mV indicate possible problems with the anemometer signal conditioner, transmitting system, averaging system and/or recording system. Any unit in this condition should be returned to the manufacturer for repair or replaced with a new unit.

12. References

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BARN VENTILATION RATE ESTIMATION

Standard Operating Procedure (SOP) A4

BARN VENTILATION RATE ESTIMATION

Standard Operating Procedure (SOP) A4

Prepared by

Teng-Teeh Lim, Matthew J. Darr (Ohio State University), and
Lingying Zhao (Ohio State University)

Reviewed by

Bill W. Bogan, Albert J. Heber and Erin Cortus

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

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1. Scope and Applicability

1.1. This method determines the total ventilation rate of a mechanically-ventilated livestock barn. The one-minute barn ventilation rate is the summation of the individual fan airflow rates over that minute.
1.2. A mechanically-ventilated barn is often ventilated in multiple ventilation stages, with each stage consisting of one or more fans and fan locations.
1.3. This method applies to both single- and variable-speed ventilation fans.
1.4. The method accounts for fan performance degradations, which generally range from 0 to 50% decrease in airflow rate. Degradation is generally higher for fans in poultry barns than in dairy and swine barns, due to the much higher dust levels in the former.

2. Summary of Method

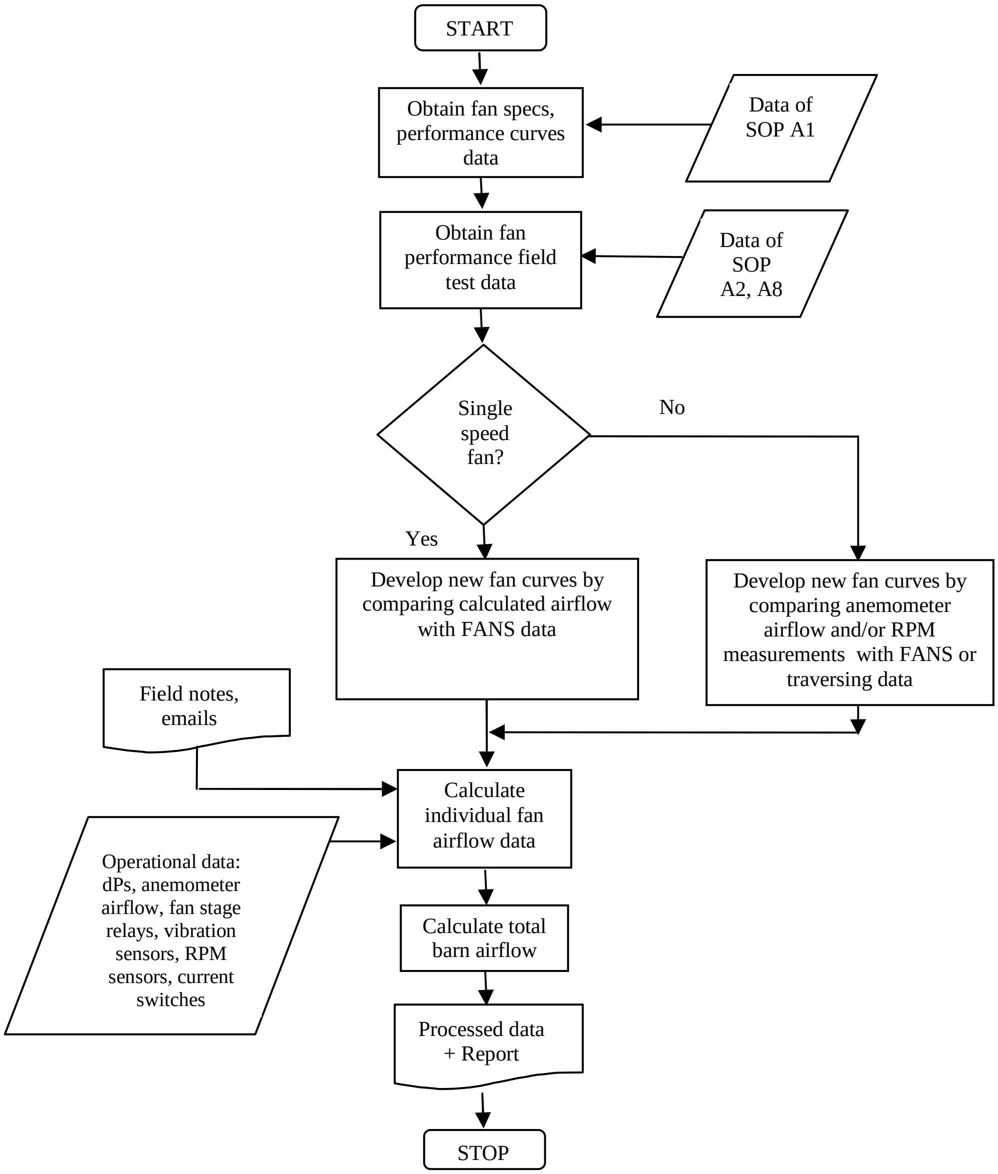
The ventilation rate of a mechanically-ventilated livestock building is the sum of the airflow of all individual fans operating at any given time. The airflow rate of a single fan is a function of its operational status, its designed performance, its degradation from that optimal performance, and the differential pressure of the building. Building static pressure will be continuously recorded (SOP A5). The operational status (operating time, %) of individual fans will be monitored using vibration sensors (SOP A7) (Ni et al., 2005), fan speed (rpm) sensors (SOP A11), current switches, and/or impeller anemometers (SOP A3). The operational status of each fan stage (which may consist of one or more individual fans) via auxiliary contacts of fan motor control relays (SOP S4) will provide a cross-reference set of data in most cases. Ventilation stage monitoring is necessary for barns where each fan is not monitored for operation status. Open impeller anemometers will, in general, be placed on selected primary representative exhaust fans, and on one representative fan for every other fan model employed at the site. These anemometers provide further information regarding fan performance. The fan performance curves will be obtained or determined for each fan model. If possible, this will involve testing an existing fan of each model (one removed from the barn) by a fan test facility (SOP A1). Published fan cuves are also available for most fan models.

Individual fan airflow capacities will then be measured and verified in the field, so that the baseline fan performance curves for each ventilation fan can be properly adjusted to reflect field conditions and fan degradation. If possible, this will be done with a calibrated portable fan tester (FANS, Fans Assessment Numeration System) that consists of multiple traversing impeller anemometers (SOP A2; Gates et al., 2004), as a transfer standard. If the FANS cannot be used, fan airflow will be determined with a manual traversing method (SOP A8).

For <u>single-speed fans</u>, the fan airflow rate is calculated based on the status of the fans (on/off and operation time in % of a minute), calibrated individual fan performance curves, and the building differential pressure.

For <u>variable-speed fans</u>, the rpm measurement (SOP A11) or the open-impeller velocity measurement (SOP A3) will be used in conjunction with the status of the fans (on/off and operation time in % of a minute), calibrated individual fan performance curves, and the building differential pressure, to calculate the fan airflow rate.

The ventilation rate for the barn as a whole is then determined by summing the individual airflow rates of all fans in the barn. The flow chart below summarizes the method for Barn Ventilation Rate Estimation.



3. Definitions

3.1.	atm	1 atmosphere (101,325 Pa)
3.2.	BESS	Bioenvironmental Systems and Simulations
3.3.	dP	Differential pressure

3.4.	FANS	Fans Assessment Numeration System
3.5.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.6.	QAPP	Quality Assurance Project Plan
3.7.	SOP	Standard operating procedure
3.8.	STP	Standard temperature and pressure

4. Health and Safety

4.1. Be careful when working near ventilation fans. The high-speed fan blades can be a hazard, especially if they are not protected by fan shutters. Safety glasses should always be worn while in the presence of an operating fan. Do not wear loose-fitting or baggy clothing, or dangling jewelry around an operational fan, and put up or secure long hair.

5. Cautions

5.1. Obtain the correct fan test data from the fan manufacturer. Since there are many similar fans, it is very important to provide the correct fan information, including the size, model number, motor details, shutter type, fan guard, housing, etc.

5.2. Ideally, *in situ* FANS measurements should be conducted at several differential pressures (dPs), which should cover the entire operating range. However, unless it is possible to intervene with the environmental control system to adjust barn dP to desired values, it may only be possible to conduct the FANS measurement replications over a narrow range of dP or a small segment of the fan performance curve. The rest of the curve is estimated.

5.2.1. Producer permission must be granted for intervention of the barn environmental control system.

5.2.2. Exceptions to this may include empty barns, or cases when proper ventilation airflow can be ensured for the comfort of animals during the FANS measurement.

5.3. When the field measurement of FANS data covers only a narrow range of the operating pressure, comparisons with the manufacturer’s fan performance curve are somewhat limited, and result in greater uncertainties in airflow rate calculations.

5.4. Dust collected on the impeller anemometer could reduce its rotational speed, and affect air velocity measurement accuracy. The impellers need to be cleaned and checked periodically according to the frequencies as stated in the Quality Assurance Project Plan (QAPP) for the particular project.

6. Interferences

6.1. Fan performance can be affected by dust accumulated on shutters, belt wear, and damage to the shutters and/or fan housing.

6.2. Strong wind around the barns can impose pressure onto the fans; however, these effects should be measured by the differential pressure sensors and the impeller anemometers.

6.3. Fan maintenance, such as changing or tightening the belt, or cleaning the shutter and/or fan housing, can affect fan performance. Obtain maintenance records from the farm manager to determine whether reevaluation of the fan capacities is necessary (SOP S1).

6.4. Barn managers sometimes change ventilation stage strategies. Follow SOP S1 to ensure that any such changes are reported to the study personnel. Cross-check the individual fan operation data (from anemometers or vibration sensors)with the ventilation stage data (from contactor relays) before performing airflow calculations. If necessary, update the number of fans controlled by each ventilation stage, so that the barn airflow will be calculated based on the new strategy.

6.5. Use of the FANS unit upstream or downstream of a ventilation fan could add a pressure drop to the working fan, and hence may reduce performance. However, both laboratory tests of the FANS at the University of Illinois Bioenvironmental Systems and Simulations (BESS) facility (Gates et al., 2004) and field measurements of layer barn ventilation fans (Lim et al., 2003) suggest that this pressure drop is insignificant.

7. Personnel Qualifications

7.1. Personnel should be knowledgeable about ventilation stage control of animal buildings, fan performance curves, and ventilation needs of animal facilities.

7.2. Personnel should be trained in the use FANS, and all instruments, and software mentioned in this SOP.

8. Equipment and Supplies

8.1. Commercial spreadsheet software (e.g. Microsoft Excel), and custom software: Air Quality Data Acquisition and Control Software (AirDAC) Raw Data Inspection (SOP B3), and CAPECAB Data Processing Software (SOP B6).

8.2. Fan Assessment Numeration System (FANS), including appropriate hardware (notebook PC and data acquisition card, cable, etc) and software (SOP A2)

8.3. SETRA Model 260 static pressure sensor (Setra Systems, Boxborough, MA) (SOP A5) or equivalent

8.4. Ventilation fan operation monitoring devices such as electromechanical relays (SOP S4), vane anemometers (SOP A3), vibration sensors (SOP A7), rpm sensors (SOP A11) and/or current detectors

9. Procedures

9.1. Gather fan information

9.1.1. Obtain specifications of each ventilation fan (Table 1).

9.1.2. Gather existing fan performance data from the fan manufacturer, or from the BESS fan test reports.

9.1.3. Learn and verify the barn’s environmental control systems, including the staging details of all ventilation fans. Consult the Site Monitoring Plan to ensure that they have not changed since this was prepared.

9.2. Ventilation fan performance evaluation in the laboratory

9.2.1. Conduct lab tests of each fan model in the barn with a fan test facility (SOP A1). Measure the performance in new or refurbished condition with the existing housing, shutters and all other accessories included.

Table 1. Fan specifications.

Parameter	Model 1	Model 2	Model 3
Manufacturer			
Fan Model			
# of this Model in Barn			
Serial Numbers			
Diameter, m			
Shutter (Yes/No, Type)			
Guard (Yes/No, Type)			
Shroud (Yes/No, Type)			
Cone (Yes/No, Type)			
Single Speed?			
Motor Manufacturer			
Motor Model			
Motor Serial Number			
Motor Size, Hp			
No Load Current			
Design Load Current			
Airflow at 0 iwg, cfm			
Airflow at 25 iwg, cfm			

9.2.2. If possible, remove the existing barn fan(s) from the monitored barn(s), and test their performance with a fan test facility to determine degraded fan performance (SOP A1). Conduct tests before and after refurbishment by cleaning and replacing worn parts (e.g. belts, shutters, etc.).

9.2.2.1. Using Microsoft Excel, fit a polynomial equation to the tested (as found or degraded) data to produce a curve, and compare this with the published or baseline data for new fan (Fig. 1). These equations will be fan-specific.

9.2.2.2. Verify that the polynomial equation is theoretically sound over the expected range of dP measurements for the barn. This may include positive dP values.

9.2.2.3. The equations representing the fan curves may be third-order (or higher) polynomial equations, and should have high R-squared values when compared with the measured data. For example, the equations used to calculate airflow rate of the fan in Fig. 1 included the published fan curve and corresponding correction factor of each fan or fan stages (Lim et al., 2003):

$$V = -1.64\text{x}10^{-7}\ \mathrm{P}^4 - 4.09\text{x}10^{-6}\,\mathrm{P}^3 - 5.09\text{x}10^{-5}\ \mathrm{P}^2 + 0.054\,\mathrm{P} + 11.433 \qquad (1)$$

$$K_1 = 1.88\text{x}10^{-6}\,\mathrm{P}^3 + 5.11\text{x}10^{-5}\ \mathrm{P}^2 + 2.78\text{x}10^{-3}\ \mathrm{P} + 0.759 \qquad (2)$$

$$\mathrm{Q}_1 = \mathrm{S\ V\ K}_1 \qquad (3)$$

Where:
V = volumetric ventilation rate of published fan curve, m^3/s
P = building static pressure, Pa.
K_1 = correction factor of ventilation fan1

Q_1 = corrected fan airflow rate for fan 1 m^3/s.
S = Operation status, fraction of time unit, which is usually one minute.

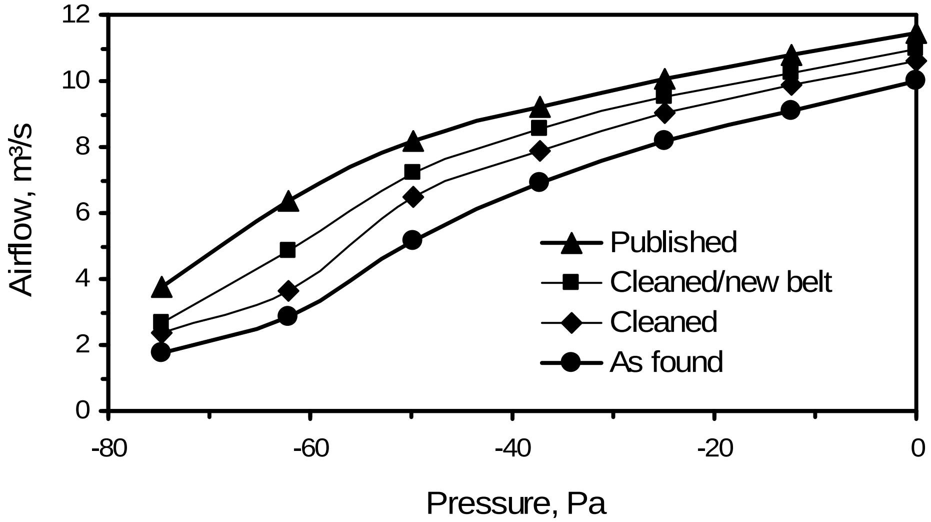


Figure 1. New (Published) and degraded (as found) fan curves. Fan was tested as found, after cleaning, and after replacing fan motor belt (Lim et al. 2003).

9.2.3. Calibrate the FANS with the fan model(s) to be tested in the field (SOP A1).

9.3. Ventilation fan performance evaluation in the field

9.3.1. Conduct fan tests in the field using a calibrated FANS (SOP A2) or the air velocity traverse method (SOP A8) to determine actual *in situ*, degraded fan curves or a degradation correction variable (K_1, Eq. 2).

9.3.1.1. For single-speed fans, fit a polynomial equation to the fan performance curves for each fan. If the measurement represents only a small segment of the dP range, average the differences between the FANS data in the field and those predicted by the degraded fan curve determined by the lab test facility, and use the value as an offset to the fan curve. Develop a new fan curve with the adjusted constant value in the as-found equation (Fig. 2).

9.3.1.2. For variable-speed fans, compare the FANS data with the airflow determined with the open anemometer or other fan speed method. Determine the needed offset (similar to Section 9.3.1.1) in the equations for estimating fan airflow.

9.4. Variables and information needed for airflow rate calculations for individual fans

9.4.1. Operational status (on/off) of all fans, based on ventilation stage status data, impeller anemometers, vibration sensors, current switches, and/or rpm sensors. If more than one measurement method is used for a fan, the data from one method can be used to cross-check the data from another method.

9.4.2. Verify that measured dP values are correct (SOP A5), and that they correspond to the location of the fan(s).

9.4.3. Study all field notes, log books, and emails to learn about any fan, and operational and fan speed sensor malfunctions.

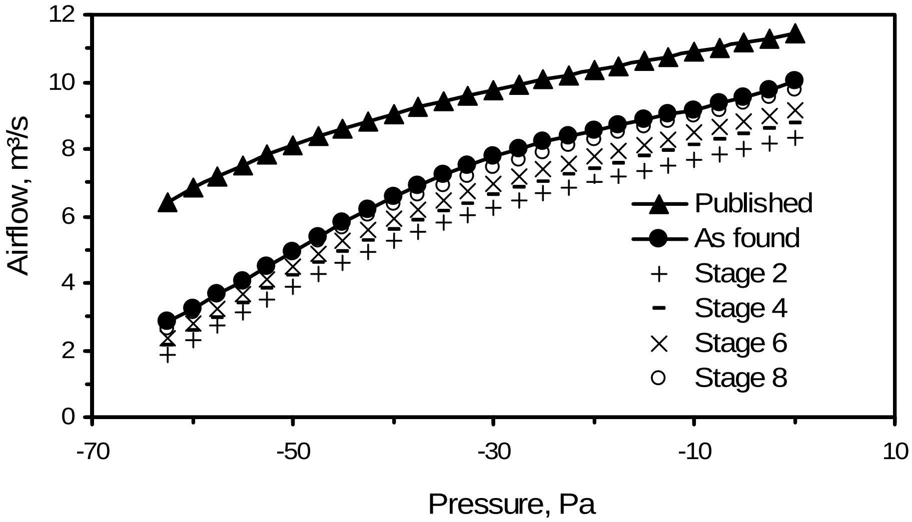


Figure 2. Published fan curve as compared with as-found fan curves for selected ventilation stages (Lim et al. 2003).

9.5. Ventilation rate calculations

9.5.1. Calculate the minute mean individual fan airflow rate based on verified fan operational status, dP and/or the degraded fan curves.

9.5.2. The equation to standardize the actual airflow (m^3/s) to the moist standard airflow (sm^3/s) is as follows:

$$Q' = \frac{Q \bullet P \bullet (273.15 + T')}{P' \bullet (273.15 + T)} \qquad (4)$$

Where:

Q' = Moist standard airflow (sm^3/s)
P' = Standard pressure (1 atm)
T' = Standard temperature (20°C)
Q = Outlet airflow rate at T (m^3/s)
P = Pressure at sampling location (atm)
T = Temperature at sampling location (°C)

9.5.3. Calculate the dry-standard airflow rate (Q″) by excluding moisture. The equation to standardize the moist standard airflow (m^3/s) to dry standard airflow (dsm^3/s) is as follows:

$$Q'' = (1 - W) \bullet Q' \qquad (5)$$

Where:

Q'' = Dry standard airflow (dsm^3/s)
W = Humidity ratio (See Appendix E of SOP B4)

9.5.4. Assign zero airflow for any non-functional fans.
9.5.5. Sum the individual fan airflow rates to obtain the barn ventilation rate.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet that is designated for this method. Supplement this electronic record with a bound record book designated for the method, which should also contain bound copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on field data sheets, and site logbooks with permanent ink, or in electronic field notes. Overstrike errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Utilize all data, including fan stage operation, anemometer, vibration sensor, observation, site field-notes, and any maintenance note provided by the farm to ensure quality control of individual fan airflow rate. Exclude fans that were idle from the pool of working fans for total ventilation rate calculation.
11.2. Conduct weekly verification of fan stage operation monitoring, anemometer, rpm sensor, current switch and/or vibration sensor operations and verify that the operational status signals agree with individual fan operation. Verify that the individual fans are operating when the ventilation stage to which they belong is operating.
11.3. Perform FANS unit calibration at the University of Illinois BESS Lab annually to ensure that the unit is functioning properly.
11.4. Conduct FANS test of each fan at least annually. After each FANS test, verify the degraded fan curves and/or degradation correction factors determined using the previous FANS test data, and correct for elapsed time if deemed necessary.
11.5. If possible, perform new FANS test on any individual fan that has undergone maintenance that is likely to significantly change its performance (such as installation of a new shutter, belt, motor, etc).

12. References

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12.14. SOP B6. 2007. Data Processing Software (CAPECAB). Standard Operating Procedure B6, v. 1.0. Purdue Ag Air Quality Lab.
12.15. SOP S1. 2006. Producer Collaborations at Barn Monitoring Sites. Standard Operating Procedure S1, v. 0.0. Purdue Ag Air Quality Lab.
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MEASUREMENT OF FAN STATIC PRESSURE IN LIVESTOCK BUILDINGS WITH SETRA MODEL 260 DIFFERENTIAL PRESSURE TRANSDUCER

Standard Operating Procure (SOP) A5

MEASUREMENT OF FAN STATIC PRESSURE IN LIVESTOCK BUILDINGS WITH SETRA MODEL 260 DIFFERENTIAL PRESSURE TRANSDUCER

Standard Operating Procure (SOP) A5

Prepared by

Teng-Teeh Lim, Bill W. Bogan, and Erin L. Cortus

Reviewed by

Steve J. Hoff (Iowa State Univ.), Richard Gates (Univ. of Kentucky), and Albert J. Heber

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. The Setra Model 260 multi-range pressure transducer is useful for measuring building differential pressure (ΔP) in facilities such as livestock buildings with negative pressure ventilation systems. Estimating air flow rate of ventilation fans based on actual fan performance curves requires measurement of ΔP.

1.2. The Setra Model 260 MS3 has four unidirectional (25, 50, 100 and 250 Pa FS) and four bidirectional ranges (±25, 50, 100 and 250 Pa FS) that can be set in the field. A bidirectional range of 100 Pa is the default range for NAEMS measurements.

1.3. The transducer measures the ΔP and converts the readings to a proportional electrical output. The manufacturer's stated transducer accuracy is ±1% full scale at constant temperature. The operating temperature limits are 0 to 50ºC (32 to 122ºF).

1.4. The negative static pressure in a barn is created by the exhaust ventilation fans and is typically -60 Pa to +10 Pa. High winds are able to pressurize a barn even with exhaust fans running. Therefore the transducer is bidirectional with a scale of -100 to +100 Pa.

1.5. The method also applies to monitoring the ΔP in the instrument shelter created by the heating, ventilating and air conditioning system, which is usually -10 Pa to +10 Pa.

2. Summary of Method

This method continuously monitors the static pressure of barn exhaust fans, for computation of building airflow rate. The Setra Model 260 transducer senses ΔP between two points with a sensitive electrical capacitor. The transducer consists of two closely-spaced, parallel, electrically-isolated metallic surfaces, one of which is essentially a diaphragm capable of slight flexing under positive or negative pressure. The diaphragm is constructed of a low-hysteresis material or a proprietary compound of fused glass and ceramic (Setraceram™). These firmly secured surfaces (or plates) are mounted such that a slight mechanical flexing of the assembly, caused by a minor change in applied pressure, alters the gap between them (creating, in effect, a variable capacitor). The resulting change in capacitance is detected and converted to a proportional analog signal. In this method, the positive (high) pressure port senses the pressure inside the building, while the reference (low) pressure port is in contact with the outside atmosphere. Polyethylene (PE) tubing is used to connect the pressure port in the barn or other locations. Typically, for facilities with fans on more than one sidewall, the ΔP across each wall with fans will be measured to account for wind interference.

3. Definitions of Terms and Acronyms

3.1.	DAC	Data acquisition and control
3.2.	ΔP	Differential static pressure
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	PE	Polyethylene
3.5.	QAPP	Quality Assurance Project Plan
3.6.	SOP	Standard Operating Procedure
3.7.	Static Pressure	Pressure that exists in the absence of air velocity
3.8.	Velocity Pressure	Pressure associated with or caused by air movement

4. Health and Safety

4.1. Be careful when working with the electrical power connections.

5. Cautions

5.1. Minimize exposure to liquids or corrosive gases, which can damage the pressure transducer unit. If possible, place the sensor in a protected location, and run tubes to remote pressure ports in the barn.

5.2. Install a pressure snubber orifice at the end of a polyethylene (PE) tube to minimize effects of air movement (from wind, fans, inlets, etc.) on the measurement. Installing the orifice will help reduce pressure pulsations and sudden fluctuations. The ports used for indoor measurements will be located far away from exhaust fans to minimize the effect of air speed (velocity pressure), see section 8.

5.3. Protect the end of the open PE tube with material such as foam to keep dust and insects out of the tube, unless a pressure snubber or orifice is used.

5.4. Keep the end of the PE tube which is used to measure ambient pressure pointing vertically downward, to prevent moisture from becoming trapped inside the tube. Installing a membrane filter holder at the end of ambient tube has proven effective in previous measurement tests.

5.5. Do not adjust the factory calibration settings of the transducer unless the transducer goes out of calibration (see Section 9.3.5).

5.6. Pressure outside the limits of the transducer can damage it.

5.7. Avoid running the PE tubing through cold areas, especially near the pressure port, to prevent condensation of water vapor that migrates into the tube by diffusion.

6. Interferences

6.1. Use of other than the recommended tube sizes (See Step 9.1.2) may lead to slower-than-optimal response times.

6.2. Airflow and air circulation, with streamlines directed at pressure ports, caused by wind and nearby operating fans may create pressure pulsations and surges due to velocity pressure. Minimize the interference by following these procedures:

  6.2.1. Measure the static pressure differential across each sidewall that has exhaust fans because static pressure varies between the four walls of a barn due to wind.

  6.2.2. Position the static pressure probe or tap perpendicular to the streamlines of flow.

  6.2.3. Use small orifices or pressure snubbers in the static pressure ports.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument before initiating the procedures listed in this SOP.

7.2. Each analyst must read the entire instrument manual and this SOP before operating or calibrating the instrument.

8. Equipment and Supplies

8.1. Setra Model 260 MS3 Differential Pressure Transducer (Setra Systems, Boxborough, MA)
8.2. Polyethylene tube for connecting unit ports to the pressure measuring locations (See Step 9.1.2)
8.3. Pressure snubber or screened orifice (Model BWFS64, O'Keefe Controls Co., Trumbull, CT) for end of tube, used for indoor measurement.
8.4. Air conditioner filter material (or equivalent) to fit inside the end of the tube and prevent dust and insects from entering tube.
8.5. Filter holder with 1/4" inlet/outlet ports (Model 4-47-4, Savillex Corporation, Minnetonka, MN, or equivalent) for end of tube, used for ambient measurement
8.6. NEMA 4 rated or equivalent junction box (for sensors located in the barn only)

9. Procedures

9.1. Installation
  9.1.1. Mount the transducer in the vertical position inside the OFIS or inside an appropriate protective enclosure in the barn. The transducers are factory calibrated in the vertical position.
  9.1.2. Connect PE tube between the pressure port at the inside or outside measurement location and the pressure port of the transducer located inside a protective shelter (eg., on-farm instrument shelter, OFIS). The selection of tube size depends on its length. To ensure the shortest response time, the manual recommends the following inside diameters.
    9.1.2.1. 0-100 ft: 3/16 in
    9.1.2.2. 100-300 ft: 1/4 in
    9.1.2.3. 300-900 ft: 3/8 in
  9.1.3. Connect the atmospheric (outside) static pressure tube to the reference (low) pressure port, which is located on the bottom of the unit (Labeled "LOW").
  9.1.4. Connect the inside static pressure tube to the positive (high) pressure port, which is located on the bottom of the unit (Labeled "HIGH"). If the inside static pressure is less than atmospheric, the reading will be negative.
  9.1.5. Protect the end of the pressure tube with foam to keep dust and insects out.
  9.1.6. Pressure snubbers or screened orifices can be used at each sampling point to minimize effects of air movement (wind) on the pressure measurement.
9.2. Electrical Connections
  9.2.1. The voltage output is a 3-wire circuit, with three terminals for wiring (Fig. 1). The terminals are clearly identified on the circuit board inside the transducer. The output signal range is 0-5 VDC for excitation of 10.2 to 42 VDC, and 0-10 VDC for excitation of 13 to 42 VDC. Because the sensor is located in the OFIS, 4-20 mA is not needed to avoid noise due to long signal wires.
  9.2.2. Connect the appropriate power and ground cables to the terminals.
  9.2.3. Connect the analog signal (VDC) output of the analyzer to terminals on the data acquisition system.

9.2.4. Use the slide switches to set the pressure range, mode (uni- or bi-directional) and output range (Fig. 2).
9.2.5. Enter the analyzer's analog signal and measurement ranges into the AirDAC software so that ΔP readings can be converted, displayed, and recorded.
9.2.6. Turn on the power to the transducer.

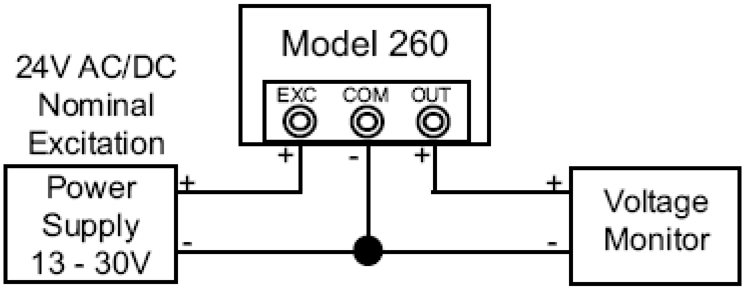

Figure 1. Model 260 pressure transducer electrical connection terminals (Setra Systems, 2007).

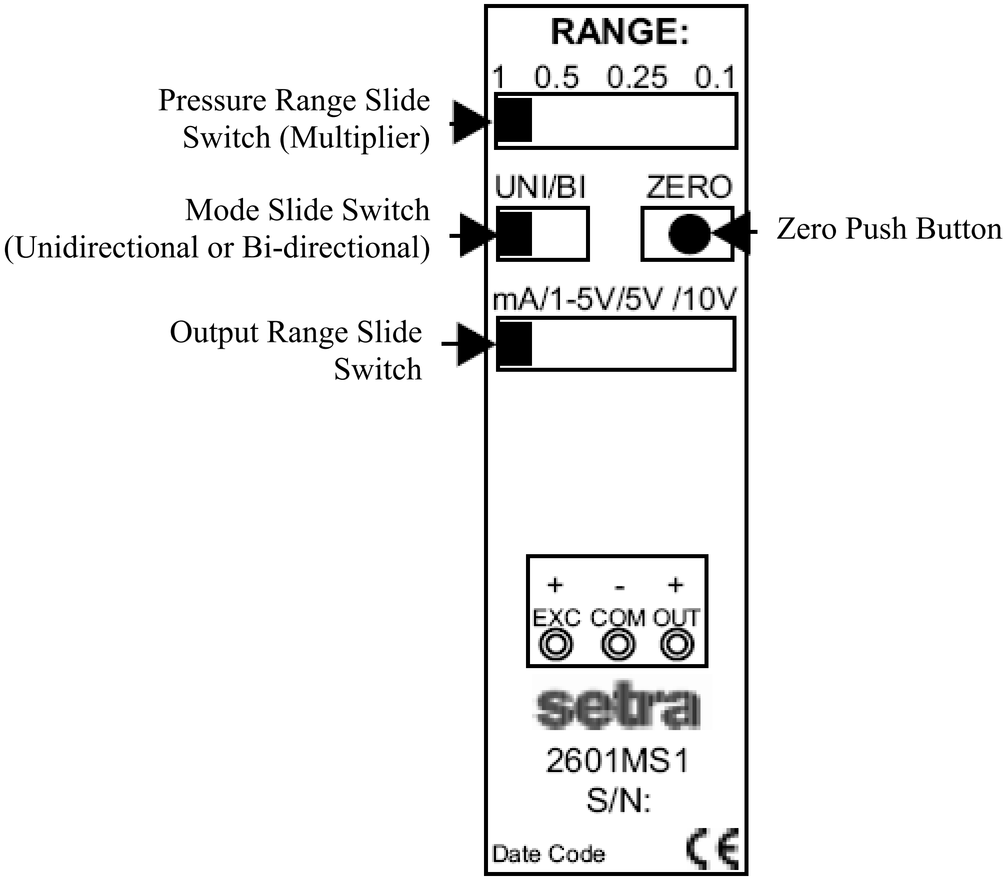

Figure 2. Model 260 pressure transducer compartment containing slide switches, zero push button and electrical connection points (Setra Systems, 2007).

9.3. Calibration

9.3.1. To apply zero pressure, disconnect the PE tubes of both pressure ports and shunt the ports together.

9.3.1.1. A short piece of tube can be used to test the sensor itself.

9.3.1.2. A long tube can be used to connect the ends of the two pressure tubes in the barn. This method is used to check the entire pressure sampling system.

9.3.1.3. Press the zero push button (Fig. 2) to adjust the zero offset.

9.3.2. Apply nonzero pressure simultaneously to transducer and a reference transducer or manometer, or use a NIST-traceable device to apply a reference pressure. Instructions for simultaneous pressure measurements by two devices are provided.

9.3.2.1. Disconnect tubes from low ports of both transducers and connect them, in parallel, using a length of PE tubing.

9.3.2.2. Connect the high ports of both transducers in parallel using a PE “T” or “Y” connector, with a stable pressure applied to connector’s third port (Fig. 2).

9.3.2.2.1. Short tubes can be used to test the sensor itself.

9.3.2.2.2. The preferred method is to apply the stable pressure at each pressure monitoring point with the “T” or “Y” connector near the transducers (Fig. 2).

9.3.2.3. Application of reference pressure

9.3.2.3.1. Positive: Place weights on top of partially filled single-port bag.

9.3.2.3.2. Negative: Monitor negative pressure created by barn exhaust fans.

9.3.2.3.3. Both: A syringe that can be drawn or pushed into the connector, as shown in Fig. 2.

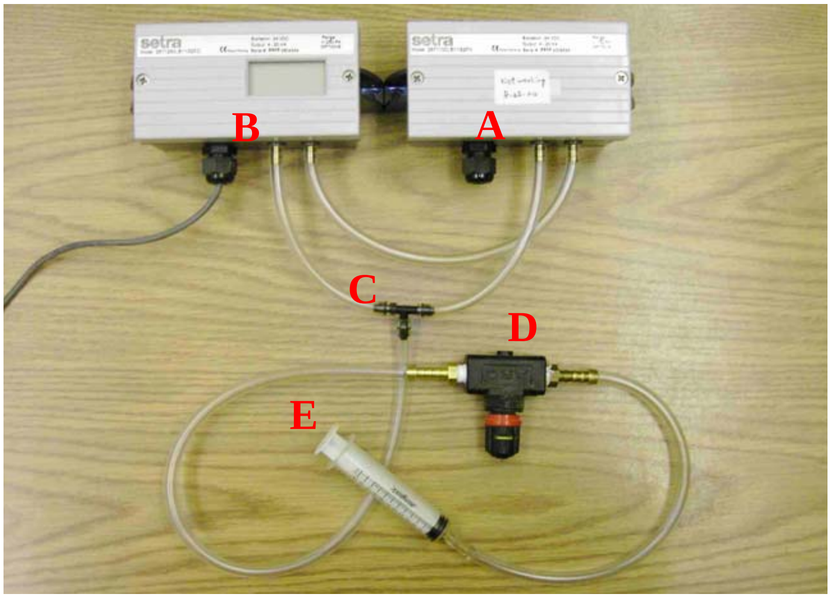

Figure 2. Calibration of a pressure transducer (A) with a calibrated reference unit (B), connected in parallel using a “T” connector (C). A pressure valve (D) and syringe (E) were used to create stable high or low pressure. Part B can be replaced with a micromanometer, in accordance with Section 9.3.2.4.1. Parts D and E can be replaced by a precision pressure generator and calibration unit (e.g. Furness Company).

9.3.2.4. Measurement of reference pressure
  9.3.2.4.1. Precision micromanometer with resolution of ±0.001 in. of water
  9.3.2.4.2. Identical or more accurate Setra transducer that is calibrated and verified with a precision check upon receipt.
  9.3.2.4.3. Inclined manometer
9.3.3. All Model 260 pressure transducers are factory-calibrated using NIST-traceable standards, and should require no further adjustment upon receipt. However, conduct a precision check upon receipt and before collecting data to verify transducer integrity.
9.3.4. Conduct zero and/or span offsets based on the precision checks. The correction can be made through adjustments to the data acquisition and control (DAC, SOP B2) system, or in the data processing (SOP B6).
9.3.5. Adjust sensor only if error is more than 5% of full scale, e.g. ±5 Pa for ±100 Pa sensor. Adjusting the sensor after factory calibration voids the certification provided by the manufacturer.
  9.3.5.1. Zero and span adjustments will only be made when using a NIST-traceable pressure standard with at least the same accuracy as the Setra transducer (<±1% FS),
  9.3.5.2. Record the reference pressure and the as-found value of the transducer.
9.4. Computer hardware & software
  9.4.1. AirDAC (SOP B2)
  9.4.2. ADPP (SOP B3)
  9.4.3. CAPECAB (SOP B6)

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which will contain copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance

11.1. Conduct zero checks at least monthly or according to the QAPP.
11.2. Conduct span checks before and after data collection, and semiannually, or according to the QAPP.
11.3. Attention will be given to visually checking measurement data frequently. Sudden variations may indicate that tube has been kinked, squeezed by a heavy object, or clogged. Conduct correction action if this occurs.
11.4. Select proper size (ID) and thickness of the PE tube (See Step 9.1.2) to ensure quick response time.
11.5. Since all Model 260 pressure transducers are factory-calibrated using NIST-traceable standards, avoid adjustment if drift is less than 5% of full scale. If is preferable to correct for zero and/or span offsets during post processing collected data.

11.6. For barns with fans on more than one sidewall, the differential static pressure across each sidewall will be measured. A common static pressure port is used inside the building and the difference in pressure between the building pressure and each sidewall is measured. Thus, one static pressure sensor is required for each sidewall.

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12.7. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturer:
SETRA, Inc.
159 Swanson Road
Boxborough, MA 01719
1-800-257-3872
http://www.setra.com/contact.htm
13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

AIR VELOCITY MEASUREMENTS WITH THE RM YOUNG MODEL 81000 3-DIMENSIONAL ULTRASONIC ANEMOMETER

Standard Operating Procedure (SOP) A6

AIR VELOCITY MEASUREMENTS WITH THE RM YOUNG MODEL 81000 3-DIMENSIONAL ULTRASONIC ANEMOMETER

Standard Operating Procedure (SOP) A6

Prepared by

Richard H. Grant, Juan Carlos Ramirez, and Bill W. Bogan

Reviewed by

Ji-Qin Ni and Albert J. Heber

Effective Date: November 6, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Measurements of air velocity through a livestock barn are necessary for determining the ventilation rate, which is, in turn, necessary for estimating emissions of airborne contaminants from the barn.

1.2. This SOP describes procedures for continuously monitoring the velocity of air moving in and out of an animal barn (for example, an open dairy barn), using multiple ultrasonic anemometers.

1.3. This procedure applies only to the RM Young Model 81000 3-D ultrasonic anemometer.

  1.3.1. The range of air velocities that can be measured is 0.01 to 40 m/s.

2. Summary of Method

The RM Young Model 81000 Ultrasonic 3-D Anemometer (Fig. 1) measures three-dimensional air velocity by determining the transit times of ultrasonic acoustic signals. Anemometers can be installed at any opening or point inside a barn where airflow measurements are needed, such as the ventilation openings of naturally-ventilated barns, which are usually in the side walls, the end walls, and the roof ridge (Fig. 2). Other places where anemometers could be used include throughways and connecting alleys within a group of barns. Each anemometer monitors the air speed through a section of an opening or passageway. The North direction of the anemometer is positioned to face the inside of the barn, and is therefore perpendicular to the plane of the barn opening that the anemometer is monitoring. Measurement data from each anemometer are available as four, 0 – 5000 mV analog voltage outputs, corresponding to air speed in the x, y, and z directions (U, V, and W) and sonic temperature. The analog outputs are connected to the data acquisition (DAQ) system for real-time monitoring, and the data are recorded in the DAQ computer. Subsequent data processing converts the measured air velocity components to the air speed perpendicular to the barn opening surface. Air flow rate in and out of the barn through that opening or passageway is obtained by multiplying the air speed perpendicular to the opening surface with the area of that opening.

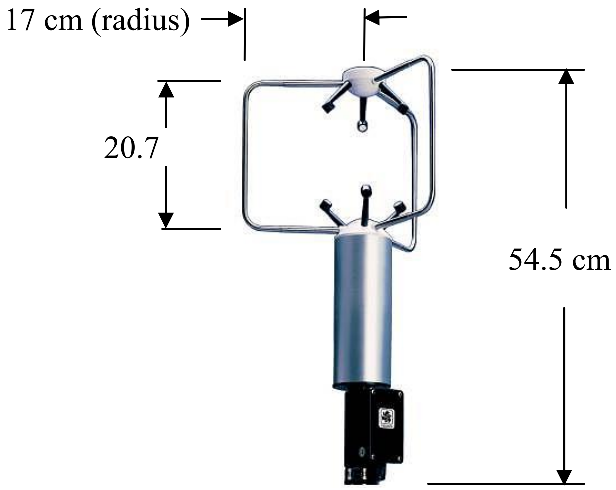

Figure 1. R.M. Young Model 81000 Ultrasonic 3-D Anemometer (Campbell Scientific Co., 2006).

3. Definitions

3.1.	ADPP	Air Data Pre-Processing software, written in Visual Basic for Applications in MS Excel
3.2.	AirDAC	Air quality monitoring Data Acquisition and Control program written in LabVIEW (SOP B2).
3.3.	Azimuth	Horizontal direction of airflow when the 3-D ultrasonic anemometer is used to measure wind velocity, degrees. It is calculated in the x-y plane.
3.4.	DAQ	Data acquisition
3.5.	Elevation	Vertical angle of airflow when the 3-D ultrasonic anemometer is used to measure wind velocity, degrees. It is the angle between the z component and the x-y resultant.
3.6.	OFIS	On-farm instrument shelter
3.7.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.8.	QAPP	Quality Assurance Project Plan
3.9.	U, V, W	Air velocity components in the x, y, and z directions, respectively
3.10.	3-D	Three-dimensional

4. Health and Safety

4.1. When installing or inspecting the anemometers at the roof ridge opening of a barn, follow the appropriate safety procedures for working on rooftops and with ladders. These are listed in SOP E5.

5. Cautions

5.1. The anemometer has electrical components, and proper care should be used as with all electrical equipment.
5.2. Handle the anemometer carefully to avoid physical damage.
5.3. Turn on the power to the anemometer only after all connections are made and verified.
5.4. If the anemometer is mounted in any orientation other than vertical (e.g. horizontal or upside-down), seal the openings around the cable entering the unit with electrical tape or silicone caulk to keep water from damaging the electronics.
5.5. Be sure that the anemometer is earth-grounded (Refer to page 8 of the instrument manual, RM Young Company, 2005).

6. Interferences

6.1. Incorrect siting will cause inaccuracies in the measurements due to failure of assumptions of spatial homogeneity and temporal stationarity of the air velocity field.
6.2. Anemometer response under light mist or heavy fog can be diminished, due to accumulation of water droplets on the anemometer transducers.
6.3. The anemometer does not respond under conditions in which freezing rain, heavy frost and/or snow accumulates on the transducers.

6.4. Accumulated dust, dirt, or fly waste on the transducers can also affect performance. Inspect the unit periodically, and clean the transducer surfaces if necessary.
6.5. The particular configuration of this anemometer can encourage nesting by birds.
6.6. Wake flow around support struts reduces anemometer performance.
6.7. If the anemometer is mounted vertically, a wind angle of attack (relative to the horizontal) of >60º will cause less accurate readings due to the physical structure of the sensor. The magnitude of these inaccuracies is unknown. Such angles of attack are introduced only when the anemometer is oriented nonperpendicular to the air velocity being measured.
6.8. A 1^{o} tilt of anemometer induces an error in the measurement of approximately 6% in the correlations of air velocity deviations and 3% in the derived friction velocity with tilt.
  6.8.1. Errors caused by slight ($<1^{o}$) tilt of the anemometer can be corrected mathematically.
  6.8.2. However, if the anemometer is tilted $>1^{o}$ the readings will be non-linear and cannot be corrected.

7. Personnel Qualifications

7.1. Personnel must read and understand the instruction manual (RM Young Company, 2005), this SOP, and SOPs B1 and B2 before installing and operating this anemometer.

8. Equipment and Supplies

8.1. R.M. Young Model 81000 3-D Ultrasonic Anemometer (R.M. Young, Traverse City, MI) with manual
8.2. 12 – 24 VDC power supply (110 mA for each anemometer)
8.3. Three (if sonic temperature data are not acquired) or four (if sonic temperature is included) different DAQ analog input channels for each anemometer
8.4. RS232 cable
8.5. Anemometer power and signal cable (8-conductor, 22-gage, shielded)
8.6. 1.34–in. (OD) diameter mounting post or pipe (to hold the instrument)
8.7. Clamps or other hardware to attach mounting posts to the supporting structure
8.8. Multimeter
8.9. Precision level
8.10. Compass
8.11. #2 common head screwdriver
8.12. 1/8″ slotted screwdriver
8.13. Computer
8.14. AirDAC program (SOP B2)
8.15. DAQ board with hardware (SOP B1)

9. Procedures

9.1. Anemometer installation
  9.1.1. The factory default configurations (Section 3.0 of the manual) are 3D wind speed, wind direction, azimuth, and sonic temperature. To change to U, V, W, and sonic

temperature, follow the procedures described in Sections 4.0, 6.0 and 6.7.1 in the instrument manual, as follows:

9.1.1.1. Remove junction box cover. Connect power and signal wires to terminals as indicated in wiring diagram (on p. 6 of the manual) for RS-232 output. Connect the RS232 cable to the COM port of a laptop or PC.

9.1.1.2. Start HyperTerm or an equivalent serial communications program with a baud rate of 38400, and flow control set to NONE.

9.1.1.3. While the anemometer is powered and operating, send the ESC character (ASCII 27) the time in rapid succession. This will access the anemometer's COMMAND menu.

9.1.1.4. Send "S" to access SETUP mode.

9.1.1.5. From the SETUP menu, send "S" for SER OUTPUT FORMAT.

9.1.1.6. From the SERIAL OUTPUT FORMAT menu, send "1" to access the CUSTOM format.

9.1.1.7. Send "5B" to setup output of U, V, W, and sonic temperature (Ts).

9.1.1.8. Send "X" to return to main (COMMAND) menu, and "X" again to return to "OPERATE" mode.

9.1.2. Establish the exact locations where the anemometers should be mounted according to the Site Monitoring Plan. Some locations may require more than one anemometer, while a single one may suffice for other locations. In general:

9.1.2.1. Measuring airflow through the ridge opening along the barn length will require multiple anemometers.

9.1.2.2. Measuring airflow through the sidewall opening along the barn length will require multiple anemometers.

9.1.2.3. One or more anemometers may be required to measure airflow through the face of the opening at the end walls (short side) of the barn, depending on its configuration. This end side could have a door (to allow the entrance of the feeding truck) or be totally open (without wall).

9.1.2.4. Measuring airflow through a connecting passageway may only require one anemometer.

9.1.2.5. In all of the above cases, the anemometer should generally be located in the plane of the narrowest part of the opening. For example, on the side opening of a naturally ventilated dairy barn, the curtains are adjusted vertically, leaving a narrow opening between the eave and the curtain in winter. The 3-D anemometer should be placed in the center of this narrow opening.

9.1.2.6. To define the best vertical location of the anemometers when the sidewalls have no restrictions (for example, no curtains or walls), locate two to four anemometers (depending of the opening height) vertically in the horizontal center of the sidewall. Divide the vertical dimension of the opening into equal lengths, and locate the anemometers at the center of each length. Compute the average air velocity and select the location where the air velocity is closest to the average to locate all the anemometers on that side.

9.1.3. Mount each anemometer securely on the mounting post, such that it will not twist, rotate, or sway. Any movement will compromise the measurements.

9.1.4. Mount the anemometers with the junction box of the anemometer facing outside the barn, so that the North (the strut opposite the junction box) points into the barn and is perpendicular to the building structure opening that the anemometer is monitoring (Fig. 3). Refer to page 9 in the instrument manual (RM Young Company, 2005) for further information regarding anemometer orientation.

9.1.5. Orient the anemometer mounting arm in the position that best facilitates easy installation, while keeping the North oriented correctly (Section 9.1.4).

9.1.6. Connect the anemometer earth ground terminal to a suitable earth ground.

9.2. Analog signal and power connection and DAQ settings

9.2.1. Consult the QAPP to determine if sonic temperature will be measured or not. This will determine the number of DAQ channels needed (Section 8.3)

9.2.2. Remove the junction box cover. Connect the multi-conductor power and signal cable to terminals as indicated in the wiring diagram on page 8 of the instrument manual (RM Young Company, 2005). Connect the other end of the cable to the data acquisition hardware (SOP B1), and to the anemometer power supply.

9.2.3. Verify that all connections are correct before turning on the DAQ system power supply.

9.2.4. Turn on the power to the DAQ system.

9.2.5. Start AirDAC (SOP B2). Go to the “DAC” tab, and configure the anemometer signal according to Table 2. Apply and save the configuration.

9.2.6. Check the real-time data displayed in rows 15 to 17 in the DAC tab or in the history plots (SOP B2).

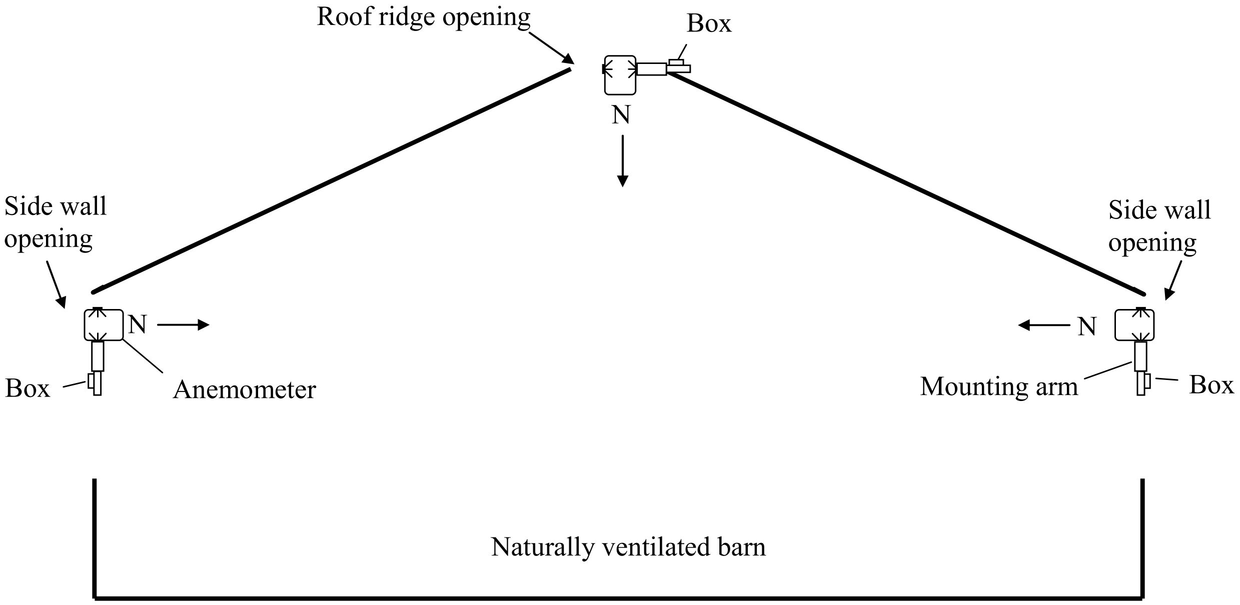

Figure 2. Orientation of 3-D anemometers in wall openings and roof ridge openings.

9.2.6.1. If the anemometer has analog output signals, verify that the DAQ hardware and software are working properly.

- 9.2.7. If the signals acquired by the data acquisition system are not valid (outside of the range presented in Table 1):
  - 9.2.7.1. Check for obstructions to the acoustic path of the anemometer. Invalid measurements can occur when the acoustic path of the sonic signal is blocked or internal circuits fail. Acoustic blockage may be caused by rain drops, ice, snow, or other debris.
  - 9.2.7.2. Check the DAQ hardware and software configuration.
  - 9.2.7.3. If the acoustic path is clear and the DAQ system is normal, but the anemometer is still not working properly, return the anemometer to the manufacturer for repair or replacement.

9.3. Initial checks and periodic verification

- 9.3.1. Follow the detailed descriptions in Section 3.0 ("Initial Checkout") of the instrument manual (RM Young Company, 2005) to conduct the initial check. These checks can either be done in the trailer (with the anemometer connected to the DAQ system), or after installation.
  - 9.3.1.1. Verify that the zero reading is stable by enclosing the unit in a bag or box. Replace the original packaging foam over the anemometer, and slide its shipping bag over it to enclose the unit.
    - 9.3.1.1.1. Record the anemometer biases in the U, V, and W components.
    - 9.3.1.1.2. If the anemometer does not indicate values of less than 0.1 m/s in all three components, send it back to the manufacturer for repair or replacement.
  - 9.3.1.2. Verify sensor response by gently blowing through the measuring section of the anemometer and observing the output to the DAQ system. Do this from two horizontal directions (i.e. x and y).
- 9.3.2. If sonic temperature is being measured, check the temperature reading of each installed 3-D ultrasonic anemometer annually, or as stated in the QAPP, by comparing it (in place) with a NIST-traceable reference thermometer or other NIST-traceable standard.
  - 9.3.2.1. If the anemometer agrees to within 2°C, leave it in place. If the anemometer reads >±2°C different from the reference thermometer, replace the signal wire and repeat the test. If the reading is still >2 °C different from the reference thermometer, replace the 3-D ultrasonic anemometer and repeat the test. Send the old anemometer to the manufacturer for repair or maintenance.
- 9.3.3. Repeat the zero check described above (Section 9.3.1.1) at the frequency specified by the QAPP.

9.4. Troubleshooting

- 9.4.1. If no signals are shown in the AirDAC for the anemometer:
  - 9.4.1.1. Verify that the anemometer is powered by 12-24 VDC. Open the junction box of the anemometer and measure the voltage between +PWR and PWR REF with a multimeter. If there is no voltage, check the continuity of wires and check the power supply inside the OFIS.
  - 9.4.1.2. If the anemometer is properly powered, check the analog output voltage at terminals V1, V2, V3, and V4 relative to VREF. The voltages should be between 0 and 5000 mV. If no analog output is detected, return the anemometer to the manufacturer for repair or replacement.

Table 1. Normal value range for each of the parameters measured.

Parameter	Specification
Wind Speed (U,V,W)	0 to 40 m/s (0 to 90 mph)
Sonic temperature	-50°C to 50°C

Table 2. Proper configuration of anemometer analog signals in AirDAC for U,V,W and sonic temperature.

1. Data heading	A#n U, m/s	A#n V, m/s	A#n W, m/s	A#n T, °C
2. Digit of precision	2	2	2	1
3. Signal lo (SL)	0	0	0	0
4. Signal hi (SH)	5	5	5	5
5. Range lo (RL)	0	0	0	220
6. Range hi (RH)	50	50	50	320
7. Absolute (abs)	0	0	0	0
8. Slope (A)	1	1	1	1
9. Intercept (B)	0	0	0	-273
10. Global Ch#				
11. Limit: Min	0	0	0	-50
12. Limit: Max	15	15	15	40
13. Hysteresis	2	2	2	5
14. Email{ ,DO#}	1	1	1	1

Note: A#n, anemometer number (n = 1, 2, …); T, sonic temperature. Fill in "10. Global Ch#" according to the actual DAQ hardware configuration. "11. Limit: Min" to "14. Email { ,DO#}" are for real-time data monitoring (Refer to SOP B2 for details).

9.4.1.3. If the anemometer has analog output signals, verify that the DAQ hardware and software are working properly.

9.4.2. If the signals acquired by the data acquisition system are not valid:

9.4.2.1. Check for obstructions to the acoustic path of the anemometer. Invalid measurements can occur when the acoustic path of the sonic signal is blocked or internal circuits fail. Acoustic blockage may be caused by rain drops, ice, snow, or other debris.

9.4.2.2. Check the DAQ hardware and software configuration.

9.4.2.3. If the acoustic path is clear and the DAQ system is normal, but the anemometer is still not working properly, return the anemometer to the manufacturer for repair or replacement.

10. Data and Records Management

10.1. Manage all data according to SOP B5.

10.2. Record anemometer installation dates and times, locations, positions, heights, orientations, analog output channel connections, wire color codes, initial test results, names of personnel conducting installation, anemometer model number and serial number, and other relevant information in the laboratory records.

10.3. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record with a bound record book designated for the method, which should contain copies of the electronic record. Overstrike all errors in writing with a single line; initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Real-time data monitoring

11.1.1. Configure the real-time data monitoring by defining rows from “11. Limit: Min” to “14. Email” (Table 2) for the analog signals that need to be monitored. Refer to SOP B2 for detailed descriptions of the configuration.

11.1.2. With the configuration described in Section 11.1.1 and Table 2, signals acquired from the anemometer are converted to engineering units, and compared with pre-determined normal ranges (Table 1) every second by AirDAC. Alarms are shown immediately, and are sent via email by AirDAC to indicate any out-of-range data that might be collected (SOP B2).

11.2. Daily data inspection

11.2.1. Plot collected anemometer data in daily figures using Air Data Pre-Processing (ADPP) software at any time after a day’s data is collected (SOP B3). Compare airflow data with the wind direction data obtained at the site using the roof-mounted vane anemometer (SOP E4). Verify that windward sides of the barn(s) show inward airflow in the sonic anemometer data during periods when the wind is blowing.

11.3. Physical inspection

11.3.1. If the real-time monitoring or the daily data inspection indicates abnormal performance, conduct a visual inspection of the anemometer.

11.3.2. Inspect the anemometer for any physical damage.

11.3.3. Inspect the anemometer for any installation change, including its position, height, and orientation. Restore the anemometer to its original status if necessary.

11.3.4. Inspect for obstructions to the acoustic path, including rain drops, ice, snow, or other debris. Clear the acoustic path if it is blocked.

11.4. Instrument check

11.4.1. Perform the following instrument checks at the frequency specified in the QAPP.

11.4.2. Standard inter-comparison: Compare the output of the anemometer with that from an unused, ‘standard’ anemometer.

11.4.2.1. Locate the two anemometers next to each other on a calibration mount, verifying that their orientation is the same. This can be accomplished using a precision level and a compass to verify its vertical position and the orientation of the support arm, which should be directed to North.

- 11.4.2.2. Conduct measurements with both anemometers for 1 h.
- 11.4.2.3. Determine the paired differences between the measurements generated by the two anemometers, and compute the mean difference.
- 11.4.2.4. If the mean difference between anemometers is < 0.4 m/s (1% of full scale), then the anemometer being checked is in good working order.
- 11.4.2.5. If the mean difference between anemometers is > 0.4 m/s, then the anemometer being checked is defective. Return it to the manufacturer for repair or replacement.

11.4.3. In-field inter-comparison: Compare output of anemometers that are measuring air velocity in a common ventilation opening at times when all units should theoretically be reading the same air velocity (perpendicular wind direction, still air). This method is the one that will be applied most often.

- 11.4.3.1. All anemometers are mounted in the same opening (e.g. ridge opening, sidewall opening) in identical fashion.
- 11.4.3.2. Compare measurements taken over periods when wind is blowing directly into the sidewall and the air velocities should theoretically be the same.
- 11.4.3.3. Compare the means and standard deviation of each anemometer. The means and standard deviations should be similar or have an explainable difference. If one of the anemometers produces outlying data as compared with the other anemometers in the opening, conduct a standard inter-comparison (Section 11.4.2) or switch with another anemometer and repeat the test. This latter option will rule out possible problems with the signal cables.
- 11.4.3.4. If this in-field inter-comparison cannot be performed at the frequency specified in the QAPP, perform the standard inter-comparison method (Section 11.4.2) instead.

12. References

12.1. ASTM. 2001. Standard Test Method for Determining the Performance of a Sonic Anemometer/Thermometer. American Society for Testing and Materials, Philadelphia, PA, No. D6011-96.

12.2. Campbell Scientific (Canada) Corporation. 2001. RM Young 81000. http://www.campbellsci.ca/CampbellScientific/Catalogue/81000.html, accessed on 7/13/2006.

12.3. Foken, T., and B. Wichura. 1996. Tools for quality assessment of surface-based flux measurements. Agric. Forest Meteorol. 78, 83-105.

12.4. RM Young Company. 2005. Model 81000 Ultrasonic Anemometer, Rev C031405. Manual PN 81000-90. R. M. Young Co., Traverse City, MI.

12.5. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.

12.6. SOP B2. 2006. Air Quality Measurement Data Acquisition and Control software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

12.7. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.8. SOP E4. 2006. Wind Speed and Direction Measurements Using the R.M. Young Model 05103L Anemometer. Standard Operating Procedure E4. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Anemometer manufacturer:

R. M. Young Company
2801 Aero Park Drive
Traverse City, MI, 49686
Customer support and repair: 231-946-3980, Fax 231-946-4772
email: met.sales@youngusa.com

FAN STATUS MONITORING USING VIBRATION SENSORS

Standard Operating Procedure (SOP) A7

FAN STATUS MONITORING USING VIBRATION SENSORS

Standard Operating Procedure (SOP) A7

Prepared by

Matthew J. Darr (Ohio State Univ.) and Lingying Zhao (Ohio State Univ.)

Reviewed by

Ji-Qin Ni, Albert J. Heber and Bill W. Bogan

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Accurate ventilation measurements are needed to obtain air emissions from barns.
1.2. Calculating fan airflow rate requires monitoring of fan status.
1.3. Sensing vibration of the fan is an effective fan monitoring strategy.
1.4. This method assumes that the ventilation fan vibrates sufficiently. It has been tested on 48” diameter belted fans but has not been tested on smaller fans and direct-drive fans.
1.5. This method has not been tested on variable speed fans.

2. Summary of Method

When a ventilation fan operates, propeller rotation causes the fan housing and hood structure to vibrate. This vibration disappears when the rotation stops. Therefore, the vibration and non-vibration of the fan housing correspond to the on and off status of the ventilation fan. A vibration sensor is used to detect this vibration and hence to monitor the on/off status of the fan. The vibration sensor is mounted directly to the fan housing or hood at the point where the vibration is sufficient to activate the sensor. The sensor provides logic zero and logic one outputs for the fan off and on states, respectively. A logic zero results if the belt breaks and the motor continues to operate because most of the vibration is derived from the rotating propeller. The logic signal is acquired by the data acquisition system in the instrument shelter every second, averaged every 15 s and 60 s, and saved in two separate data files, one for 15 s and another for 60 s data, with time stamps and other acquired measurement variables.

3. Definitions

3.1.	Fan Hood:	Fiberglass cover used to direct the exhaust air out of an agricultural fan. It is typically cantilevered off the side or end wall of a barn.
3.2.	Vibration Sensor:	Any sensor that can adequately detect the differences in vibration of a fan hood when the fan is and is not operating. Sensor should be of adequate quality to withstand the environmental conditions of external agricultural fans.

4. Health and Safety

4.1. Before mounting vibration sensor, make sure the fan power is disconnected.
4.2. Never stand directly in front of the fan when adjusting sensitivity of the vibration sensor.

5. Cautions

5.1. Rigidly mount the vibration sensor to the fan hood to ensure that mechanic vibration is transferred from the fan hood into the sensor (refer to Sections 9.1.2 - 9.1.4).
5.2. Carefully adjust the vibration sensor to allow the sensor to correctly pick up the fan operation signal. Fan size and type cause differences in vibration characteristics, thus the user must adjust individual sensors when they are installed in individual fan hoods (refer to Section 9.2.1).

5.3. Protect sensors from wet environments common to barns all year round (refer to Section 9.3.3).

6. Interferences

6.1. Other sources of mechanical vibration (other fans) near the fan may cause false positive readings. The sensor sensitivity should be adjusted to remove the false positives.
6.2. Malfunction of the data acquisition system will cause false signals to be recorded. Make sure that the data acquisition system is working properly.
6.3. Failure of the 5 VDC power supply to the vibration sensor will cause false negatives. Make sure that the sensors are properly powered.

7. Personnel Qualifications

7.1. Personnel should be trained by experienced researchers on the installation, adjustment, wire connection, and signal testing of the vibration sensor before initiating the procedure.
7.2. Each analyst must read and understand this SOP.

8. Equipment and Supplies

8.1. OSU-06 (Ohio State University, Columbus, Ohio) vibration sensors.
8.2. Data acquisition system to record status of each vibration sensor (refer to SOPs B1 and B2).
8.3. Electric drill and 9/64 inch drill bit to make holes in the fan hood.
8.4. Screws (#6 x 32) to fix the sensor to the fan hood. Choose a length suitable to clear the thickness of the fan housing but short enough that the screw will not interfere with the fan itself.
8.5. Lock washers, lot nuts, or thread lock to be used with the screws.
8.6. A screwdriver to drive in the screws.
8.7. A multimeter to check the sensor signal.
8.8. Sensor power supply and signal cable (3-conductor, 22 gage shielded).
8.9. Digital camera.

9. Procedures

9.1. Installation
  9.1.1. Determine the location of maximum vibration along the sidewall or bottom wall of the fan hood or fan housing by touching a hand to the hood and feel the vibration. Possible locations for sensor installation are shown in Fig. 1.
  9.1.2. Drill a 9/64 inch hole in the fan hood to accommodate a #6 x 32 mounting screw.
    9.1.2.1. Do not drill the mounting hole at the location where the fan propeller is inside the fan housing, as the rotating propeller might hit mounting screw head (Fig. 1).
  9.1.3. Securely fasten the vibration sensor to the sidewall using a #6 x 32 screw placed through the vibration sensor and the clearance hole in the sidewall.

- 9.1.4. Use either lock washers, lock nuts, or thread lock to ensure that the mounting screw will not loosen over long term exposure to vibration.

9.2. Calibration

- 9.2.1. After installation, each vibration sensor output must be adjusted to match the sensor sensitivity with the mechanical vibration present at the fan housing or hood.
  - 9.2.1.1. Start the calibration with the fan running and the sensor outputting an off signal.
  - 9.2.1.2. Increase sensitivity until the sensor output signal indicates an on status.
  - 9.2.1.3. Stop fan and verify that the vibration sensor has returned to an off status state.
  - 9.2.1.4. Verify that other vibration sources such as adjacent fans, do not activate the sensor.

9.3. Connection to data acquisition module

- 9.3.1. Connect the digital output signal from the vibration sensor to a digital input data acquisition board (refer to SOP B1).
- 9.3.2. Supply 5 VDC to the vibration sensor from the data acquisition system. This power supply must be fused and provide a means of reverse polarity protection.
- 9.3.3. Use weather tight connectors to prevent corrosion of electrical connections. If it is possible, install the sensor on the bottom side of the fan housing or hood to avoid direct rain and sun radiation.

10. Data and Records Management

10.1. Record the sensor make and model, locations of installation, data acquisition channel connections (refer to the measurement and control signal channel design in SOP B1), initial test results, and installation/testing personnel to the field notes spreadsheet of the project. Take digital photos as documentation if it is necessary.

10.2. Manage the data according to SOP B5 (Data Management).

11. Quality Control and Quality Assurance Section

11.1. Initial checks

- 11.1.1. Upon installation, check all vibration sensors for appropriate operation and adjust their sensitivity as necessary.

11.2. Maintenance

- 11.2.1. Compare the vibration sensor signal with the fan stage process relay signal and evaluate the discrepancies between the two signals.

12. References

12.1. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.

12.2. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure. Purdue Ag Air Quality Lab.

12.3. Ni, J.-Q, A.J. Heber, T.L. Lim, and C.A. Diehl. 2005. A low-cost technique to monitor ventilation fans at animal buildings. In Proceedings of the Seventh International Livestock Environment Symposium, 389 – 395. St. Joseph MI: ASAE.

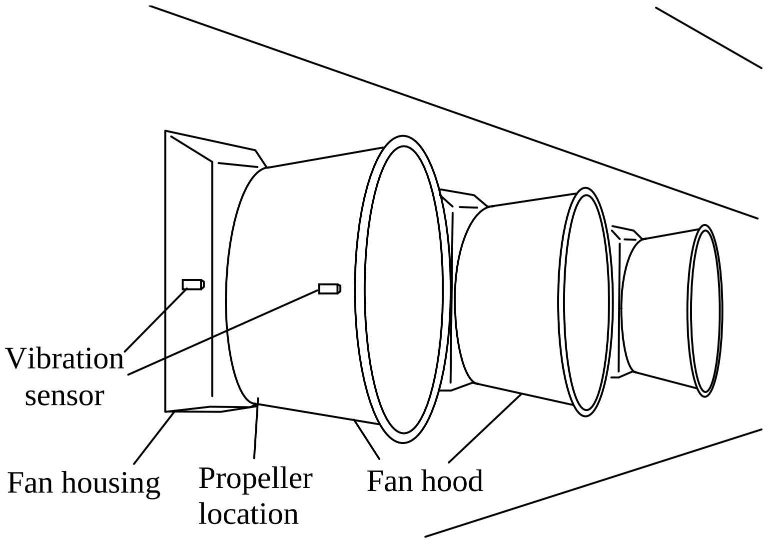

Figure 1. Locations of vibration sensors (Adapted from Ni et al., 2005). Each fan needs only one sensor.

VENTILATION FAN AIRFLOW MEASUREMENTS USING THE AIR VELOCITY TRAVERSE METHOD

Standard Operating Procedure (SOP) A8

VENTILATION FAN AIRFLOW MEASUREMENTS USING THE AIR VELOCITY TRAVERSE METHOD

Standard Operating Procedure (SOP) A8

Prepared by
Teng-Teeh Lim

Reviewed by
Albert J. Heber and Bill W. Bogan

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Accurate *in situ* measurements of ventilation fan airflow rates are needed to calculate emission rate.

1.2. A method is needed to conduct airflow tests on fans that cannot be analyzed using the Fans Assessment Numeration System (FANS, SOP A2) for the following reasons:

- 1.2.1. Fans are located in areas that are physically inaccessible to the relatively large FANS analyzer.
- 1.2.2. Fans are too large (> 54″)
- 1.2.3. Fans are too small (< 24″)
- 1.2.4. A proper seal can not be made between the FANS analyzer and the ventilation fan, due to obstructions
- 1.2.5. FANS analyzer is not available

1.3. This method traverses the air velocity over the fan (airflow) cross-section at the inlet or outlet.

- 1.3.1. The method is applicable to wall or pit ventilation fans of mechanically-ventilated barns.
- 1.3.2. The method is applicable to single- or variable-speed fans.
- 1.3.3. The method is applicable to all fan sizes (typically 10″ to 60″ diameter).
- 1.3.4. This procedure takes approximately 10 min per fan to complete.

2. Summary of Method

The as-found (degraded) fan airflow capacity can be determined by multiplying the mean traverse velocity by the cross-sectional area of the measured airflow. To apply this method, it is necessary to divide the air stream cross-section into multiple sections of equal area. Air velocity is measured at the center of each section (Henderson and Perry, 1976). The accuracy of the calculated airflow rate increases as more sections are measured, because the airflow velocity profile is usually non-uniform. The fan operating pressure and fan speed should be held constant during the test. The velocity can be measured using a calibrated pitot tube and pressure transducer, a hot-wire anemometer, or a vane anemometer.

3. Definitions

3.1.	dP	Differential pressure
3.2.	FANS	Fans Assessment Numeration System
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	SOP	Standard Operating Procedure

4. Health and Safety

4.1. Be careful when working close to high-speed fan blades.

4.2. Wear safety glasses while working around an operating fan.

5. Cautions

5.1. Avoid intervening with the barn environmental control system to adjust fan operating pressure to desired values, unless the barn is empty, or when proper ventilation airflow can be ensured for the comfort of the animals in the barn.

5.2. Air velocity meters have specific limitations:

5.2.1. Hot-wire anemometers are non-directional.

5.2.2. Vane anemometers cover larger measurement areas, thus limiting the number of traverse points for small ventilation fans.

5.2.3. Pitot tubes require sensitive pressure transducers.

6. Interferences

6.1. High wind speeds around the barn can affect ventilation fan operation. Avoid conducting traverse measurements when wind speeds are >5 m/s (>11 mph).

6.2. Avoid removing fan shutter and guard when conducting the measurement.

6.3. Dust collected on the air velocity meter can reduce accuracy.

6.4. When the traverse measurement covers only a narrow range of differential pressure (dP), comparison with the full fan performance curve is not possible. This can result in greater uncertainty of the calculated airflows.

6.4.1. If possible, measure airflow at several dPs (by turning other fans on or off to increase or decrease the overall dP), to span the more of the operating range. However, avoid intervening with the environmental control system unless the conditions in Section 5.1 can be met.

6.5. Avoid standing in or blocking the air stream during the test, as this will affect the flow profile.

6.6. Airflow at the exit side of the ventilation fan is more turbulent than at the fan inlet, which can reduce the accuracy of velocity measurements. If possible, conduct the air velocity traverse at the fan inlet.

7. Personnel Qualifications

7.1. Personnel should understand barn ventilation systems and static pressure controls, and be able to identify the normal ranges of barn dP and fan performance.

7.2. Each analyst must read and understand this SOP and the applicable instrument manual(s), and be trained in the use of the velocity meter before initiating the procedure.

8. Equipment and Supplies

8.1. Air velocity meter

8.1.1. Portable vane anemometer (Model 451126, Extech, Bohemia, NY, or equivalent)

8.1.2. Hot-wire anemometer (Model 444, Kurz, Inc., Monterey, CA, or equivalent)

8.1.3. Pitot tube and pressure sensor (Model 267 Differential Pressure Transducer, Setra Systems, Boxborough, MA)

8.2. Stopwatch

9. Procedures

9.1. Determine the number and locations of traverse points.

9.1.1. When choosing traverse locations, consider factors including safety, accessibility, flow turbulence (swirling airflow), and airflow blockage.

9.1.2. For a square or rectangular duct or inlet area, divide the cross-section into equal squares or rectangles.

9.1.2.1. Use at least 16 traverse points.

9.1.3. For round ducts or fan shrouds, measure at least two axes (horizontal and vertical) of traverse points. The minimum number of traverse points is eight (8) points per axis. Fig. 1 shows an example in which 10 points per axis may be measured.

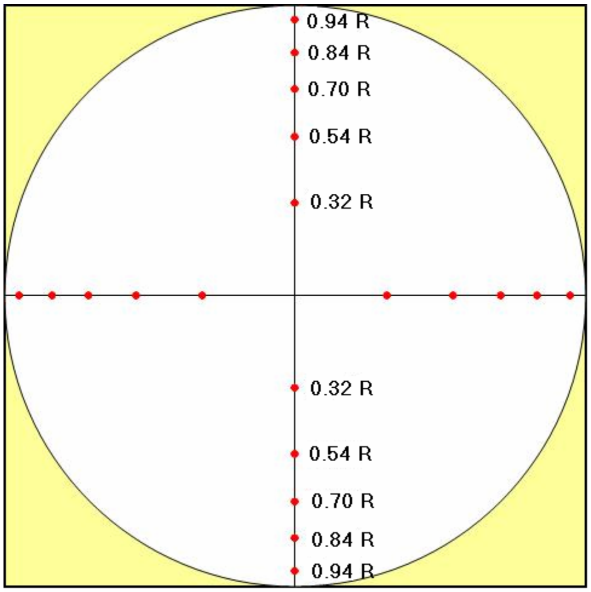

Figure 1. Example of 10 traverse points per axis, with traverse point distances as a percentage of diameter. The entire traverse includes both vertical and horizontal axes, for a total of 20 points. Distances are given a fractions of radius (R), starting at the center.

9.1.3.1. Apply the following equation to determine the location of each traverse point on a radius, from the center of the duct:

$$L_i = \sqrt{\frac{(i-0.5)R^2}{n}} \qquad (1)$$

Where:
L_i Distance to the i^{th} traverse point on a radius, from the center
i i^{th} traverse point on a radius, from the center
R Radius of the total cross-sectional area of airflow
n Total number of traverse points on a radius

9.2. Measure air velocity at each point.

- 9.2.1. Attach the pitot tube, hot-wire tip or rotating vane to a probe (if the device does not have a long enough probe for the fan) that is sufficiently long to allow the operator to stand outside the airflow area, to avoid airflow blockage.
- 9.2.2. Mark the probe with unit measurements, or with the distances of the desired traverse points with respect to a fixed fan fixture or wall, so that the exact locations can be readily established during the traverse without obstructing the flow.
- 9.2.3. Maintain the fan operating pressure and speed.
  - 9.2.3.1. Manipulate fan controls as necessary to "freeze" the fan speed.
  - 9.2.3.2. Manipulate inlet controls as necessary to "freeze" the inlet openings.
- 9.2.4. Use a stopwatch to ensure the same measurement time for each traverse point, and use an air velocity meter or pressure sensor (for pitot tube measurement) equipped with an averaging function. Report all measurement results as velocity (m/s).
- 9.2.5. Record the date, time, analyst, barn, fan and other information. An example of a field record sheet is given in Table 1:

Table 1. Example of fan traverse field data sheet.

Date		Analyst	
Measurement site		Facility name	
Fan number		Fan size	
Traverse location		Traverse points	
Air meter S/N		Calibration date	
Notes			
Results			
Traverse location #*	Distance*	Velocity, m/s	Note

* Include a drawing that clearly defines the traverse locations and distances.

9.3. Calculate the airflow rate

- 9.3.1. Calculate the average velocity (m/s) of the traverse points.
- 9.3.2. Calculate the cross-sectional flow area (m^2).
- 9.3.3. Calculate the fan airflow rate (m^3/s) by multiplying the mean velocity by flow area.

10. Data and Records Management

10.1. Maintain laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike errors in writing with a single line. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Verify the traverse values in a laboratory equipped with a fan test facility or compare the mean velocity to calibrated, portable fan tester data (SOP A2).
11.2. At the beginning and end of each set of field measurements, perform a “zero air speed” measurement to make sure the anemometer reads zero. If the anemometer appears to be malfunctioning, have it checked by the manufacturer.
11.3. Have the air velocity measurement devices calibrated and certified by manufacturers annually.
11.4. Worn or improperly-functioning backdraft shutters can alter the velocity profile and affect the fan capacity. Inspect and verify the integrity of the shutter, motor, and blades, and note them in the field notes.

12. References

12.1. Henderson, S. M., and R. L. Perry. 1976. Velocity measurement. In Agricultural Process Engineering, 57-60. Westport, Ct.: AVI Publishing.
12.2. SOP A1. 2006. Laboratory Testing of Ventilation Fan Performance. Standard Operating Procedure A1. Purdue Ag Air Quality Lab.
12.3. SOP A2. 2006. Measurement of Ventilation Fan Flowrate Using the Fan Assessment Numeration System (FANS). Standard Operating Procedure A2. Purdue Ag Air Quality Lab.
12.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

SOP A9. STANDARD OPERATING PROCEDURE

FOR MEASUREMENT OF AIRFLOW RATE OR CALIBRATION OF AIR SAMPLING

INSTRUMENTS WITH GILIBRATOR 2 CALIBRATION SYSTEMS

SOP A9. STANDARD OPERATING PROCEDURE FOR MEASUREMENT OF AIRFLOW RATE OR CALIBRATION OF AIR SAMPLING INSTRUMENTS WITH GILIBRATOR 2 CALIBRATION SYSTEMS

Prepared by
Hua Xu

Reviewed by
Teng-Teeh Lim and Albert J. Heber

Effective Date: November 5, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Contaminant emission studies require the use of various flow controllers and flow meters. Frequent verification and calibration are needed to ensure functionality and data quality. The flow controllers and measurement devices may include:

1.1.1. Mass flow meter in the PAAQL Gas Sampling System (SOP G1).

1.1.2. Mass flow controllers of PM sampling and monitoring devices.

1.1.3. Mass flow meters in the sampling trains for collection of sorbent tube (SOP V1), canister (SOP V2), and impinger (SOP V3) samples for VOC analyses.

1.2. The Gillian Gilibrator 2 Calibration System is useful for measurement or calibration of air sampling equipment as a primary standard. This SOP is written only for the Gilibrator 2 Calibration System.

1.2.1. The Gilibrator 2 is a high accuracy, electronic flow meter that provides instantaneous airflow readings and cumulative averaging of multiple samples.

1.2.2. The three interchangeable Wet Cell Assemblies provide an overall range of flow rates from 1 cc/m to 30 L/min using the following flow cells:

1.2.2.1. Low flow cell (1 to 250 cc/min)

1.2.2.2. Standard flow cell (20 cc/min to 6 L/min)

1.2.2.3. High flow cell (2 to 30 L/min)

2. Summary of Method

The purpose of the method is to measure airflow rate or calibrate air sampling equipment using the Gillian Gilibrator 2 Calibration System as a primary standard. A primary standard airflow measurement is a volume (V, measured volume of space between two infrared sensors) divided by a time interval (t, the time interval needed for the soap bubble film to travel between the two sensors that bound the volume) as performed by the control unit of the Gilibrator 2. Therefore, the flow rate is the volume per unit of time (V/t), which is calculated and then displayed directly on the unit's Liquid Crystal Display (LCD).

3. Definitions of Terms and Acronyms

AC	Alternating current
cc	Cubic centimeters
LCD	Liquid crystal diode
LPM	Liters per minute
NIST	National Institute of Standards and Technology
PAAQL	Purdue Agricultural Air Quality Lab
PM	Particulate matter
RMA	Returned material authorization
SOP	Standard operating procedure

4. Health and Safety

4.1. Be careful when working with electrical power connections.
4.2. Do not pressurize the cell assembly. Excessive pressure may cause the cell to rupture, resulting in personal injury.

5. Cautions

5.1. Do not remove, cover or alter any labels or tags on the instrument.
5.2. Batteries must be fully charged (usually for 14 h) for the instrument to function properly.
5.3. Always turn off the instrument before changing any batteries.
5.4. Use only the manufacturer’s soap solution (Part No. 800450) with the wet flow cell assembly. Use of other soap solution may damage the flow cell.
5.5. Do not overfill the soap solution reservoir.
5.6. Do not attempt to repair or modify the instrument. If repair is needed, contact the Sensidyne Service Department to arrange for a Returned Material Authorization (RMA).
5.7. When the wet cell assembly will not be used for a long period of time, install rubber storage tubing between the inlet and outlet bosses to prevent the soap solution from evaporating, as this would change the soap concentration.
5.8. When a wet cell assembly is to be transported by air, disconnect the storage tubing from either the air outlet boss (upper) or air inlet boss (lower). Otherwise, the flow cell assembly could become over-pressurized, possibly causing a rupture within the bubble generator.
5.9. Do not transport unit with soap solution or storage tubing in place.
5.10. Always mount or remove the cell assembly by grasping and rotating the lower part of the assembly.
5.11. Never lean on the bubble generator to press the plate into place. Placing excessive weight on the cell assembly may break the instrument.
5.12. Never use alcohol, acetone or any other harsh solvent or cleaner to clean the bubble generator cell.

6. Personnel Qualifications

6.1. Personnel should be trained in the use of the instrument before initiating the procedure.
6.2. Each analyst must read and fully understand the entire instrument manual and this SOP before operating or maintaining the instrument.

7. Equipment and Supplies

7.1. Flow calibration system (Gilian Gilibrator 2, Sensidyne Inc, Clearwater, FL), consisting of the following components (Fig. 1):

7.1.1. Control unit base
7.1.2. Wet cell assemblies:
  7.1.2.1. Low flow cell (1 to 250 cc/min)
  7.1.2.2. Standard flow cell (20 cc/min to 6 L/min)
  7.1.2.3. High flow cell (2 to 30 L/min)
7.1.3. AC charger
7.1.4. Tubing (including rubber storage tubing)
7.1.5. Soap solution and dispenser

8. Procedures

8.1. Assembly
8.1.1. Connect the battery charger to the charger jack in the control unit and to an appropriate AC outlet. Make sure the batteries are fully charged (≥ 14 h) before operating.
8.1.2. Mount the wet cell assembly according to Figs. 2 and 3.
  8.1.2.1. Position the control unit base on a flat level surface.
  8.1.2.2. Select the appropriate wet cell assembly (low, standard, or high flow) according to measurement requirements.
  8.1.2.3. Grasp the cell assembly on the lower portion, and move it to the mounting plate on the control unit.
  8.1.2.4. Align the mounting pins of the flow cell with the mounting plate slot. Make sure the bottom of the flow cell mounts flush with the mounting plate.
  8.1.2.5. Rotate the cell assembly clockwise until it clicks into place. The front cell assembly should face toward the display on the control unit.
8.1.3. Add soap solution to the wet cell assembly.
  8.1.3.1. Remove the storage tubing from the air outlet boss (upper).
  8.1.3.2. Using the storage tubing as a funnel, slowly add the soap solution to the reservoir from the dispenser.
  8.1.3.3. Fill until the solution level reaches the angled edge at the bottom of the bubble generator ring.
8.1.4. Connect the instrument (a flowmeter or an air sampling pump) that is to be checked or calibrated to the Gilian Gilibrator 2 Calibration System.
  8.1.4.1. If the flow of the instrument to be checked or calibrated is positive, connect the tubing to the lower boss.
  8.1.4.2. If the flow of the instrument to be checked or calibrated is negative, connect the tubing to the upper boss.

8.2. Operation
8.2.1. Start-up
  8.2.1.1. Turn on the sampling source.
  8.2.1.2. Push the “Bubble Initiate” button several times to wet the inner walls of the flow tube.
  8.2.1.3. Press the “ON” button on the control unit, and wait about 10 s for the unit to self-test.

8.2.2. Bubble generation
- 8.2.2.1. Push the “Bubble Initiate” button again, and hold until the first bubble is initiated and travels up to the flow tube.
- 8.2.2.2. A timing sequence is initiated when the rising bubble passes the lower sensor.
- 8.2.2.3. The timing sequence is completed when the bubble passes the upper sensor.
- 8.2.2.4. The timing information is transmitted to the control unit, where flowrate is calculated and then displaced on the LCD (Fig. 4).
- 8.2.2.5. Release the button and initiate a second bubble to travel up to the flow tube.
- 8.2.2.6. Repeat this procedure to obtain additional readings.

8.2.3. Flow readout
- 8.2.3.1. The measured flow rate of the last test, the cumulative average flow rate across tests, and the current test/sample number are displayed on the LCD of control unit (Fig. 4).
- 8.2.3.2. Press the DELETE/RESET button for ~ 1 s to delete an obviously false reading.
- 8.2.3.3. Press the DELETE/RESET button for ~ 3 s to reinitiate the entire sequence.

8.3. Calibration
- 8.3.1. The instrument should only be calibrated by the manufacturer.

9. Data and Records Management

9.1. Always observe the individual measurements for consistent readings.
9.2. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
9.3. Manage all data according to SOP B5.
9.4. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line, and initial and date all such corrections.
9.5. Keep a record of the calibration certificate, and make sure the calibration record (expiration date) is shown on the calibration system.

10. Quality Control and Quality Assurance

10.1. Conduct general and additional wet cell maintenance as per the instrument manual.
10.2. Return the instrument to the manufacturer annually for calibration.
10.3. All devices should be certified for accuracy, and traceable to the National Institute of Standards and Technology (NIST).

11. References

11.1. Gilibrator Manual. 1998. Gilian Gilibrator 2 Calibration System Operation & Service Manual. Revision G (Document No. 850190M). Sensidyne, Inc., Clearwater, FL.
11.2. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
11.3. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1.

Purdue Ag Air Quality Lab.

11.4. SOP V1. 2006. Sampling of Volatile Organic Compounds (VOCs) in Air Samples through Use of Sorbent Tubes. Standard Operating Procedure V1. Purdue Ag Air Quality Lab.

11.5. SOP V2. 2006. VOC Sampling Using Canisters. Standard Operating Procedure V2. Purdue Ag Air Quality Lab.

11.6. SOP V3. 2006. Collection of Organic Amines in Air Samples Through Use of Sulfuric Acid-Containing Impingers. Standard Operating Procedure V3. Purdue Ag Air Quality Lab.

12. Contact Information

12.1. Manufacturer:

Sensidyne, Inc.
16333 Bay Vista Drive
Clearwater, Florida 33760 USA
http://www.sensidyne.com/

12.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com

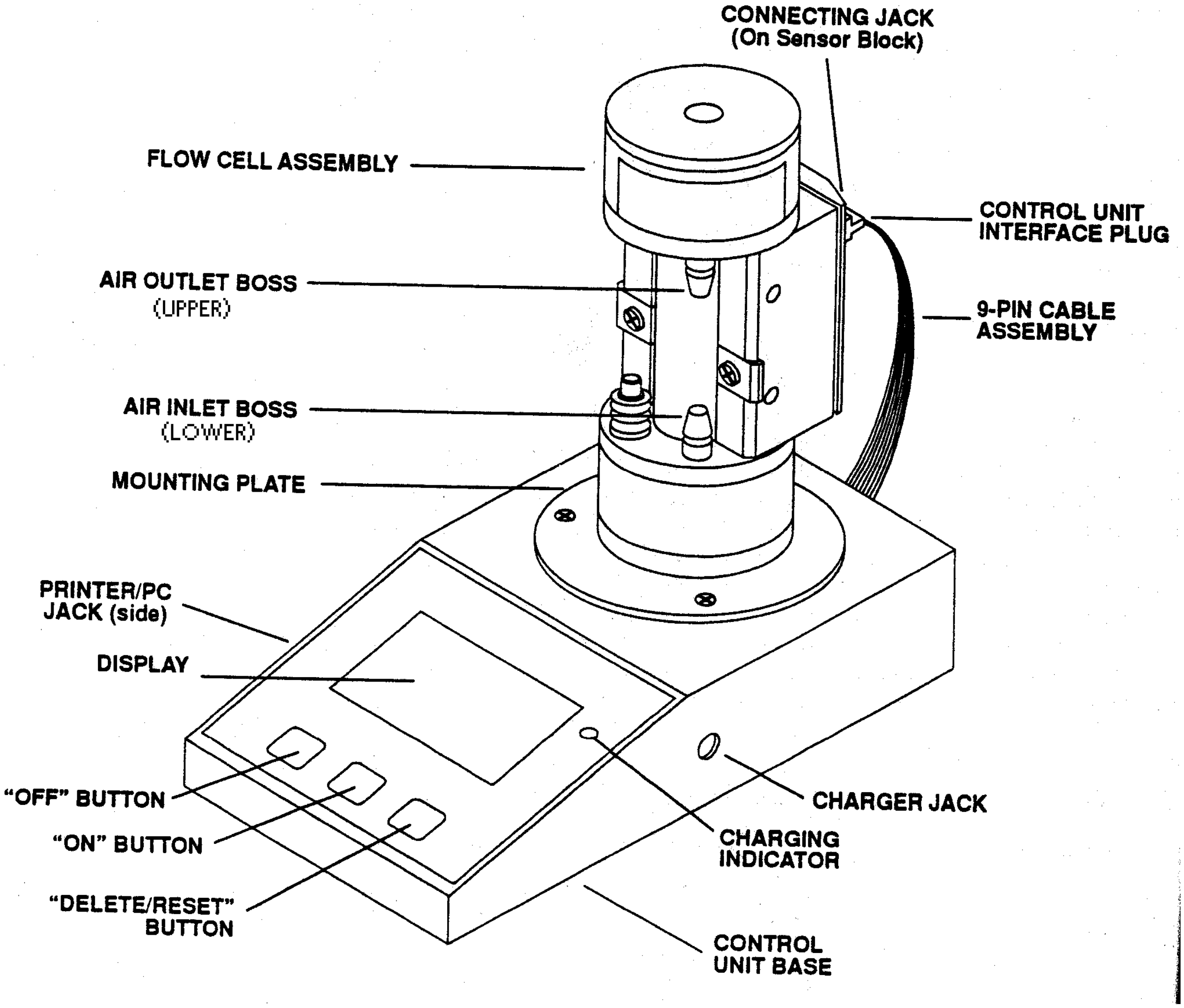
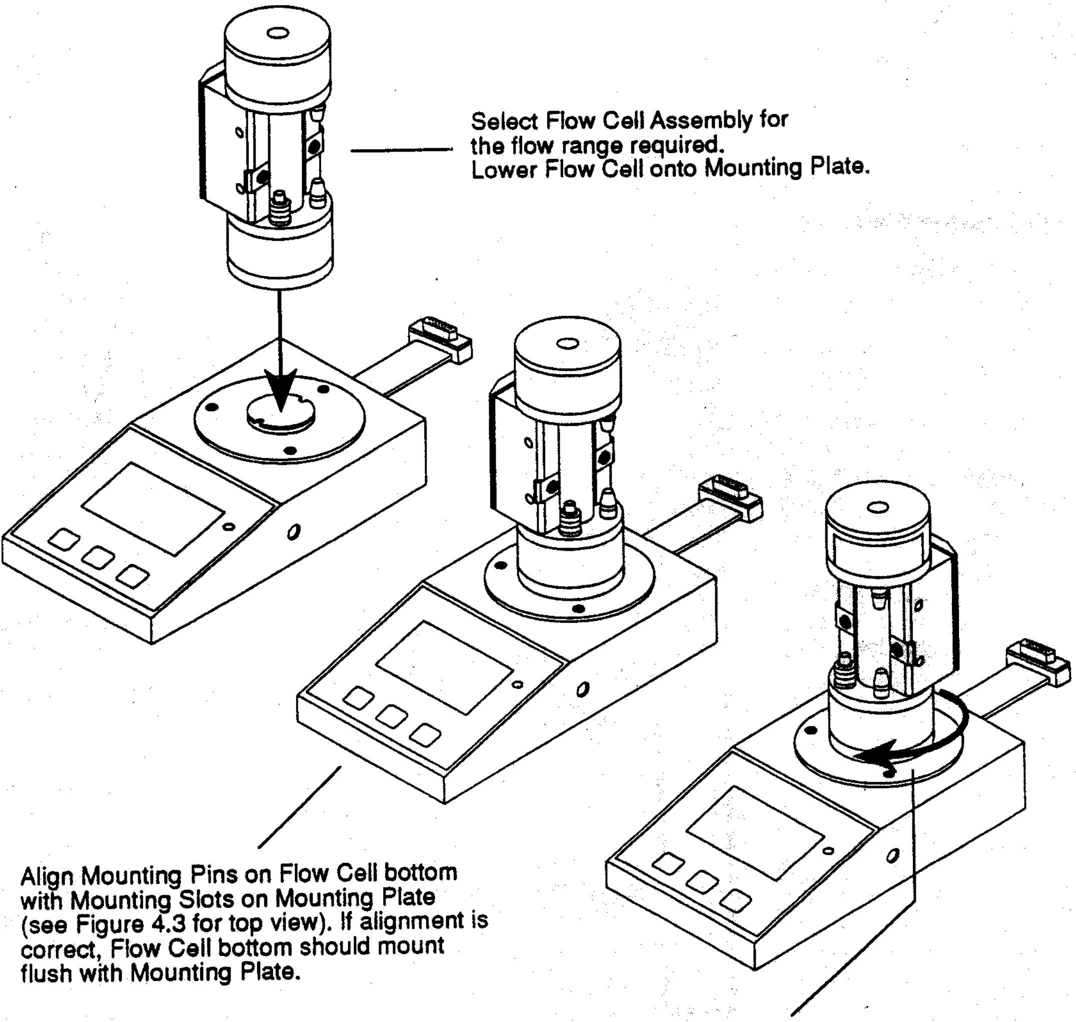


Figure 1: The Gilian Gilibrator 2 Calibration System.



Select Flow Cell Assembly for the flow range required. Lower Flow Cell onto Mounting Plate.

Align Mounting Pins on Flow Cell bottom with Mounting Slots on Mounting Plate (see Figure 4.3 for top view). If alignment is correct, Flow Cell bottom should mount flush with Mounting Plate.

Grasp **lower portion** of Flow Cell and rotate in direction of arrow until cell clicks in.

NOTE: Always grasp **lower portion** when mounting or removing Flow Cell.

Figure 2: Flow Cell Mounting (3D View).

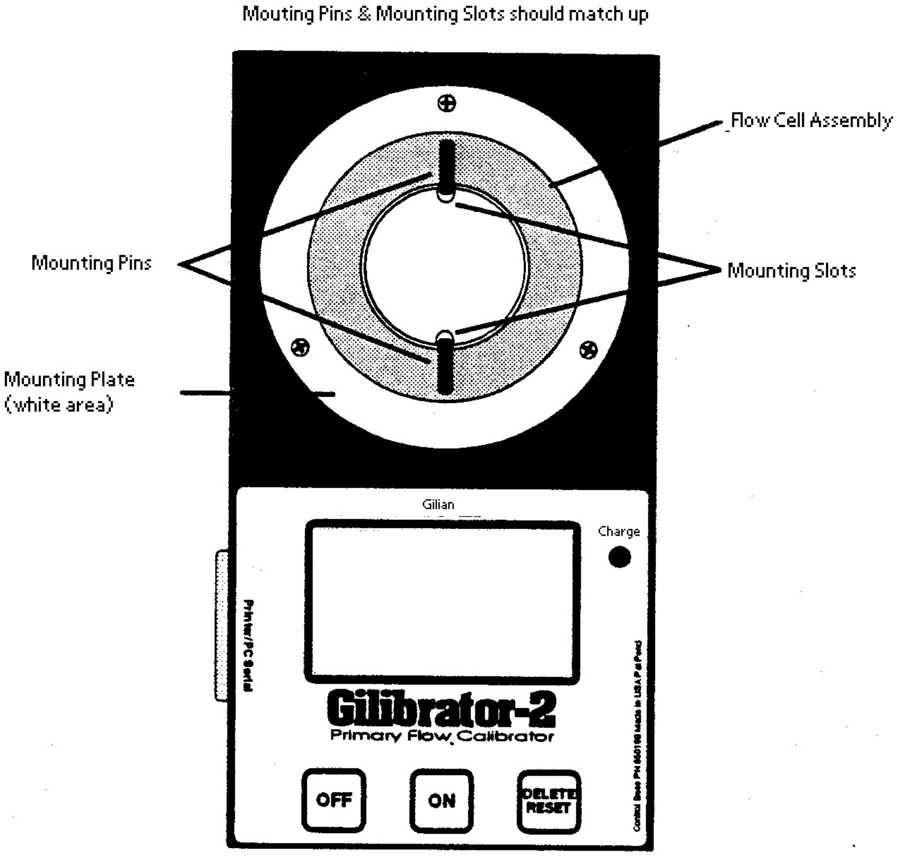


Figure 3: Flow Cell Mounting (Top View).

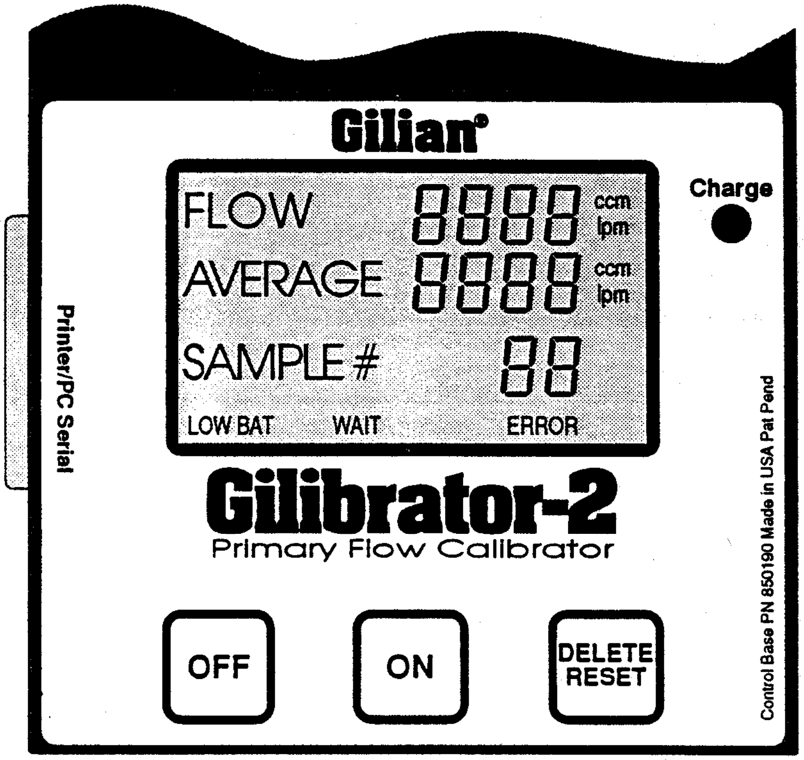


Figure 4: Gilian Gilibrator 2 Liquid Crystal Display.

FAN STATUS MONITORING USING RPM SENSORS

Standard Operating Procedure (SOP) A11

FAN STATUS MONITORING USING RPM SENSORS

Standard Operating Procedure (SOP) A11

Prepared by

Erin L. Cortus and Bill W. Bogan

Reviewed by

Albert J. Heber

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Accurate fan airflow measurements are needed to obtain air emissions from mechanically ventilated livestock barns.
1.2. Calculating fan airflow rate requires monitoring of fan status.
1.3. Monitoring the rotational speed of a fan increases the accuracy of the flow calculation because fan airflow is directly proportional to fan speed at a given fan static pressure.
1.4. RPM sensors provide measurements of both operational status and rotational speed; thus, they are an effective fan monitoring strategy.
1.5. This method is applicable to any size of ventilation fan, and to both single-speed and variable-speed fans.
1.6. This method is implemented using solid-state Hall-effect sensors, which produce a signal when a magnet is in close proximity to the sensor. When the magnet is attached on a rotating part of the fan to monitor speed, the application is to measure rotational speed of the fan.
1.7. The rotational speed of the fan is expressed as revolutions per minute (RPM). Therefore, the Hall-effect sensor will be referenced as an RPM sensor in this method.
1.8. This method will focus on the use and installation of threaded barrel proximity sensors (Model MP100701, Cherry Corporation, Pleasant Prairie, WI) and threaded barrel geartooth sensors (Model GS100701, Cherry Corporation, Pleasant Prairie, WI).

2. Summary of Method

An RPM sensor detects the rotational speed of an individual ventilation fan impeller or an associated part such as a pulley or pulley shaft. This method uses Hall-effect proximity sensors, which are solid-state devices that operate by monitoring the electronic signal created by a changing magnetic field. In simplified terms, when the sensor detects a magnetic field, a voltage is electromagnetically induced in the sensor’s circuitry that causes a transistor to activate and produce an output signal. The output signal changes as the magnetic field changes due to the rotating magnet or metal part passing near the fixed sensor. A pulse in the output signal is created each time the magnet passes the sensor. The speed of the rotation is determined by the number of pulses in a time interval. The MP100701 proximity sensor (Cherry Corporation, Pleasant Prairie, WI) is a Hall-effect sensor that senses an external magnet that is attached to the rotating part. A geartooth sensor, such as the GS100701 sensor (Cherry Corporation, Pleasant Prairie, WI) incorporates a stationary magnet within the sensor which detects the proximity of a moving discontinuous ferrous material. Hall-effect sensors have no moving parts within the sensor and are not susceptible to dust and environmental contamination.

3. Definitions

3.1.	DAQ	Data acquisition
3.2.	Fan Hood:	Fiberglass cover used to direct the exhaust air out of an agricultural fan. It is typically cantilevered off the side or end wall of a barn.
3.3.	Hall effect	Voltage induced across a current-carrying material when it is

		perpendicular to a magnetic field
3.4.	MCC	Measurement Computing Corporation
3.5.	Tachometer	Device that measures rotational speed
3.6.	RPM	Revolutions per minute
3.7.	USB	Universal serial bus

4. Health and Safety

4.1. Make sure the fan power supply is disconnected before installing RPM sensors,. If the power disconnect is not located near the fan, post signage at the power disconnect location to warn others not to turn the fan on.

4.2. Be careful when working near operational ventilation fans. The high-speed fan blades = hazardous, especially if they are not protected by fan shutters.

4.3. Be wary that wind can cause the fan blades to suddenly start spinning. Fix the fan blades in place before working in and around the fan.

4.4. Wear safety glasses while working near operating fans. Do not wear loose-fitting or baggy clothing, or dangling jewelry around an operational fan, and tie up long hair.

4.5. Protect your eyes and face from dust when working around the fan. Sudden dust clouds can form when the fans are turned on.

4.6. Ensure that magnets are not left in areas where animals may access them. If swallowed, magnets can cause serious digestive system problems.

5. Cautions

5.1. Excess moisture in the environment can enter the sensor housing where the wire leads are attached. In environments where the sensors may be frequently splashed with water (i.e. farrowing barns), apply room temperature-vulcanizing (RTV) silicone or its equivalent around the wire leads to increase resistance to water damage.

5.2. The sensors are operated in close proximity to a moving target. Ensure that the sensor is securely fastened to the sensor support and all wires are securely fastened away from moving parts to avoid damage to both the sensor and fan.

5.3. When using a magnet target, ensure that the magnet is securely set in place before turning on the fan.

5.4. The RPM sensor is susceptible to electrical surges caused by lightning. Proper grounding of the barn is recommended to minimize the risk of lightning damage.

6. Interferences

6.1. Malfunctioning of the data acquisition (DAQ) system will cause false signals to be recorded. Make sure that the DAQ system is working properly.

6.2. Make sure the signal wires from the RPM sensor are firmly attached and tidy to avoid being blown loose over time.

6.3. Signal noise can interfere with the RPM measurements. Using shielded multi-conductor cable and grounding the shield wire to the ground on the DAQ board can often alleviate the noise in the signal.

6.4. The sensing target should remain consistent in strength and location during the operation of the fan. Avoid placing the target near the edge of a fan blade, where the position of the target relative to the sensor may change with speed.
6.5. Poor signals may result if the gap between the sensor and sensor target is too large. Preliminary testing can determine the allowable gap distance.
6.6. When monitoring the rotation of a pulley wheel for belt-driven fans, monitor the rotation of the fan pulley, and not the drive pulley. Besides turning at different speeds due to different diameters, any belt slippage between the pulleys leads to overestimated fan rotational speeds when the drive pulley is monitored.
6.7. AirDAC determines the rotational speed on a per-second basis (i.e. X number of turns per second) and reports this value in rotations per minute; thus, the 1-s readings in RPM will increment by 60 RPM for every revolution increase per second. The one-minute average RPM values are a more accurate measurement of RPM.

7. Personnel Qualifications

7.1. Personnel should be trained by experienced researchers on the installation, adjustment, wire connections, and signal testing of the RPM sensor before initiating the procedure.
7.2. Each analyst must read and understand this SOP.

8. Equipment and Supplies

8.1. RPM sensors. Sensors covered under this SOP include the following:
  8.1.1. Threaded-barrel magnetic proximity sensors (Cherry part #MP100701 or equivalent)
  8.1.2. Threaded-barrel geartooth sensors (Cherry part #GS100701 or equivalent)
8.2. Sensor target.
  8.2.1. Magnet (for Model MP100701 or equivalent only). Magnets can be purchased at craft and hobby supply stores and electronics stores.
  8.2.2. Surface of discontinuous ferrous material (for Model GS100701 or equivalent only). This may be the spokes of a fan pulley, or a bolt attached to a rotating surface.
  8.2.3. Quick-set epoxy.
8.3. Sensor mounting supplies. The specific supplies will vary based on the installation method, but may include brackets, cable ties, bolts, etc.
8.4. DAQ system (SOPs B1 and B2) to record signals from each vibration sensor
  8.4.1. USB-4303 Counter/Timer (Measurement Computing Corporation, Middleboro, MA)
8.5. Multimeter
8.6. Signal cable (3-conductor, 22 gage shielded)
8.7. Portable tachometer
8.8. Digital camera (optional)
8.9. Pull-up resistor (optional)

9. Procedures

9.1. Initial testing

9.1.1. Test the RPM sensor and its reaction to the proposed sensor target (i.e. magnet) to determine the mounting location and method.

9.1.2. Connect the sensor to a 5-VDC power supply and the output wire to the multimeter.

9.1.3. Vary the distance between the sensor and the target, and monitor the signal output using the multimeter. Determine the maximum gap that ensures a signal is induced.

9.2. Sensor installation

9.2.1. Turn off the fan and fix the fan blade in place to prevent the wind from turning the blade. Put up signs to inform others that you are working with the fan, if necessary.

9.2.2. Inspect the fan(s) to be monitored, and evaluate different mounting locations, based on the fan configuration and the maximum allowable distance between sensor and target (Section 9.1). A sensor bracket may be required to hold the sensor in position. Potential installation methods are described below, but others may be available.

9.2.2.1. Mount the sensor to face a moving target on the fan shaft (Fig. 1).

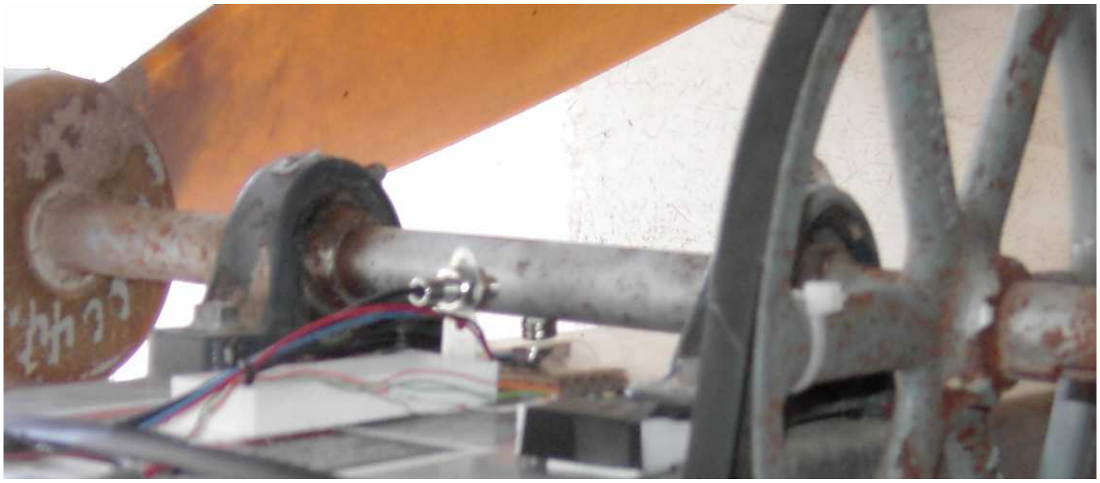


Figure 1. RPM sensor mounted perpendicular to fan shaft.

9.2.2.2. Mount the sensor to face the fan pulley. The target may be either the pulley spoke for a geartooth sensor, or a target attached to the pulley (Fig. 2).

9.2.2.3. Mount the sensor to face a target attached to a fan blade. The target should be as close to the center of the fan as possible. The sensor may be mounted facing the back or the front of the fan blade.

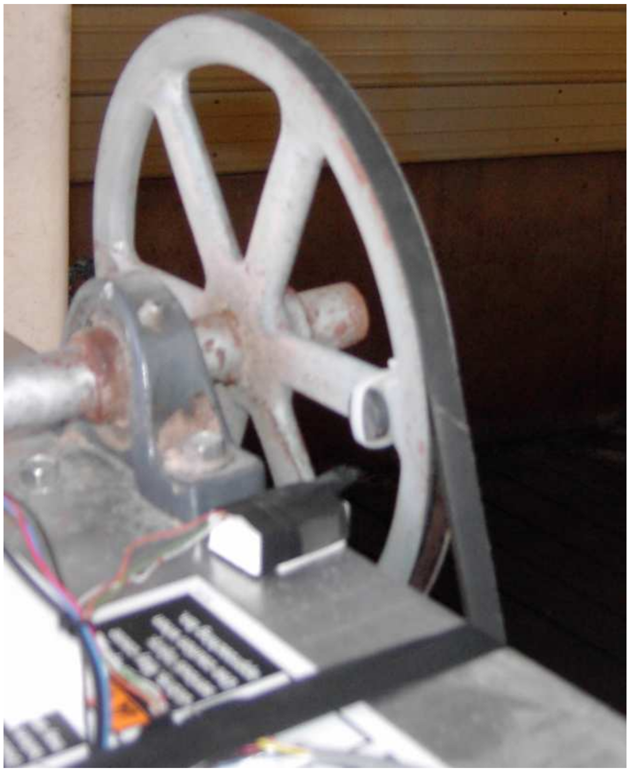
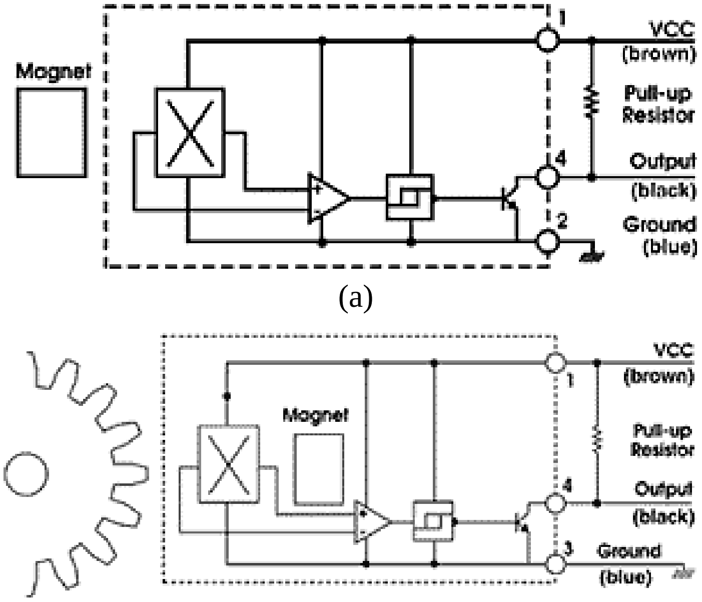


Figure 2. RPM sensor mounted perpendicular to fan pulley.

Figure 3. RPM sensor mounted to fan grating, perpendicular to fan blade.

9.3. Sensor target installation (for magnet targets only)
  9.3.1. Clean the surface where the target will be attached (Figs. 1-3). If necessary, use sandpaper to roughen the surface.
  9.3.2. Apply epoxy to the target and surface according to product directions.
  9.3.3. Allow epoxy to set before starting the fan.

9.4. Connection to DAQ module
  9.4.1. The wire leads for the sensor are described in Fig. 4. The pull-up resistor is not required when using the MCC USB-4303.



(a)

(b)

Figure 4. Block diagram and wire leads for Models MP1007 (a) and GS1007 (b) sensors (Cherry, 2007).

  9.4.2. Connect the VCC (Brown) wire lead to a 5-VDC power supply, either on the USB-4303 counter module (Fig. 5; +5VDC), or on the DAQ board.
  9.4.3. Connect the Output (Black) wire lead to a channel on the USB-4303 counter module (Fig. 5; 1INP1 to 1INP5 or 2INP1 to 2INP5).
  9.4.4. Connect the Ground (Blue) wire lead to the ground of the USB-4303 counter module (Fig. 5, GND), or a ground connection on the DAQ board.
  9.4.5. AirDAC settings. Enter a scalar value for the slope if the sensor detects multiple targets per revolution. For example, enter a slope of 0.25 if a geartooth sensor detects four fan pulley spokes each revolution.

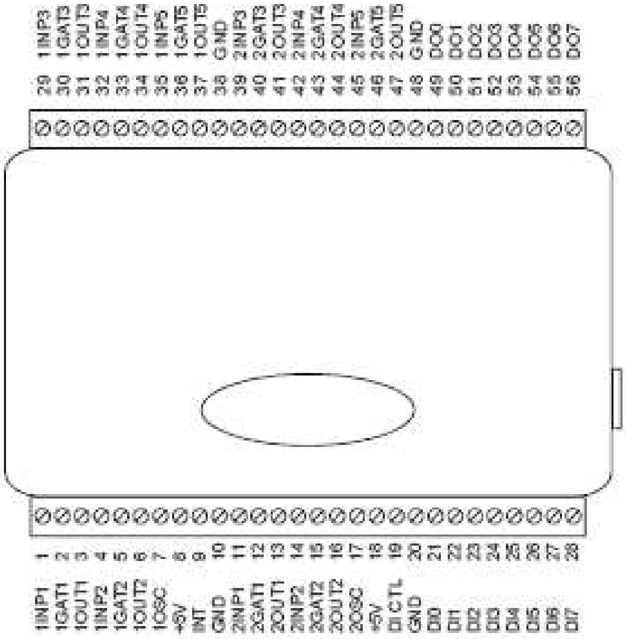


Figure 5. USB-4303 terminal descriptions (MCC, 2007)

9.5. Calibration checking with tachometer
  9.5.1. Following the tachometer instructions, measure the rotational speed of the fan blade(s) using the appropriate targets for the tachometer. If necessary, adjust the tachometer measurement for the number of sensing targets per revolution.
  9.5.2. Compare the tachometer measurements to the RPM sensor measurement.
9.6. Computer hardware & software
  9.6.1. AirDAC (SOP B2)
  9.6.2. ADPP (SOP B3)
  9.6.3. CAPECAB (SOP B6)

10. Data and Records Management

10.1. Maintain laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Record the sensor make and model, locations of installation, DAQ channel connections (refer to the measurement and control signal channel design in SOP B1), initial calibration check results, and installation/testing personnel to the field notes spreadsheet of the project. Take digital photos as documentation if necessary.
10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.
10.4. Manage the data according to SOP B5.

11. Quality Control and Quality Assurance

- 11.1. Initial checks
  - 11.1.1. Upon installation, check all RPM sensors against the tachometer for appropriate operation, and adjust their positioning as necessary.
- 11.2. Periodic checks
  - 11.2.1. Check all RPM sensors against the tachometer for appropriate operation at the QAPP-specified frequency, and adjust their positioning as necessary.

12. References

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12.3. Measurement Computing Corporation. 2007. USB 4303 9513-based Counter/Timer User’s Guide. Online at http://www.measurementcomputing.com/PDFManuals/usb-4303.pdf. Accessed 11/14/07.
12.4. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.
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12.7. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
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DATA ACQUISITION AND CONTROL HARDWARE
Standard Operating Procedure (SOP) B1

DATA ACQUISITION AND CONTROL HARDWARE

Standard Operating Procedure (SOP) B1

Prepared by

Ji-Qin Ni and Bill W. Bogan

Reviewed by

Matt J. Darr (Ohio State Univ.), Teng-Teeh Lim and Albert J. Heber

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Monitoring emissions from animal feeding operation (AFO) facilities requires a large number of sensors, instruments and sampling points. A system is needed to control all of these, and to collect the data which they generate.

1.2. The data acquisition and control (DAC) hardware will be used to take measurements and log digital and analog data, actuate controls of devices and control systems, and communicate with remote computers via an Ethernet line.

1.3. This SOP applies only to the specific hardware components involved in data acquisition and system control. Details on the individual instruments and devices which feed data to, and are under the control of, the DAC system, are provided in the SOPs for those individual instruments.

2. Summary of Method

This SOP describes the data acquisition and control (DAC) hardware for monitoring AFO emissions. It outlines the installation, configuration, and testing of individual DAC components or modules. Various Quality Control (QC) topics relevant to DAC hardware are also discussed.

DAC hardware that is used in the NAEMS for air emissions monitoring include FieldPoint modules (analog input from gas analyzers, thermocouple signals, and digital output) by NI (National Instruments Corporation, Austin, TX), and USB devices by MCC (Measurement Computing Corporation, Middleboro, MA). A PC with Windows XP running the AirDAC software (SOP B2) interfaces automatically with the DAC hardware to log data from various instruments and sensors, and to control designated devices. Devices that are controlled by the DAC system include solenoids in the Gas Sampling System (GSS) (SOP G1) and relays for heater controls in the heated raceways (SOP U3).

3. Definitions

3.1.	AFO	Animal feeding operation
3.2.	AI	Analog input
3.3.	DAC	Data acquisition and control
3.4.	DI	Digital input
3.5.	DO	Digital output
3.6.	FP	FieldPoint
3.7.	GSS	Gas sampling system
3.8.	I/O	Input/output
3.9.	MCC	Measurement Computing Corporation
3.10.	NAEMS	National Air Emission Monitoring Study
3.11.	NI	National Instruments Corporation
3.12.	OFIS	On-farm instrument shelter
3.13.	PAAQL	Purdue Agricultural Air Quality Lab
3.14.	PC	Personal computer

3.15.	QC	Quality control
3.16.	RH/T	Relative humidity/temperature
3.17.	TC	Thermocouple
3.18.	TEOM	Tapered element oscillating microbalance
3.19.	USB	Universal serial bus

4. Health and Safety

4.1. Make sure that all wiring meets applicable electrical codes, and exercise the following precautions:
  4.1.1. Insulate signal connections for the maximum voltage for which the respective FieldPoint module is rated.
  4.1.2. Do not exceed the maximum voltage for which a particular module is rated.
  4.1.3. Do not wire a “live” module that is currently receiving electrical signals.
  4.1.4. Do not remove or add terminal bases when power is connected to the FieldPoint system.
  4.1.5. Avoid all direct contact with the terminal base signal wiring when “hot swapping” modules.
  4.1.6. Do not operate the DAC system around flammable gases or fumes.

5. Cautions

5.1. The FieldPoint modules are intended for indoor use, with an operating temperature of -25ºC to 55ºC, and relative humidity of 10% to 90%, in non-condensing air.
5.2. Do not substitute parts or modify the FieldPoint modular system. Use the system only with the modules, accessories, and cables specified in the installation instructions. Failure to do so could create a hazardous situation and/or damage the system itself.
5.3. All FieldPoint modules have built-in safety protections, which may be compromised if the units are damaged in any way. Do not use damaged FieldPoint modules; return them to the manufacturer for repair or discard them.
5.4. Only operate the FieldPoint modules at or below Pollution Degree 2 (generally only nonconductive pollution, although temporary periods of conductive pollution can occur). Typical outdoor dust at agricultural facilities constitutes Pollution Degree 3. Only operate FieldPoint modules inside the OFIS (SOP U1), or inside an enclosure with suitable particulate filters installed.
5.5. Use only soft, nonmetallic brushes to clean FieldPoint modules, and ensure that the modules are completely dry and contaminant-free before returning to use.
5.6. When handling I/O boards, use a wrist-grounding strap or hold on to a grounded object prior to opening any anti-static shipping packaging. Touch the antistatic container to the computer chassis before removing the board from the container.
  5.6.1. Do not touch any of the exposed pins or circuit connections on the board.
5.7. Before disconnecting any instrument or sensor from the FP-AI terminal base, turn off the instrument/sensor to avoid short-circuiting the signal wires, which could damage the instrument/sensor.

5.8. If a sensor that is already powered, e.g. an activity sensor, has to be connected to the data acquisition hardware, connect the signal ground wire to the data acquisition ground terminal before connecting the signal voltage wire. Otherwise, excessive high voltages may be introduced to the data acquisition system.

6. Interferences

6.1. Static electricity can interfere with or damage the DAC hardware. Make sure that all signal wires are properly shielded and grounded to avoid this interference.

6.2. Heat dissipated from adjacent equipment, for example, power supplies, can generate thermal gradients to thermocouple junction terminals. The FP-TC-120 corrects gradient errors up to 0.2°C; this is equivalent to a heat dissipation of approximately 4 W. Take steps to ensure that no other equipment on the DAC panel (Figure 1) in the vicinity of the TC-120 module dissipates more heat than this. For example, do not place a heater below the DAC panel.

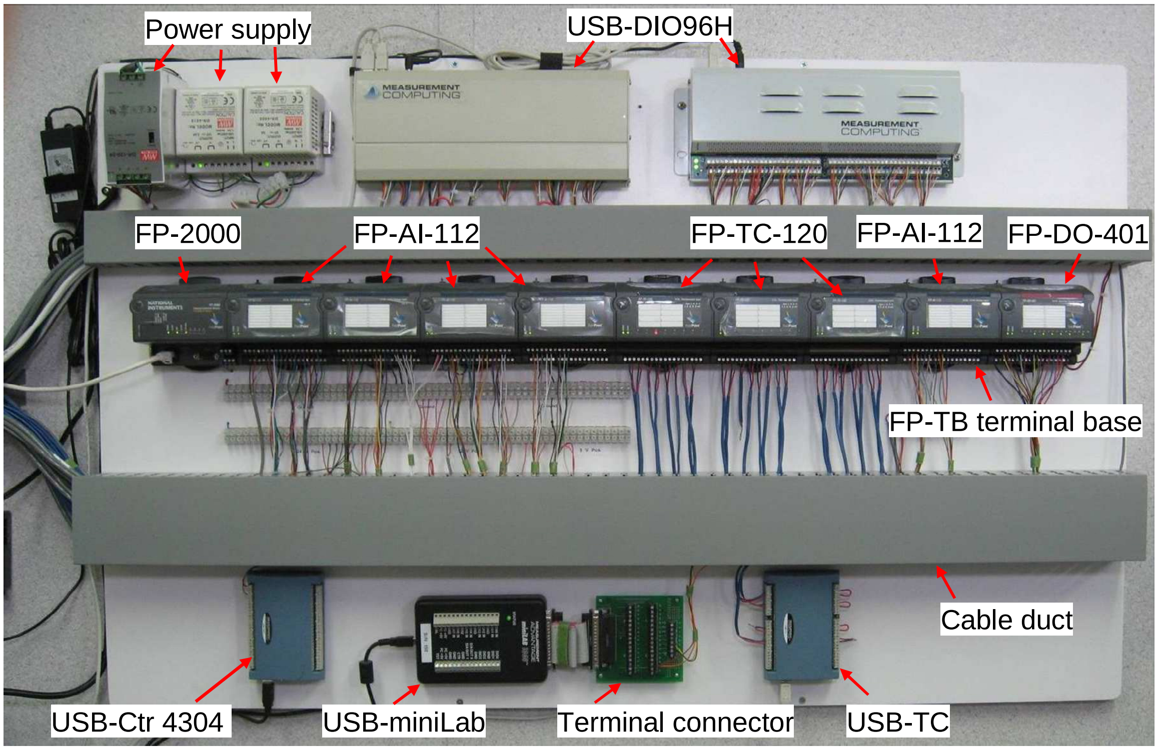


Figure 1. An example of DAC panel with power supply units, FieldPoint modules and USB devices.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the hardware before initiating any procedure.

7.2. Each analyst must read and understand the entire applicable instrument manual and this SOP before working with any of the individual DAC hardware components.
7.3. Personnel should have basic understanding of measurement and control systems.

8. Equipment and Supplies

8.1. FieldPoint modules (National Instruments Corporation, Austin, TX)
  8.1.1. FP-20xx FieldPoint Network Modules. One FP-20xx Network Module can support up to nine terminal bases.
  8.1.2. FP-AI-110 8-Channel, 16-Bit Analog Input Modules (optional)
  8.1.3. FP-AI-112 16-Channel, 16-Bit Analog Input Modules
  8.1.4. FP-TC-120 8-Channel Thermocouple Input Modules
  8.1.5. FP-DO-401 16-Channel, 5 to 30V Discrete Output Modules
  8.1.6. FP-TB-1 Terminal Bases (for FP-AI-11x and FP-DP-401 modules)
  8.1.7. FP-TB-3 Terminal Bases (for FP-TC-120 modules)
8.2. USB-based 96-bit digital I/O device with high current output (PCI-DIO96H, MCC, Middleboro, MA) (optional)
8.3. USB-based 10-channel counter device (USB-4303, MCC) (optional)
8.4. USB-based 8-channel 16-bit analog input device (USB-AI 608FS, MCC) (optional)
8.5. USB-based 8-channel thermocouple device (USB-TC, MCC) (optional)
8.6. USB-based 4-channel analog input (differential or 8-channel single-ended) and 28-channel DI device (USB miniLab, MCC) (optional)
8.7. Software
  8.7.1. LabVIEW (Version 7.1, NI), and Data Processing Report Generation Toolkit (Version 1.0.1, NI)
  8.7.2. FieldPoint™ for FieldPoint RT Controllers (Version 4.1 or later, NI)
  8.7.3. MCC DAQ Software (MCC), including InstaCal™ (Version 5.58 or later), TracerDAQ™ (Version 1.21 or later), and UL for LabVIEW.
8.8. Ethernet crossover cable - Category 5 (available in local store, e.g. RadioShack) for communication between FP network module and computer
8.9. USB cable(s) for connecting USB-based data acquisition devices to the computer

9. Procedures

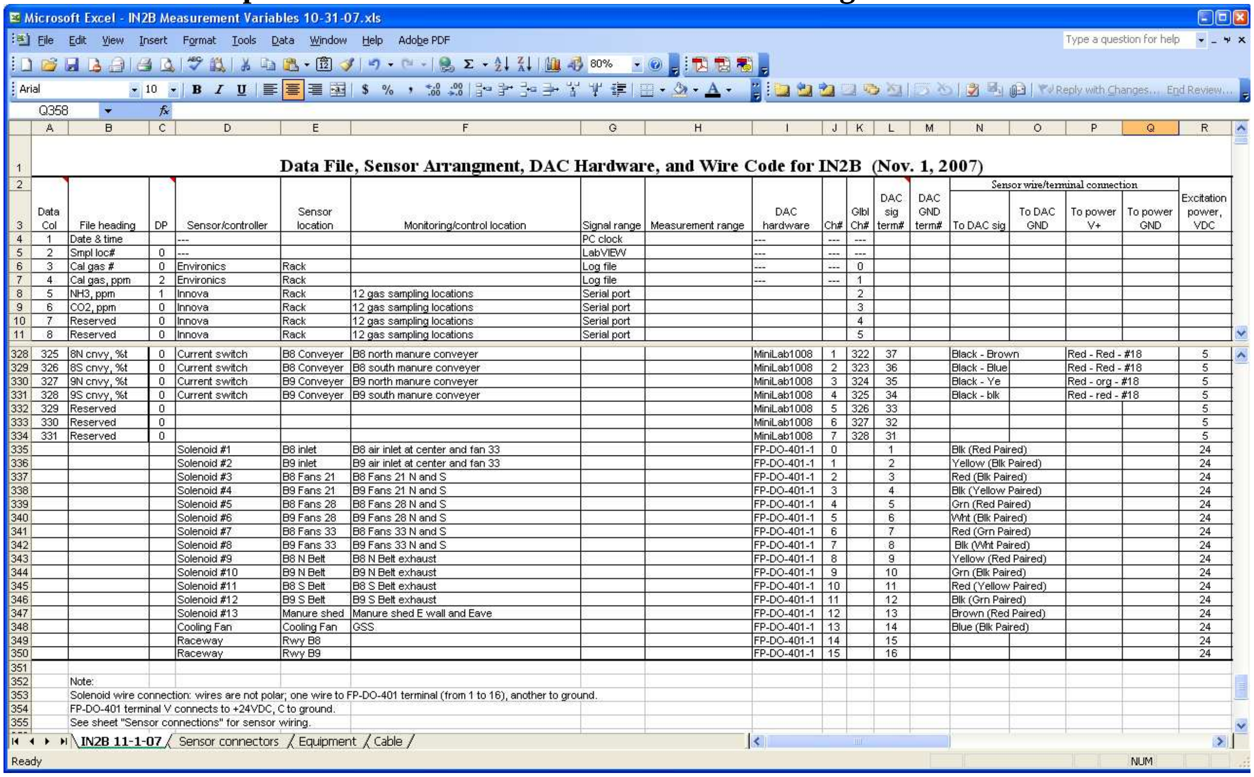
9.1. Design the DAC hardware and software configuration by listing all the measurement and control channels in an Excel spreadsheet (Table 1).
  9.1.1. Arrange the FieldPoint module sequence as follows:
  9.1.2. FP-20xx (single) - FP-AI-11x (multiple) - FP-TC-120 (multiple) - FP-TC-410 (single or multiple). Except for the FP-20xx, the sequence of the other modules can be arranged differently.
  9.1.3. Arrange the instrument/sensor connection sequence to the analog inputs as follows:
  9.1.4. Gas analyzers - GSS sensors - TEOMs - Pressure transducers - Barn RH/T sensors - Weather sensors - Activity sensors - Other sensors.
9.2. Install LabVIEW (Version 7.1), Data Processing Report Generation Toolkit, FieldPoint,

and MCC DAQ software including InstaCal™, TracerDAQ™, and UL for LabVIEW.

9.3. Install and configure the FieldPoint modules.

- 9.3.1. Assemble individual DAC module bases and boards onto the DAC panel (Figure 1) in the OFIS. The FP modules may be dismounted when transporting the OFIS.
- 9.3.2. Mount the FieldPoint modules to the terminal bases (Figure **2**) on the DAC Panel (also refer to FieldPoint Operating Instructions for details). Record all serial numbers of the modules prior to mounting.
- 9.3.3. Place a protective cover (included) over the unused bus connector of the last terminal base in the series.
- 9.3.4. Connect the RJ-45 Ethernet port of the FP-Network module to the PC using a category 5 Ethernet crossover cable.

Table 1. An example of a DAC measurement and control design table.



Data File, Sensor Arrangment, DAC Hardware, and Wire Code for IN2B (Nov. 1, 2007)

	Data Col	File heading	DP	Sensor/controller	Sensor location	Monitoring/control location	Signal range	Measurement range	DAC hardware	Ch#	Glbl Ch#	DAC sig term#	DAC GND term#	Sensor wire/terminal connection				Excitation power, VDC
														To DAC sig	To DAC GND	To power V+	To power GND	
4	1	Date & time		---			PC clock		---	---	---							
5	2	Smpl loc#	0	---			LabVIEW		---	---	---							
6	3	Cal gas #	0	Environics	Rack		Log file		---	---	0							
7	4	Cal gas, ppm	2	Environics	Rack		Log file		---	---	1							
8	5	NH3, ppm	1	Innova	Rack	12 gas sampling locations	Serial port				2							
9	6	CO2, ppm	0	Innova	Rack	12 gas sampling locations	Serial port				3							
10	7	Reserved	0	Innova	Rack	12 gas sampling locations	Serial port				4							
11	8	Reserved	0	Innova	Rack	12 gas sampling locations	Serial port				5							
328	325	8N cnvy, %t	0	Current switch	B8 Conveyer	B8 north manure conveyer			MiniLab1008	1	322	37		Black - Brown		Red - Red - #18		5
329	326	8S cnvy, %t	0	Current switch	B8 Conveyer	B8 south manure conveyer			MiniLab1008	2	323	36		Black - Blue		Red - Red - #18		5
330	327	9N cnvy, %t	0	Current switch	B9 Conveyer	B9 north manure conveyer			MiniLab1008	3	324	35		Black - Ye		Red - org - #18		5
331	328	9S cnvy, %t	0	Current switch	B9 Conveyer	B9 south manure conveyer			MiniLab1008	4	325	34		Black - blk		Red - red - #18		5
332	329	Reserved	0						MiniLab1008	5	326	33						5
333	330	Reserved	0						MiniLab1008	6	327	32						5
334	331	Reserved	0						MiniLab1008	7	328	31						5
335				Solenoid #1	B8 inlet	B8 air inlet at center and fan 33			FP-DO-401-1	0		1		Blk (Red Paired)				24
336				Solenoid #2	B9 inlet	B9 air inlet at center and fan 33			FP-DO-401-1	1		2		Yellow (Blk Paired)				24
337				Solenoid #3	B8 Fans 21	B8 Fans 21 N and S			FP-DO-401-1	2		3		Red (Blk Paired)				24
338				Solenoid #4	B9 Fans 21	B9 Fans 21 N and S			FP-DO-401-1	3		4		Blk (Yellow Paired)				24
339				Solenoid #5	B8 Fans 28	B8 Fans 28 N and S			FP-DO-401-1	4		5		Grn (Red Paired)				24
340				Solenoid #6	B9 Fans 28	B9 Fans 28 N and S			FP-DO-401-1	5		6		Wht (Blk Paired)				24
341				Solenoid #7	B8 Fans 33	B8 Fans 33 N and S			FP-DO-401-1	6		7		Red (Grn Paired)				24
342				Solenoid #8	B9 Fans 33	B9 Fans 33 N and S			FP-DO-401-1	7		8		Blk (Wht Paired)				24
343				Solenoid #9	B8 N Belt	B8 N Belt exhaust			FP-DO-401-1	8		9		Yellow (Red Paired)				24
344				Solenoid #10	B9 N Belt	B9 N Belt exhaust			FP-DO-401-1	9		10		Grn (Blk Paired)				24
345				Solenoid #11	B8 S Belt	B8 S Belt exhaust			FP-DO-401-1	10		11		Red (Yellow Paired)				24
346				Solenoid #12	B9 S Belt	B9 S Belt exhaust			FP-DO-401-1	11		12		Blk (Grn Paired)				24
347				Solenoid #13	Manure shed	Manure shed E wall and Eave			FP-DO-401-1	12		13		Brown (Red Paired)				24
348				Cooling Fan	Cooling Fan	GSS			FP-DO-401-1	13		14		Blue (Blk Paired)				24
349				Raceway	Rwy B8				FP-DO-401-1	14		15						24
350				Raceway	Rwy B9				FP-DO-401-1	15		16						24

Note:
Solenoid wire connection: wires are not polar; one wire to FP-DO-401 terminal (from 1 to 16), another to ground.
FP-DO-401 terminal V connects to +24VDC, C to ground.
See sheet "Sensor connections" for sensor wiring.

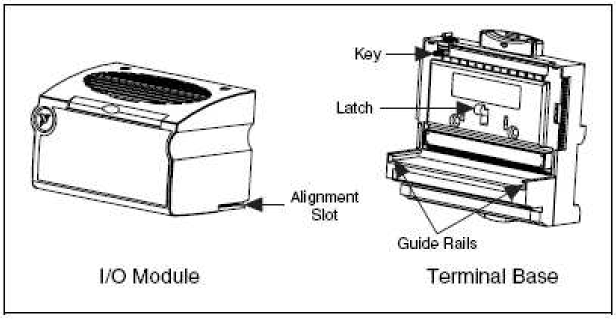
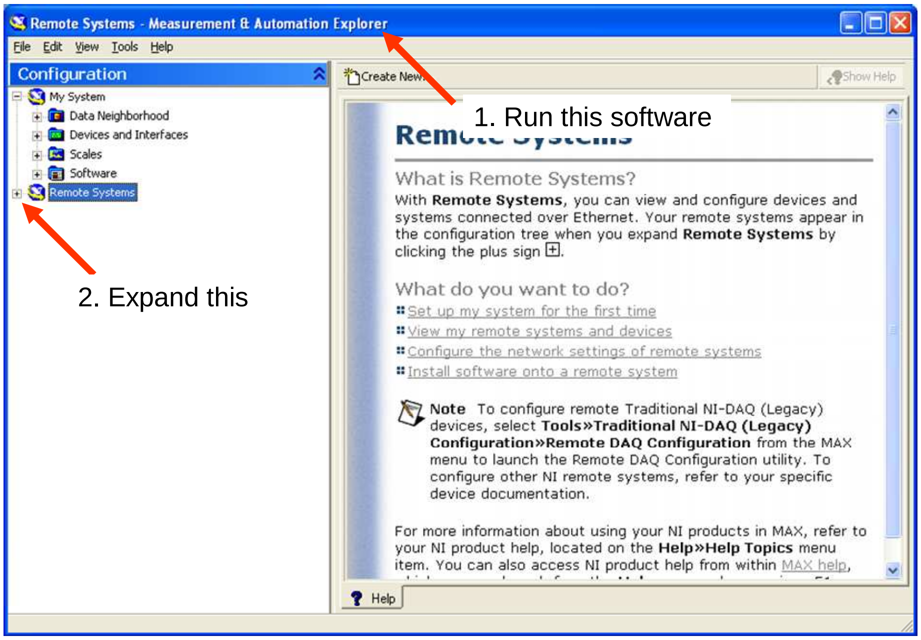


Figure 2. Connection points between I/O modules and terminal base.

9.4. Verify that the power cord and fuse connection to the power supplies are all correct and in good condition.

9.5. Plug in power supply. The FP-Network module will run a self-test. At the conclusion of this self-test (when the “STATUS” LED begins flashing) the module is ready for configuration (refer to FP-2000/2010/2015 User Manual, Part number 370705A-01 for details).

9.6. At initial setup, launch Measurement & Automation Explorer software in the DAC computer. On the Configuration panel, expand “Remote System” and follow the example illustrated from Figures 3 to 10.



Remote Systems

What is Remote Systems?

With **Remote Systems**, you can view and configure devices and systems connected over Ethernet. Your remote systems appear in the configuration tree when you expand **Remote Systems** by clicking the plus sign ⊞.

What do you want to do?

- Set up my system for the first time
- View my remote systems and devices
- Configure the network settings of remote systems
- Install software onto a remote system

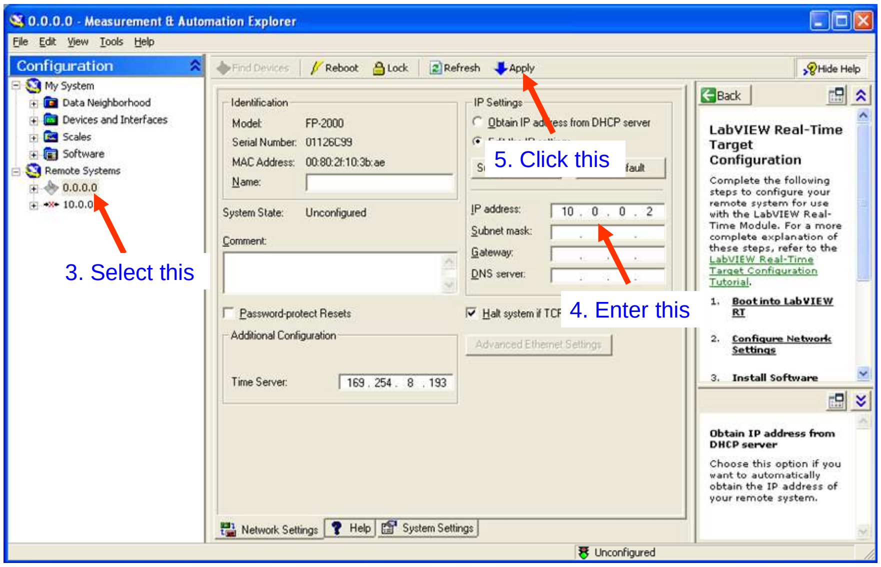
Note To configure remote Traditional NI-DAQ (Legacy) devices, select **Tools»Traditional NI-DAQ (Legacy) Configuration»Remote DAQ Configuration** from the MAX menu to launch the Remote DAQ Configuration utility. To configure other NI remote systems, refer to your specific device documentation.

For more information about using your NI products in MAX, refer to your NI product help, located on the **Help»Help Topics** menu item. You can also access NI product help from within MAX help,

1. Run this software

2. Expand this

Figure 3. Configure the FieldPoint modules at Measurement & Automation Explorer.



Model: FP-2000
Serial Number: 01126C99
MAC Address: 00:80:2f:10:3b:ae
Name:
System State: Unconfigured
Comment:
☐ Password-protect Resets
Additional Configuration
Time Server: 169 . 254 . 8 . 193

IP Settings
○ Obtain IP address from DHCP server
● Edit the IP settings
IP address: 10 . 0 . 0 . 2
Subnet mask:
Gateway:
DNS server:
☑ Halt system if TCP/IP fails
Advanced Ethernet Settings

LabVIEW Real-Time Target Configuration

Complete the following steps to configure your remote system for use with the LabVIEW Real-Time Module. For a more complete explanation of these steps, refer to the LabVIEW Real-Time Target Configuration Tutorial.

1. Boot into LabVIEW RT
2. Configure Network Settings
3. Install Software

Obtain IP address from DHCP server

Choose this option if you want to automatically obtain the IP address of your remote system.

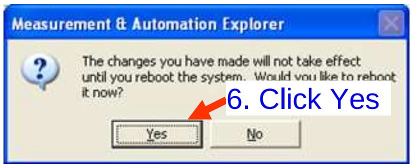
Unconfigured

3. Select this

4. Enter this

5. Click this

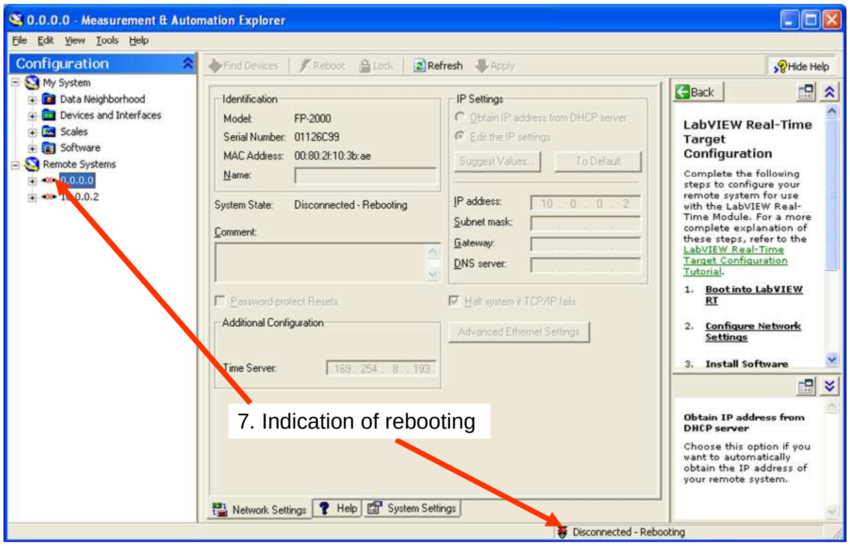
Figure 4. Configure the FieldPoint modules Step 3-5.



The changes you have made will not take effect until you reboot the system. Would you like to reboot it now?

6. Click Yes

Figure 5. Configure the FieldPoint modules Step 6.

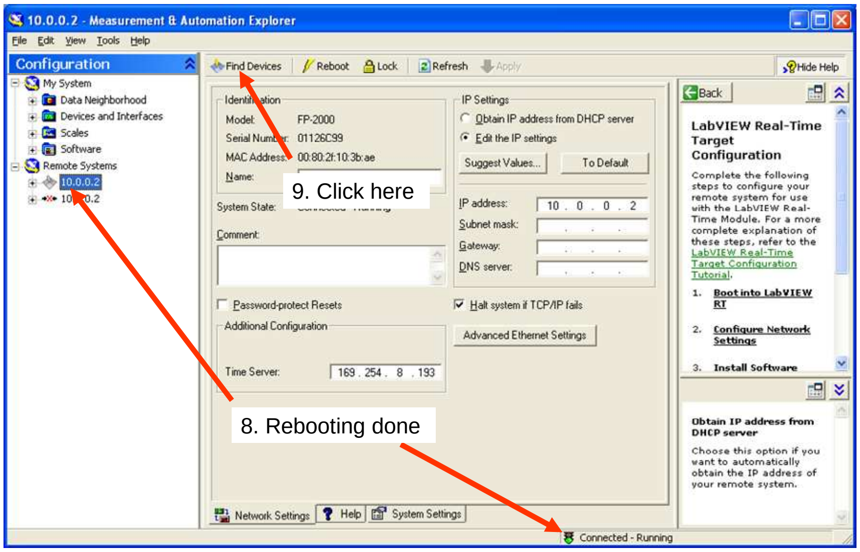


Model: FP-2000
Serial Number: 01126C99
MAC Address: 00:80:2f:10:3b:ae
Name:
System State: Disconnected - Rebooting
Comment:
Time Server: 169 . 254 . 8 . 193
IP address: 10 . 0 . 0 . 2

Disconnected - Rebooting

7. Indication of rebooting

Figure 6. Configure the FieldPoint modules Step 7.



Identification
Model: FP-2000
Serial Number: 01126C99
MAC Address: 00:80:2f:10:3b:ae
Name:
System State: Connected - Running
Comment:

IP Settings
○ Obtain IP address from DHCP server
● Edit the IP settings
IP address: 10 . 0 . 0 . 2
Subnet mask:
Gateway:
DNS server:

☐ Password-protect Resets
☑ Halt system if TCP/IP fails

Additional Configuration
Time Server: 169 . 254 . 8 . 193

LabVIEW Real-Time Target Configuration

Complete the following steps to configure your remote system for use with the LabVIEW Real-Time Module. For a more complete explanation of these steps, refer to the LabVIEW Real-Time Target Configuration Tutorial.

1. Boot into LabVIEW RT
2. Configure Network Settings
3. Install Software

Obtain IP address from DHCP server

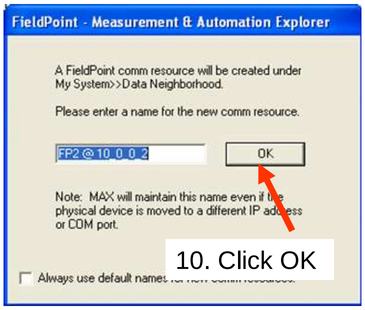
Choose this option if you want to automatically obtain the IP address of your remote system.

Connected - Running

9. Click here

8. Rebooting done

Figure 7. Configure the FieldPoint modules Step 8-9.



A FieldPoint comm resource will be created under My System>>Data Neighborhood.

Please enter a name for the new comm resource.

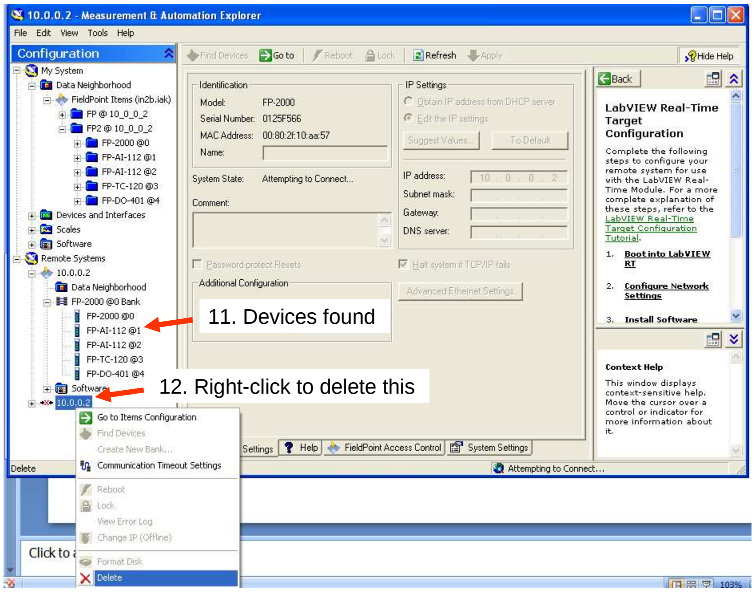
FP2 @ 10_0_0_2

Note: MAX will maintain this name even if the physical device is moved to a different IP address or COM port.

☐ Always use default names

10. Click OK

Figure 8. Configure the FieldPoint modules Step 10.



Identification
Model: FP-2000
Serial Number: 0125F566
MAC Address: 00:80:2f:10:aa:57
Name:
System State: Attempting to Connect...
Comment:

IP Settings
○ Obtain IP address from DHCP server
● Edit the IP settings
IP address: 10 . 0 . 0 . 2
Subnet mask:
Gateway:
DNS server:

☐ Password-protect Resets
☑ Halt system if TCP/IP fails

Additional Configuration

LabVIEW Real-Time Target Configuration

Complete the following steps to configure your remote system for use with the LabVIEW Real-Time Module. For a more complete explanation of these steps, refer to the LabVIEW Real-Time Target Configuration Tutorial.

1. Boot into LabVIEW RT
2. Configure Network Settings
3. Install Software

Context Help

This window displays context-sensitive help. Move the cursor over a control or indicator for more information about it.

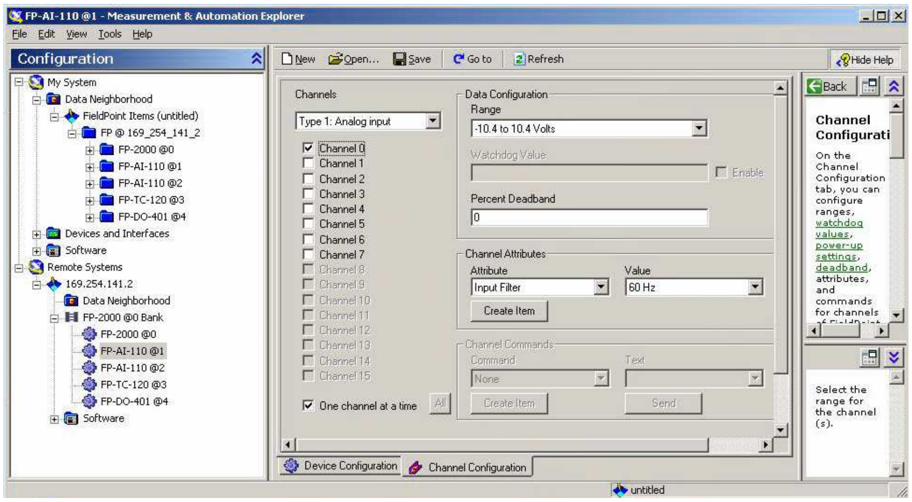
Attempting to Connect...

11. Devices found

12. Right-click to delete this

Figure 9. Configure the FieldPoint modules Step 11-12.

9.6.1. In the “Remote Systems” box, configure the “Range” of analog input channels one by one (Figure 10) according to the DAC design table (Table 1).



Channels: Type 1: Analog input

☑ Channel 0
☐ Channel 1
☐ Channel 2
☐ Channel 3
☐ Channel 4
☐ Channel 5
☐ Channel 6
☐ Channel 7
☐ Channel 8
☐ Channel 9
☐ Channel 10
☐ Channel 11
☐ Channel 12
☐ Channel 13
☐ Channel 14
☐ Channel 15

☑ One channel at a time

Range: -10.4 to 10.4 Volts

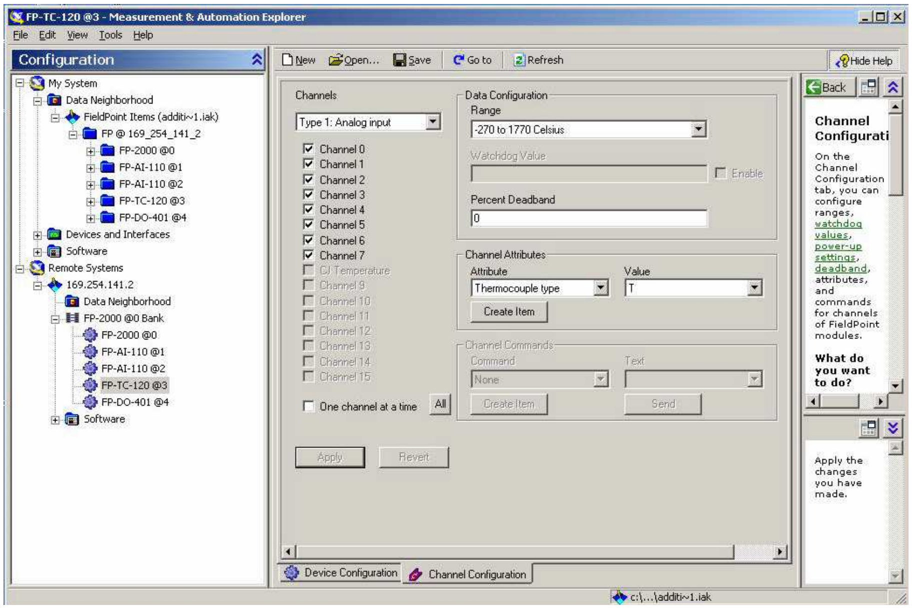
Percent Deadband: 0

Channel Attributes: Attribute: Input Filter; Value: 60 Hz

Select the range for the channel(s).

Figure 10. Configuring channels for analog FP-AI-11x modules.

9.6.2. Set “Range” at “-270 to 1770 Celsius” and “Channel Attributes” at “Thermocouple type T” for all channels in FP-TC-120 modules (Figure 11).



Channels: Type 1: Analog input

☑ Channel 0
☑ Channel 1
☑ Channel 2
☑ Channel 3
☑ Channel 4
☑ Channel 5
☑ Channel 6
☑ Channel 7
☐ CJ Temperature
☐ Channel 9
☐ Channel 10
☐ Channel 11
☐ Channel 12
☐ Channel 13
☐ Channel 14
☐ Channel 15

☐ One channel at a time

Range: -270 to 1770 Celsius

Percent Deadband: 0

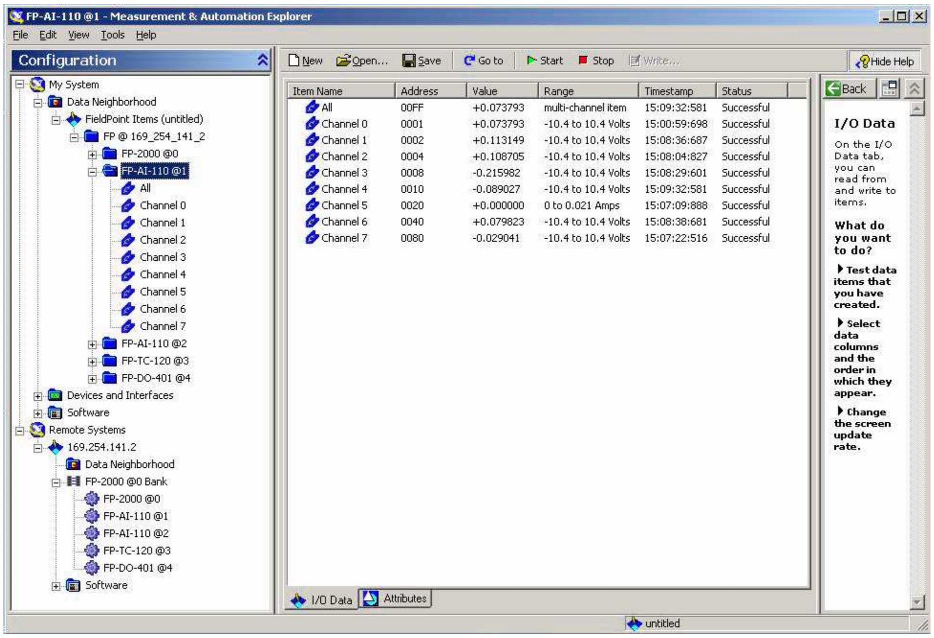
Channel Attributes: Attribute: Thermocouple type; Value: T

Apply the changes you have made.

Figure 11. Configuring channels for thermocouple FP-TC-120 modules.

9.6.3. Test the hardware and configuration. In the “Data Neighborhood,” select the FieldPoint module. At the top of the right panel, click “Start”. If the “Status” column for the FP-AI-11x, FP-TC-120, and FP-DO-401 modules indicates “Successful” for all channels, the modules are working properly (Figure 12). If “Successful” is not indicated for all channels, refer to the "Help" section of the Measurement & Automation Explorer to debug. Contact the manufacturer if necessary (Section 13.1).

9.6.4. Save the configuration by clicking Save and assigning the filename C:\AirDAC\Program\ XXnY.iak, where XXnY is the abbreviation of the site.



Item Name	Address	Value	Range	Timestamp	Status
All	00FF	+0.073793	multi-channel item	15:09:32:581	Successful
Channel 0	0001	+0.073793	-10.4 to 10.4 Volts	15:00:59:698	Successful
Channel 1	0002	+0.113149	-10.4 to 10.4 Volts	15:08:36:687	Successful
Channel 2	0004	+0.108705	-10.4 to 10.4 Volts	15:08:04:827	Successful
Channel 3	0008	-0.215982	-10.4 to 10.4 Volts	15:08:29:601	Successful
Channel 4	0010	-0.089027	-10.4 to 10.4 Volts	15:09:32:581	Successful
Channel 5	0020	+0.000000	0 to 0.021 Amps	15:07:09:888	Successful
Channel 6	0040	+0.079823	-10.4 to 10.4 Volts	15:08:38:681	Successful
Channel 7	0080	-0.029041	-10.4 to 10.4 Volts	15:07:22:516	Successful

I/O Data

On the I/O Data tab, you can read from and write to items.

What do you want to do?

- **Test data items that you have created.**
- **Select data columns and the order in which they appear.**
- **Change the screen update rate.**

Figure 12. A test of data acquisition signals in Measurement & Automation Explorer.

9.6.5. Refer to "Help" in Measurement & Automation Explorer if further assistance is required during the configuration process.

9.7. Install and configure the USB-based data acquisition devices, e.g. the DIO96H device.

9.7.1. Connect the USB-DIO 96H to one of the PC's USB ports with a USB cable.

9.7.2. Connect the AC Adapter to the power and the USB-DIO 96H.

9.7.3. A "Found New Hardware" balloon will appear on the PC. Another balloon will appear when the device is successfully installed.

9.7.4. Run InstaCal from the desktop or from Start->Programs->InstaCal (Figure 13). If the hardware is successfully detected, a Plug and Play Board Detection window (Figure 14) will appear. Click the OK button to close the window.

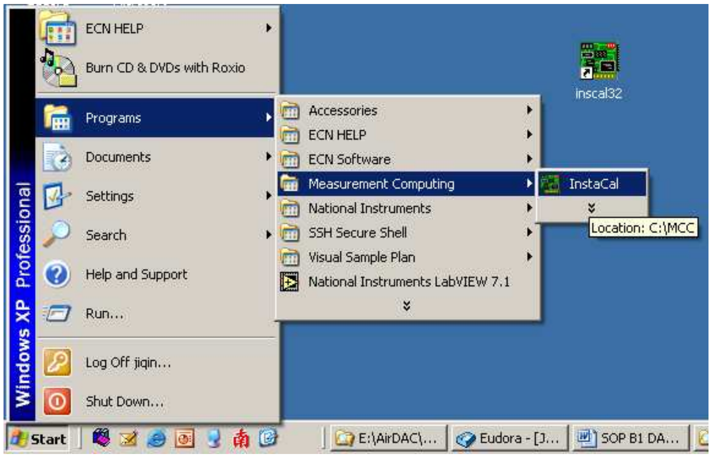
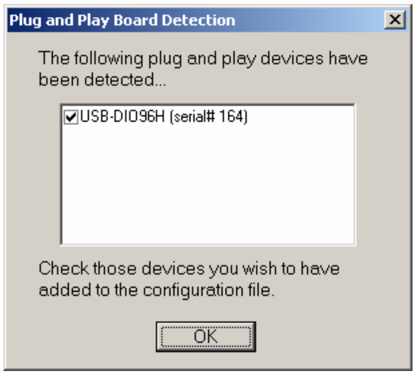


Figure 13. Running InstaCal, the MCC hardware configuration program.



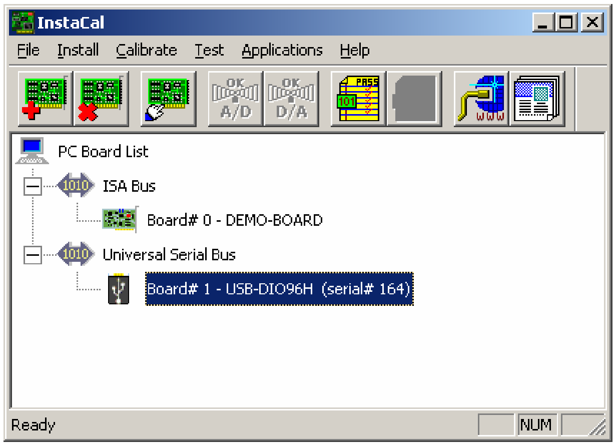
The following plug and play devices have been detected...

☑USB-DIO96H (serial# 164)

Check those devices you wish to have added to the configuration file.

Figure 14. Detection of the USB-DIO 96H by InstaCal.

9.8. The device will appear under the Universal Serial Bus heading in InstaCal (Figure 15). Record the board number (Board# n), as this will be used in the AirDAC program (SOP B2). Close InstaCal by clicking the ☒ or selecting File > Exit.



PC Board List
- ISA Bus
  - Board# 0 - DEMO-BOARD
- Universal Serial Bus
  - Board# 1 - USB-DIO96H (serial# 164)

Figure 15. USB DIO96H device configured by InstaCal.

9.9. Connect measurement/control device signals to DAC hardware.

9.9.1. Turn off the power to the DAC hardware, gas analyzers, TEOMs and other sensors before initial connection to avoid potential damage of the devices.

9.9.2. Connect analog input signals to the FP-AI terminal bases according to the DAC channel table (Table 1).

9.9.3. Connect thermocouple wires to the FP-TC terminal bases. On Type T thermocouples, the blue (copper) is + and the red (constantan) is -. If shielded extension wires are used, connect one end of the shield to the corresponding "COM" terminal as per the table below.

Input Channel	Terminal Numbers		
	IN(+)	IN(-)	COM
0	1	2	18
1	3	4	20
2	5	6	22
3	7	8	24
4	9	10	26
5	11	12	28
6	13	14	30
7	15	16	32

9.9.4. Connect DI signals to the USB DIO96H device connection terminals according to the DAC channel table.

9.9.5. Connect DO for controlling devices (GSS solenoids, raceway heating relays) to the FP-DO terminal bases according to the DAC channel table.

9.9.6. Connect other signal wires to the relevant DAC devices, e.g. USB-based counters if they are configured in the system.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the designated electronic field notes spreadsheet. Supplement this electronic record with a bound record book, which should also contain bound copies of the electronic record.

10.2. Manage all data and files (including the configuration files) according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Calibration of FieldPoint modules

11.1.1. National Instruments products require calibration two years after their manufacture, and every year thereafter. Calibration of FP-AI modules involves expensive instrumentation, and is preferably done by returning the module to the manufacturer.

11.1.2. Maintain calibration records in a separate sheet in the Excel file with the DAC measurement and control table (Table 1). Place a calibration sticker on each piece of hardware, indicating date of last calibration.

11.2. Test the FP-AI modules at the initial setup and every year thereafter.

11.2.1. Disconnect the instrument/sensor signal from the channel to be tested

11.2.1.1 Before disconnecting from the FP-AI terminal base, turn the instrument/sensor off to avoid short-circuiting the signal wires.

11.2.2. Use a short wire to short-circuit the two terminals that were connected to the instrument/sensor.

11.3. Launch Measurement & Automation Explorer (Section 9.6.3) and check the values displayed in the right panel (Figure 12). The channel being tested should display a stabilized, near-zero value (< ± 1 mV or < ± 1 µA). If it is not stable, the channel is not working properly.

11.4. Disconnect the short-circuit wire from the terminals. Connect a known voltage or a known current to the terminals. Use a voltage or current equivalent to the high range signal of the instrument/sensor that is hooked up to the channel. For example, use 10.000 V to test the channel for a gas analyzer that has signal range from 0 to 10 VDC. Check the value of the channel in the Measurement & Automation Explorer. The displayed value should stabilize close to the generated value (within ±0.1%). If it is not stable, the channel is not working properly.

11.5. If the displayed values from the zero test are > ± 1 mV or > ± 1 µA (Sections 11.2.2-11.3) or are > ±0.1% compared with the known values from the voltage/current test (Section 11.4), but are stable, use the AirDAC program to make corrections by entering the zero and voltage/current values in “3. Signal low” and “4. Signal high,” respectively, in the AirDAC DAQ table (SOP B2).

11.6. Do not use any channel that fails the voltage test. If a channel fails the current signal test, test it for voltage signals.

11.6.1. A channel that works properly with voltage signals but not current signals may be used for voltage signal acquisition.

11.6.2. Re-arrange the channels when necessary by switching the channels and adjusting the “10. Global ch#” in the AirDAC DAQ table (SOP B2) to avoid using any non-working channels.

11.6.3. If the module does not have enough functional channels, replace it and send it to the manufacturer for repair.

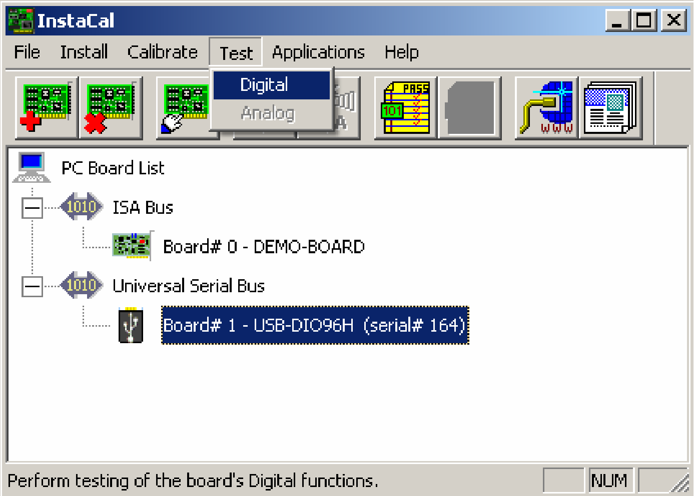
11.7. Test the FP-TC modules at setup and every year thereafter. Combine the FP-TC channel test with thermocouple calibration (SOP E1). Do not use any channel that fails the test.

11.8. Verifying and testing the FP-DO-401 channels

11.8.1. Verify DO channels that are used to control the GSS solenoids as part of the daily data check. If the air sample flow rate at a certain sampling location decreases by more than 30% of the initial value during the 10-min sampling time, the relevant solenoid in the GSS may have been receiving decreasing energizing power, which can be due to a mal-functioning FP-DO-401 channel. To test this, measure the voltage that the solenoid receives (while it is being energized) using a multimeter. If the voltage is not stable, the FP-DO-401 relevant channel should be removed from use.

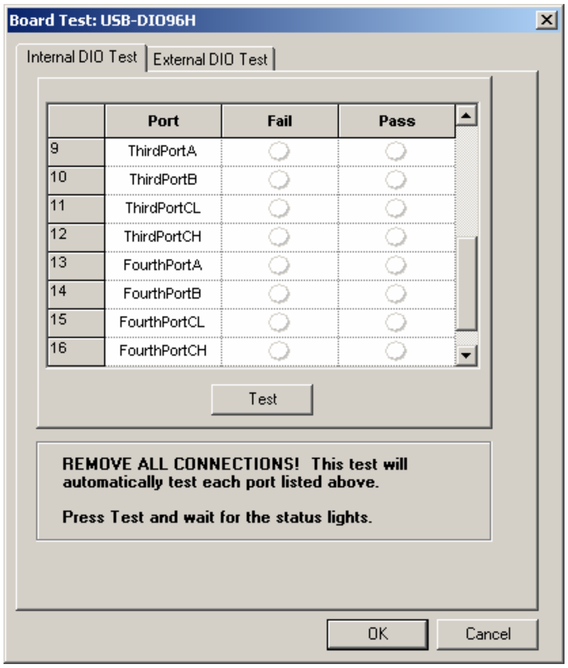
11.9. Test of USB DIO96H digital input signals

- 11.9.1. Launch InstaCal and select the USB DIO96H device. In the “Test” menu, select “Digital” (Figure 16). A new test window will appear.
- 11.9.2. Select the Internal DIO test tab and click Test (**Error! Reference source not found.**).
- 11.9.3. If it is necessary, select the External DIO test tab and follow the instructions to the external signal test.
- 11.9.4. Make sure all DI channels that are being used are working properly to acquire data.



Perform testing of the board's Digital functions.

Figure 16. Test the USB DIO96H device using InstaCal.



	Port	Fail	Pass
9	ThirdPortA	○	○
10	ThirdPortB	○	○
11	ThirdPortCL	○	○
12	ThirdPortCH	○	○
13	FourthPortA	○	○
14	FourthPortB	○	○
15	FourthPortCL	○	○
16	FourthPortCH	○	○

REMOVE ALL CONNECTIONS! This test will automatically test each port listed above.

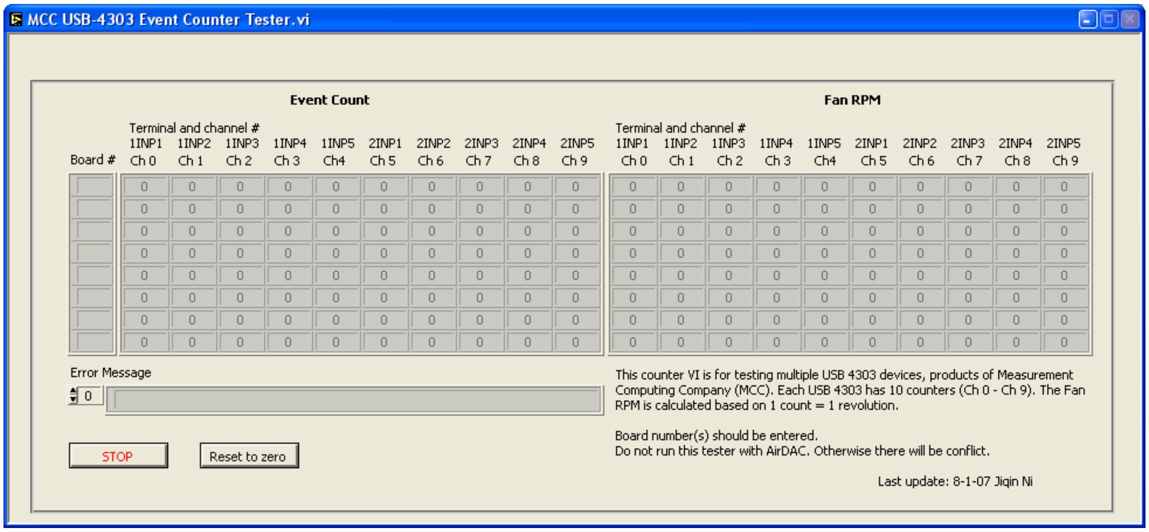
Press Test and wait for the status lights.

Figure 17. Internal DIO test tab in InstaCal.

11.10. Test of USB-4303 counter signals

11.10.1. Run the “MCC USB-4303 Event Counter Tester.vi” located in C:\AirDAC\Program\NI Special\ by double-clicking it.

11.10.2. In the window that appear (Figure 18), enter the USB 4303 device board number in the Board# on the left side of the window. The Event Count, Fan RPM and Error Message will indicate the status of the hardware and the signals that each channel receives.



Event Count

Terminal and channel #

Board #	1INP1 Ch 0	1INP2 Ch 1	1INP3 Ch 2	1INP4 Ch 3	1INP5 Ch4	2INP1 Ch 5	2INP2 Ch 6	2INP3 Ch 7	2INP4 Ch 8	2INP5 Ch 9
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0

Fan RPM

Terminal and channel #

1INP1 Ch 0	1INP2 Ch 1	1INP3 Ch 2	1INP4 Ch 3	1INP5 Ch4	2INP1 Ch 5	2INP2 Ch 6	2INP3 Ch 7	2INP4 Ch 8	2INP5 Ch 9
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0

Error Message: 0

This counter VI is for testing multiple USB 4303 devices, products of Measurement Computing Company (MCC). Each USB 4303 has 10 counters (Ch 0 - Ch 9). The Fan RPM is calculated based on 1 count = 1 revolution.

Board number(s) should be entered.
Do not run this tester with AirDAC. Otherwise there will be conflict.

Last update: 8-1-07 Jiqin Ni

Figure 18. Test the USB 4303 counter device.

12. References

12.1. AI Module Manual. 2002. FieldPoint Operating Instructions: FP-AI-110 and cFP-AI-110. NI, Austin, TX.

12.2. AI Module Manual. 2004. FP-AI-112 and FP-AI-112 Operating Instructions. NI, Austin, TX.

12.3. DO Module Manual. 2002. FieldPoint Operating Instructions: FP-DO-401 and cFP-DO-401. NI, Austin, TX.

12.4. TC Module Manual. 2002. FieldPoint Operating Instructions: FP-TC-120 and cFP-TC-120. Part Number: 323344A-01. NI, Austin, TX.

12.5. FP User Manual. 2003. FP-2000/2010/2015 User Manual. NI, Austin, TX.

12.6. Measurement Computing. 2006. USB-DIO 96H/50 User’s Guide. File location: C:\Program Files\Measurement Computing\DAQ\Documents\UsersGuides\USB\USB-DIO96H.pdf.

12.7. Measurement Computing. 2006. USB-4303 User’s Guide. File location: C:\Program Files\Measurement Computing\DAQ\Documents\UsersGuides\USB\USB-4303.pdf.

12.8. Measurement Computing. 2006. USB-1608FS User’s Guide. File location: C:\Program Files\Measurement Computing\DAQ\Documents\UsersGuides\USB\USB-1608FS.pdf.

12.9. Measurement Computing. 2006. USB-TC User’s Guide. File location: C:\Program Files\Measurement Computing\DAQ\Documents\UsersGuides\USB\USB-TC.pdf.

12.10. Measurement Computing. 2006. MiniLAB-1008 User's Guide. File location: C:\Program Files\Measurement Computing\DAQ\Documents\UsersGuides\ USB\MiniLAB-1008.pdf.
12.11. Quick Start Guide - Measurement Computing Data Acquisition. September 2005. MCC, Middleboro, MA.
12.12. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.13. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.14. SOP E1. 2006. Temperature Measurement Using Thermocouples. Standard Operating Procedure E1. Purdue Ag Air Quality Lab.
12.15. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
12.16. SOP U1. 2006. On-farm Instrument Shelters for Barn Sources. Standard Operating Procedure U1. Purdue Ag Air Quality Lab.
12.17. SOP U3. 2006. Heated Raceway. Standard Operating Procedure U3. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturers:
  13.1.1. National Instruments Corporation
  13.1.2. 11500 N Mopac Expwy
  13.1.3. Austin, TX 78759-3504.
  13.1.4. Technical Support: (800) 531-5066
  13.1.5. Measurement Computing Corporation
    16 Commerce Boulevard
    Middleboro, MA 02346
    (508) 946-5100
    info@measurementcomputing.com
  13.1.6. Technical Support: measurementcomputing.com/contact.html

13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

DATA ACQUISITION AND CONTROL SOFTWARE (AirDAC)

Standard Operating Procedure (SOP) B2

DATA ACQUISITION AND CONTROL SOFTWARE (AirDAC)

Standard Operating Procedure (SOP) B2

Prepared by

Ji-Qin Ni and Bill W. Bogan

Reviewed by

Teng-Teeh Lim and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Specialized software is required for Data Acquisition and Control (DAC) in the National Air Emission Monitoring Studies at livestock facilities. This SOP describes the operating procedure for the specialized DAC software, AirDAC.

1.1.1. This software acquires data from an array of sensors and analyzers, of which the analog or digital signal cables are connected to the DAC hardware described in SOP B1.

1.1.2. The software converts the incoming analog data signals into data with engineering units, based on the signal range and measurement range settings. It allows further adjustments to be made to the data by applying linear equations, which can be based on calibration models. It averages the digital signals over a pre-specified range of time.

1.1.3. The software provides digital output controls for various devices, including, for example, the solenoids in the Gas Sampling System (GSS).

1.2. The software acquires up to 254 analog and digital signals at a sampling frequency of 1 Hz. The software controls up to 32 digital outputs for controlling the GSS, raceway heaters, and other devices. The software averages data every 15 and 60 s, and saves them into two separate data files.

1.3. The data collected by AirDAC are analyzed according to SOPs B3, B4, and B6.

2. Summary of Method

The AirDAC software, developed by PAAQL in the LabVIEW programming language (National Instruments Corporation, Austin, TX), works with data acquisition and control hardware (National Instruments and Measurement Computing Corporation). The software controls sampling location, acquires and displays real-time data, delivers data files, and displays the system’s operating status to research personnel.Figure 1 provides a flow diagram for AirDAC.

AirDAC accepts initial configuration at startup. Two data files, for 15-s and 60-s data records, respectively, are created at the initial startup, and again at midnight of each subsequent day. The software reads DAQ, digital outputs (DO), alarm, and email configurations before it reads data from DAQ hardware every second in the main (DAC) loop. The acquired data are calculated using parameters and coefficients defined in the configuration, and averaged and saved every 15 s and 60 s into two separate data files.

The second loop, parallel to the DAC loop, displays real-time monitoring and control data, checks the measurement system, sends alarm and data emails, and accepts dynamic run-time re-configuration. The run-time configuration accepts sensor and measurement range changes, linear models for data correction (e.g. calibration curves), alarm and email settings, DAQ channel changes, DO settings, and sampling sequence and sampling cycle (sampling time and frequency) changes. Whenever a new configuration is applied, AirDAC automatically saves it in an Excel file.

AirDAC uses All-data Monitoring, visual alarm display, alarm emails, and 1-min data emails to ensure measurement quality control. AirDAC also allows automatic and manual controls over air sampling locations.

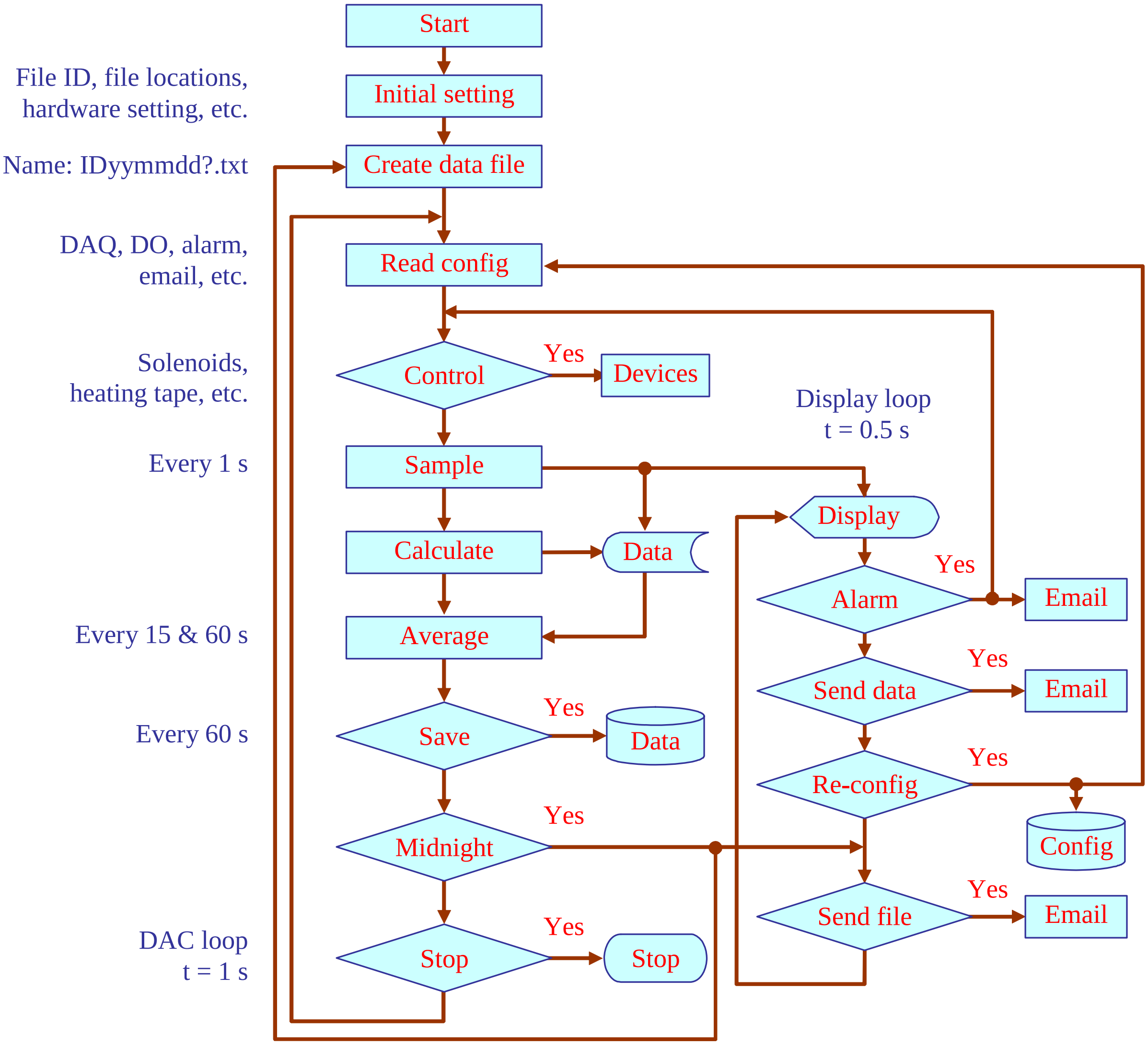


Figure 1. Flow diagram of AirDAC software.

3. Definitions

3.1.	AI	Analog input
3.2.	AirDAC	Air emission monitoring Data Acquisition and Control software, written in the LabVIEW programming language
3.3.	CPU	Central processing unit of a PC
3.4.	DAC	Data acquisition and control
3.5.	DAQ	Data acquisition
3.6.	Data reading	One data point read by AirDAC (i.e. every second).
3.7.	Data record	A single data point saved in data files by AirDAC. It is the average of either 15 or 60 1-s data readings.
3.8.	DIO	Digital input/output
3.9.	DO	Digital output
3.10.	GSS	Gas Sampling System (SOP G1)
3.11.	LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench. A platform and development environment for a visual programming language (a dataflow language), produced by NI
3.12.	MCC	Measurement Computing Corporation
3.13.	NI	National Instruments Corporation
3.14.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.15.	S	The signal output currently being received from an instrument
3.16.	Sampling cycle	The amount of time that the sampling system takes to scan through all the sampling locations, and return to the starting location. For example, the sampling cycle is 2 h (120 min) for a monitoring site with 12 locations, with a sampling time of 10 min each.
3.17.	Sampling frequency	The frequency of sampling at a particular sampling location relative to the sampling cycle. For example, when the ambient sample location is set at a sampling frequency of 1/3, it is sampled once every three sampling cycles.
3.18.	Sampling period	Duration of time used to sample at a certain location. For example, when the ambient sampling time is set at 20 min, it is sampled for 20 min before the sampling system switches to the next location.
3.19.	Sampling sequence	The sequence of sampling among different sample locations
3.20.	TC	Thermocouple
3.21.	USB	Universal serial bus
3.22.	X	The data converted from analog signals into engineering units based on sensor signal range and measurement range settings, or the data averaged from digital signals into percentage of time.
3.23.	Y	The adjusted X values after applying linear equations, which can be calibration curves. These are the data saved in data files.

4. Interferences

4.1. LabVIEW might be interfered with by other running software. One such interference was caused by the Purdue University wireless internet connection, Purdue Air Link. Other similar software may cause similar interferences. No solution, other than to avoid running other software while AirDAC is running, has been found.

4.2. Data reading may slow to more than 1 s if other major software is running and using a large percentage of the PC's CPU capacity. Close other software if the DAC loop time, displayed in the AirDAC front panel's M/C tab, shows an average of more than 1.000 s.

4.3. Electric static charges (e.g. from the operation of a >20 kV electrostatic space charge system for PM removal) may interfere with DAC hardware, DAC software, and computer operations. These static charges could also damage the DAC hardware. Properly shield the sensor signal wires, and ground the shield.

4.4. After the AirDAC startup, during which the configuration file is read, Excel will not show the "Save changes?" warning dialog (**Figure 2**) when an Excel workbook that has unsaved changes is being closed. Save open and unsaved Excel workbooks, close them, and close Excel. The problem will be solved when Excel is re-opened.

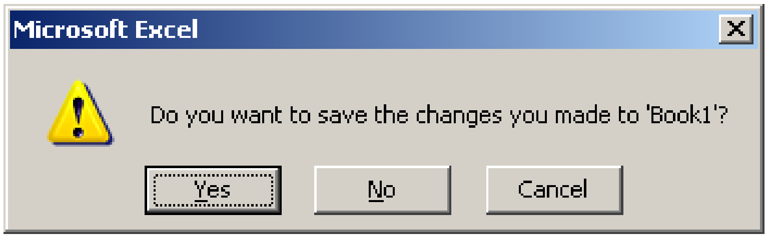

Do you want to save the changes you made to 'Book1'?

Figure 2. The Excel "Save changes" warning dialog box.

4.5. The number of data files automatically saved by AirDAC is limited to 27 per day, because the last character "?" in the data file names (IDsyyyymmdd?.txt and IDyyyymmdd?.txt) will become "|", and a Windows file name cannot contain this character. However, this only happens during AirDAC testing (during which the software may be restarted this many times in one day), and not during normal use.

4.5.1. If this situation happens, delete or remove some of the IDsyyyymmdd?.txt and IDyyyymmdd?.txt files for the day from the "Data" folder to restart AirDAC.

4.6. The LabVIEW email feature has been found to not work with some computers. More information about this can be found in the web page: http://digital.ni.com/public.nsf/allkb/42556976302AFF3C86256D7C0080AB5C). This may be related to the installation of Microsoft Windows XP Service Pack 2 (SP2). More information can be found in: http://support.microsoft.com/default.aspx?kbid=842242.

5. Personnel Qualifications

5.1. Most of these procedures assume a familiarity with the use of personal computers, general computer application software (e.g. MS Windows, MS Office), and a basic understanding of relevant data acquisition software, including Measurement & Automation Explorer and LabVIEW software.

5.2. LabVIEW Self-Paced Training (http://sine.ni.com/nips/cds/view/p/lang/en/nid/10450) or LabVIEW Basics I: Introduction (http://sine.ni.com/nips/cds/view/p/lang/en/nid/2241) is recommended.

5.3. All personnel operating AirDAC are required to read and understand this SOP.

5.4. If the DAC hardware includes MCC USB DIO devices, the operator is also required to read the instructions of those devices.

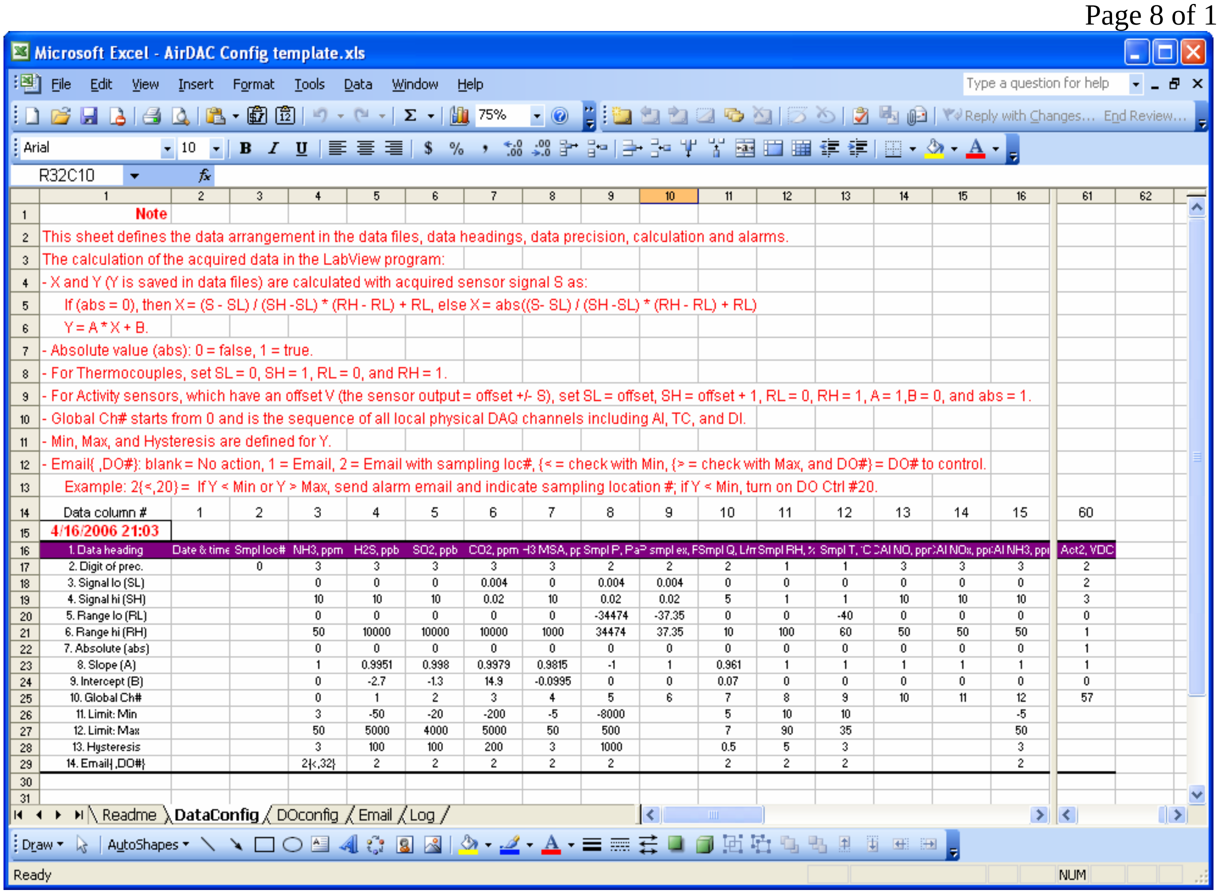
5.5. Only authorized personnel are allowed to work on AirDAC, or modify its configuration.

6. Equipment and Supplies

- 6.1. PC with 1.5 GHz or higher CPU speed, 512 MB or more RAM, and 80 GB or more hard disk space
- 6.2. Software
  - 6.2.1. Windows XP operating system
  - 6.2.2. LabVIEW version 7.1 (NI) and LabVIEW Report Generation Toolkit (NI)
  - 6.2.3. FieldPoint™ for FieldPoint RT Controllers (Version 4.1 or later) (NI)
  - 6.2.4. MCC DAQ Software (MCC), including InstaCal™ (Version 5.58 or later), TracerDAQ™ (Version 1.21 or later), and UL for LabVIEW
  - 6.2.5. AirDAC software, stored in C:\YYsiten\AirDAC\Program\
  - 6.2.6. AirDAQ Configuration file, stored in C:\YYsiten\AirDAC\Program\
- 6.3. FieldPoint modules (NI) connected to the computer and configured (SOP B1)
- 6.4. USB-based 96-bit digital I/O device with high current output (PCI-DIO96H, MCC) connected to the computer and configured

7. Procedures

- 7.1. Prepare AirDAQ configuration file
  - 7.1.1. Make a copy of the “AirDAC Config template.xls” file (**Figure 3**), provided by PAAQL, to C:\YYsiten\AirDAC\Program\. Rename it as “AirDAC Config *YYn*.xls”, where *YY* is the two-letter state abbreviation and *n* is a site-specific number.
  - 7.1.2. Modify the DataConfig, DOconfig, and Email sheets according to the Notes in the sheets, and modify the DAC design table according to SOP B1. Alternatively, these can be configured while running AirDAC (See Sections 7.3.9 – 7.3.17).
- 7.2. Test DAC hardware
  - 7.2.1. Locate the C:*YY*site*n*\AirDAC\Program*YY*site*n*.iak file in Windows Explorer, and double-click to run. Or run the Measurement & Automation Explorer from Windows Start->Programs->National Instrument->Measurement & Automation (Figure 4), then open the iak file from C:*YY*site*n*\AirDAC\Program*YY*site*n*.iak file. The iak file was generated during DAC hardware setup (See SOP B1 for details).
  - 7.2.2. Check each FieldPoint module to ensure that it is configured correctly, and that it is ready to acquire data.
  - 7.2.3. If modifications are made and need to be kept, save the *YY*site*n*.iak file.
- 7.3. Test and configure the AirDAC: Initial operation
  - 7.3.1. Run the C:*YY*site*n*\AirDAC\Program\AirDAC start.vi file by double-clicking it. An AirDAC start window (Figure 5) will open.
  - 7.3.2. Click Change to modify initial configurations. The Change button becomes Apply and save. In the “Initial setting” tab (Figure 5) enter a 2-letter data file ID.
  - 7.3.3. Check the “Wind direction” if wind direction measurement is included. Enter the wind direction column number, in which the wind direction data is saved in raw data files. Select the wind direction calculation method between “Scalar” (Webmet, 2005) and “Take last second” only. Enter the WD in degrees to correct wind sensor installation error. Measure the error from due north. For example, if the wind direction sensor shows due east when it should be due north, the error is 90°.



Note

This sheet defines the data arrangement in the data files, data headings, data precision, calculation and alarms.

The calculation of the acquired data in the LabView program:

- X and Y (Y is saved in data files) are calculated with acquired sensor signal S as:
    If (abs = 0), then X = (S - SL) / (SH -SL) * (RH - RL) + RL, else X = abs((S- SL) / (SH -SL) * (RH - RL) + RL)
    Y = A * X + B.
- Absolute value (abs): 0 = false, 1 = true.
- For Thermocouples, set SL = 0, SH = 1, RL = 0, and RH = 1.
- For Activity sensors, which have an offset V (the sensor output = offset +/- S), set SL = offset, SH = offset + 1, RL = 0, RH = 1, A = 1,B = 0, and abs = 1.
- Global Ch# starts from 0 and is the sequence of all local physical DAQ channels including AI, TC, and DI.
- Min, Max, and Hysteresis are defined for Y.
- Email{ ,DO#}: blank = No action, 1 = Email, 2 = Email with sampling loc#, {< = check with Min, {> = check with Max, and DO#} = DO# to control.
    Example: 2{<,20} = If Y < Min or Y > Max, send alarm email and indicate sampling location #; if Y < Min, turn on DO Ctrl #20.

Data column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	60
4/16/2006 21:03																
1. Data heading	Date & time	Smpl loc#	NH3, ppm	H2S, ppb	SO2, ppb	CO2, ppm	H3 MSA, pp	Smpl P, Pa	P smpl ex, F	Smpl Q, L/m	Smpl RH, %	Smpl T, °C	AI NO, ppm	AI NOx, ppb	AI NH3, ppm	Act2, VDC
2. Digit of prec.		0	3	3	3	3	3	2	2	2	1	1	3	3	3	2
3. Signal lo (SL)			0	0	0	0.004	0	0.004	0.004	0	0	0	0	0	0	2
4. Signal hi (SH)			10	10	10	0.02	10	0.02	0.02	5	1	1	10	10	10	3
5. Range lo (RL)			0	0	0	0	0	-34474	-37.35	0	0	-40	0	0	0	0
6. Range hi (RH)			50	10000	10000	10000	1000	34474	37.35	10	100	60	50	50	50	1
7. Absolute (abs)			0	0	0	0	0	0	0	0	0	0	0	0	0	1
8. Slope (A)			1	0.9951	0.998	0.9979	0.9815	-1	1	0.961	1	1	1	1	1	1
9. Intercept (B)			0	-2.7	-1.3	14.9	-0.0995	0	0	0.07	0	0	0	0	0	0
10. Global Ch#			0	1	2	3	4	5	6	7	8	9	10	11	12	57
11. Limit: Min			3	-50	-20	-200	-5	-8000		5	10	10			-5	
12. Limit: Max			50	5000	4000	5000	50	500		7	90	35			50	
13. Hysteresis			3	100	100	200	3	1000		0.5	5	3			3	
14. Email{ ,DO#}			2{<,32}	2	2	2	2	2		2	2	2			2	

Figure 3. The AirDAC Config template.xls file.

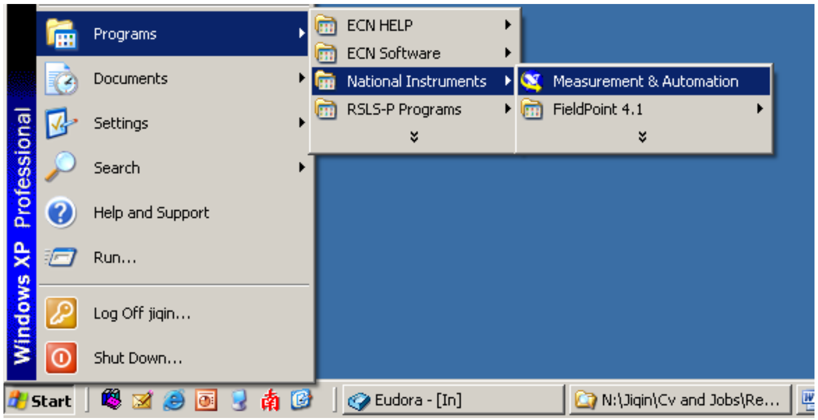


Figure 4. Run Measurement & Automation Explorer.

7.3.4. Locate the file. If necessary, click the 📂 button to browse.

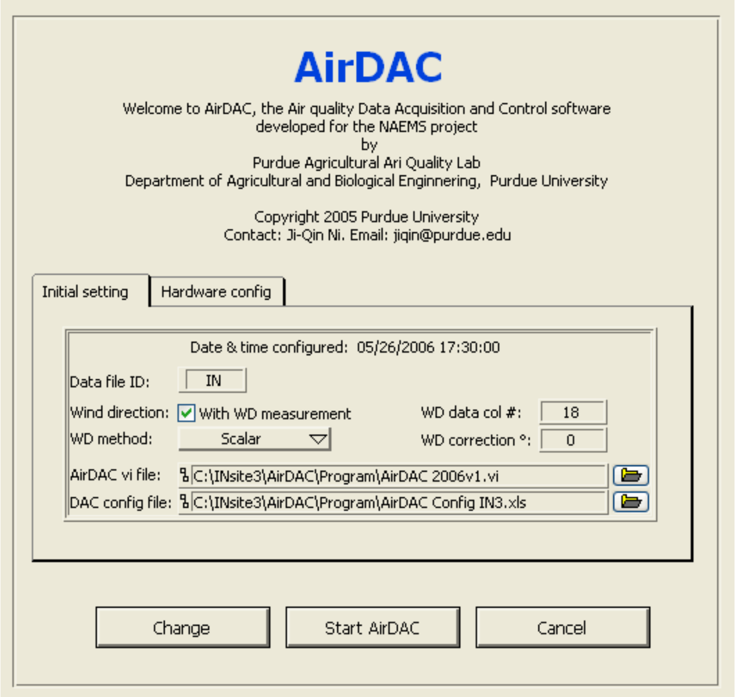
7.3.5. Click the “DAC hardware” tab (Figure 6). Select multiple FieldPoint modules of AI, TC and DO. Enter the USB device board number(s) (Refer to SOP B1 for the DAC hardware configuration and recorded board number(s)).

7.3.6. Click the [Apply and save] button to save the initial configuration.

7.3.7. To run AirDAC, click the [Start AirDAC] button in the AirDAC start screen (Figure 6). The front panel of the AirDAC will appear (Figure 7).

7.3.8. Activate the DAC tab (Figure 8). DAC table rows “1. Data heading” through “10.

Global ch #" are for data acquisition and calculation. Rows "11. Limit: Min" through "14. Email{ ,DO#}" are for measurement watch and device control. Rows "15. Signal" through "17. Adjusted (Y)" are for signal and calculated data monitoring.


AirDAC

Welcome to AirDAC, the Air quality Data Acquisition and Control software
developed for the NAEMS project
by
Purdue Agricultural Ari Quality Lab
Department of Agricultural and Biological Enginnering, Purdue University

Copyright 2005 Purdue University
Contact: Ji-Qin Ni. Email: jiqin@purdue.edu

Date & time configured: 05/26/2006 17:30:00

Data file ID: IN

Wind direction: ☑ With WD measurement

WD data col #: 18

WD method: Scalar

WD correction °: 0

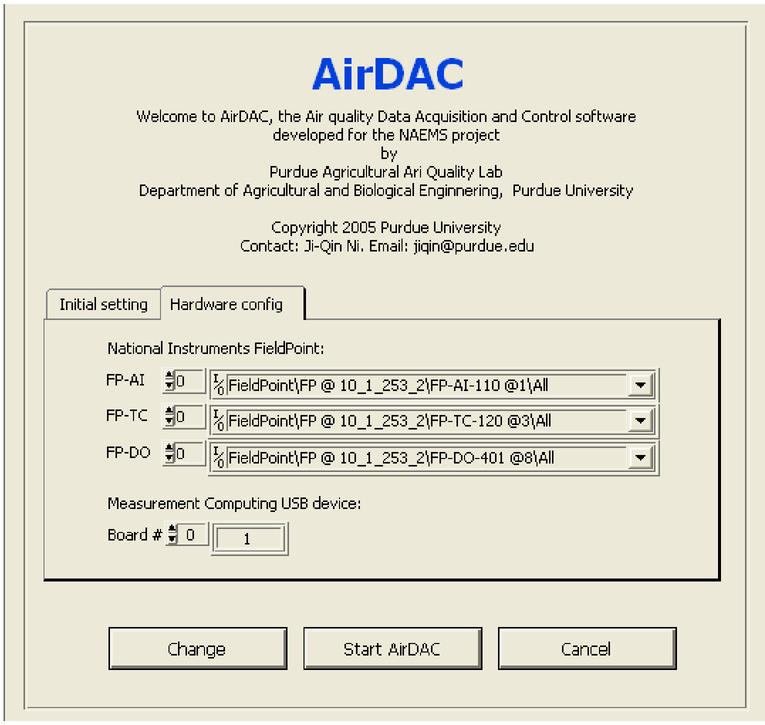
AirDAC vi file: C:\INsite3\AirDAC\Program\AirDAC 2006v1.vi

DAC config file: C:\INsite3\AirDAC\Program\AirDAC Config IN3.xls

Figure 5. AirDAC start.vi with initial setting display.

7.3.9. Fill in the table from row "1. Data heading" through row "14. Email{ ,DO#}" according to the DAC design table (SOP B1) and the instructions in the lower part of the DAQ tab in AirDAC (Figure 8). The units in "1. Data heading" are for the "16. Converted" and "17. Adjusted" values. Leave the cells from row 2 through 14 in column 1 blank. Leave the cells from row 3 through 14 in column 2 blank. Type "0" for column 2 row 2 (Figure 8).

7.3.9.1. Alternatively, fill in the table in the Excel file during Step 7.1 before running AirDAC.



AirDAC

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Contact: Ji-Qin Ni. Email: jiqin@purdue.edu

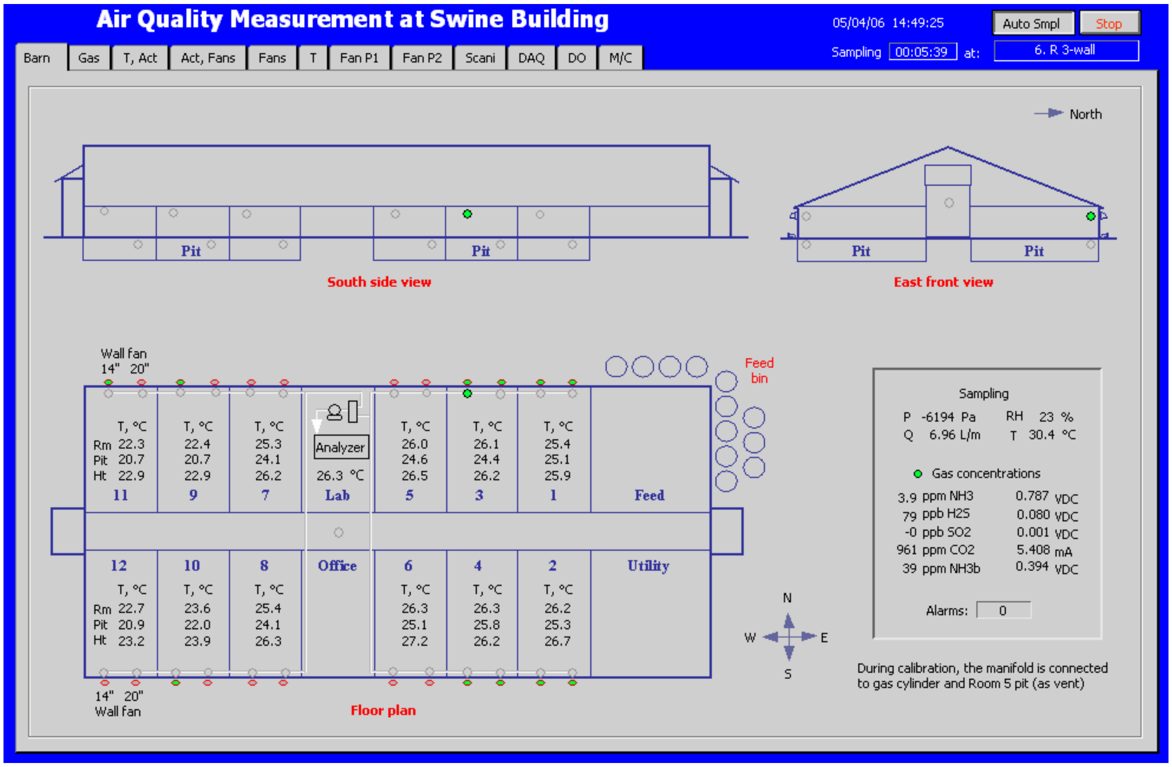
National Instruments FieldPoint:

FP-AI 0 FieldPoint\FP @ 10_1_253_2\FP-AI-110 @1\All
FP-TC 0 FieldPoint\FP @ 10_1_253_2\FP-TC-120 @3\All
FP-DO 0 FieldPoint\FP @ 10_1_253_2\FP-DO-401 @8\All

Measurement Computing USB device:

Board # 0 1

Figure 6. AirDAC start.vi with hardware configuration display.



Air Quality Measurement at Swine Building

05/04/06 14:49:25

Sampling 00:05:39 at: 6. R 3-wall

T, °C	11	9	7	5	3	1
Rm	22.3	22.4	25.3	26.0	26.1	25.4
Pit	20.7	20.7	24.1	24.6	24.4	25.1
Ht	22.9	22.9	26.2	26.5	26.2	25.9

Lab 26.3 °C

T, °C	12	10	8	6	4	2
Rm	22.7	23.6	25.4	26.3	26.3	26.2
Pit	20.9	22.0	24.1	25.1	25.8	25.3
Ht	23.2	23.9	26.3	27.2	26.2	26.7

Sampling

P -6194 Pa RH 23 %
Q 6.96 L/m T 30.4 °C

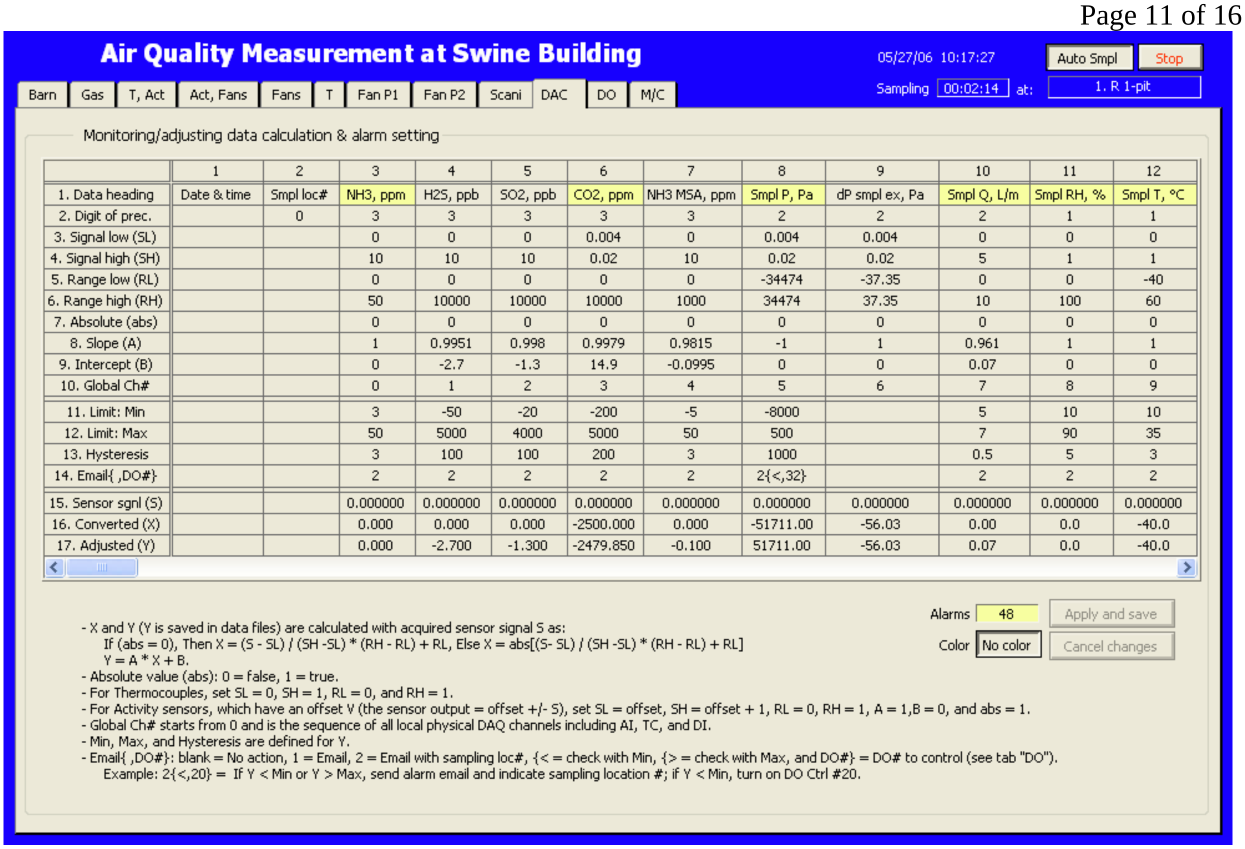
● Gas concentrations

3.9 ppm NH3	0.787	VDC
79 ppb H2S	0.080	VDC
-0 ppb SO2	0.001	VDC
961 ppm CO2	5.408	mA
39 ppm NH3b	0.394	VDC

Alarms: 0

During calibration, the manifold is connected to gas cylinder and Room 5 pit (as vent)

Figure 7. An example of the AirDAC front panel.



05/27/06 10:17:27

Sampling 00:02:14 at: 1. R 1-pit

Monitoring/adjusting data calculation & alarm setting

	1	2	3	4	5	6	7	8	9	10	11	12
1. Data heading	Date & time	Smpl loc#	NH3, ppm	H2S, ppb	SO2, ppb	CO2, ppm	NH3 MSA, ppm	Smpl P, Pa	dP smpl ex, Pa	Smpl Q, L/m	Smpl RH, %	Smpl T, °C
2. Digit of prec.		0	3	3	3	3	3	2	2	2	1	1
3. Signal low (SL)			0	0	0	0.004	0	0.004	0.004	0	0	0
4. Signal high (SH)			10	10	10	0.02	10	0.02	0.02	5	1	1
5. Range low (RL)			0	0	0	0	0	-34474	-37.35	0	0	-40
6. Range high (RH)			50	10000	10000	10000	1000	34474	37.35	10	100	60
7. Absolute (abs)			0	0	0	0	0	0	0	0	0	0
8. Slope (A)			1	0.9951	0.998	0.9979	0.9815	-1	1	0.961	1	1
9. Intercept (B)			0	-2.7	-1.3	14.9	-0.0995	0	0	0.07	0	0
10. Global Ch#			0	1	2	3	4	5	6	7	8	9
11. Limit: Min			3	-50	-20	-200	-5	-8000		5	10	10
12. Limit: Max			50	5000	4000	5000	50	500		7	90	35
13. Hysteresis			3	100	100	200	3	1000		0.5	5	3
14. Email{ ,DO#}			2	2	2	2	2	2{<,32}		2	2	2
15. Sensor sgnl (S)			0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
16. Converted (X)			0.000	0.000	0.000	-2500.000	0.000	-51711.00	-56.03	0.00	0.0	-40.0
17. Adjusted (Y)			0.000	-2.700	-1.300	-2479.850	-0.100	51711.00	-56.03	0.07	0.0	-40.0

Alarms 48

Color No color

- X and Y (Y is saved in data files) are calculated with acquired sensor signal S as:
  If (abs = 0), Then X = (S - SL) / (SH -SL) * (RH - RL) + RL, Else X = abs[(S- SL) / (SH -SL) * (RH - RL) + RL]
  Y = A * X + B.
- Absolute value (abs): 0 = false, 1 = true.
- For Thermocouples, set SL = 0, SH = 1, RL = 0, and RH = 1.
- For Activity sensors, which have an offset V (the sensor output = offset +/- S), set SL = offset, SH = offset + 1, RL = 0, RH = 1, A = 1,B = 0, and abs = 1.
- Global Ch# starts from 0 and is the sequence of all local physical DAQ channels including AI, TC, and DI.
- Min, Max, and Hysteresis are defined for Y.
- Email{ ,DO#}: blank = No action, 1 = Email, 2 = Email with sampling loc#, {< = check with Min, {> = check with Max, and DO#} = DO# to control (see tab "DO").
  Example: 2{<,20} = If Y < Min or Y > Max, send alarm email and indicate sampling location #; if Y < Min, turn on DO Ctrl #20.

Figure 8. An example of DAC tab in AirDAC showing some yellow-colored visual alarms when there was no DAC hardware connected.

7.3.10. Verify the entries and check the data displayed in rows 15 through 17 (S, X, and Y).

7.3.11. Click the “Apply and Save” button to save the configuration to the AirDAC Config *YY*Site*n*.xls file. When the “Apply and Save” and “Cancel changes” buttons become disabled (gray), the new configuration has been applied and saved.

7.3.12. Activate the DO tab (Figure 9). Click the “Change” button to activate the controls. Fill in the Name and Time, and select Control Type, Sequence, Frequency, and FP-DO channels based on the site monitoring plan, the GSS connection, and the instructions in the tab. Verify the entries and make sure that they are correct.

7.3.13. Click “Apply and Save” to save the configuration to the AirDAC Config *YY*Site*n*.xls file. When the “Apply and Save” and the “Cancel changes” buttons become disabled (gray), the new configuration has been applied and saved. Click the “Change” button to disable and protect the settings.

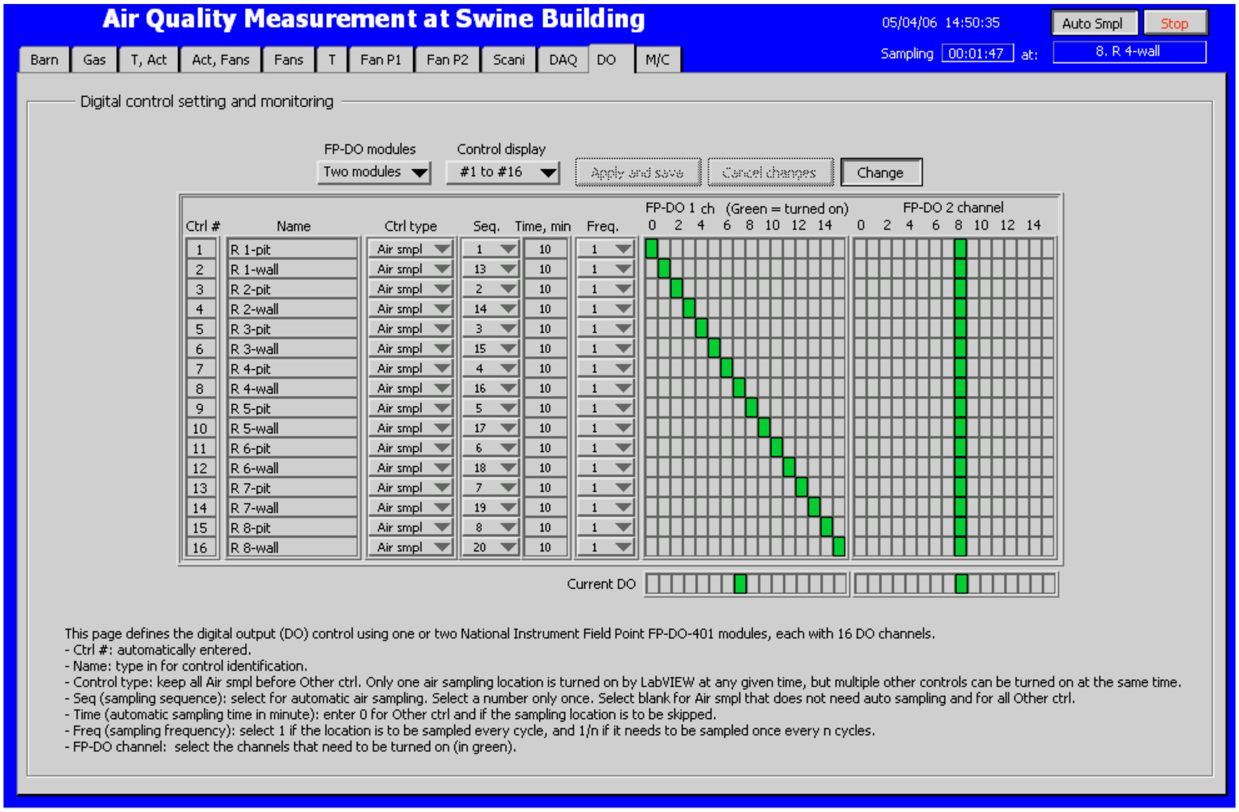
7.3.14. Activate the M/C tab (Figure 10). Fill in the Mail server & return address. Fill in the Email recipient’s address and define the email types that each recipient will receive.

7.3.15. Include odorair@ecn.purdue.edu as one of the data file recipients to deliver daily data files to PAAQL.

7.3.16. Verify the entries and make sure that they are correct.

7.3.17. Click the “Apply and Save” button to save the configuration to the AirDAC Config *YY*Site*n*.xls file. When the “Apply and Save” and the “Cancel changes” buttons become disabled (gray), the new configuration has been applied and saved.

7.3.18. To stop AirDAC, press the Stop button in the upper right corner of the front panel window. In the dialog window that appears, select OK.



05/04/06 14:50:35

Sampling 00:01:47 at: 8. R 4-wall

Digital control setting and monitoring

FP-DO modules: Two modules

Control display: #1 to #16

Ctrl #	Name	Ctrl type	Seq.	Time, min	Freq.
1	R 1-pit	Air smpl	1	10	1
2	R 1-wall	Air smpl	13	10	1
3	R 2-pit	Air smpl	2	10	1
4	R 2-wall	Air smpl	14	10	1
5	R 3-pit	Air smpl	3	10	1
6	R 3-wall	Air smpl	15	10	1
7	R 4-pit	Air smpl	4	10	1
8	R 4-wall	Air smpl	16	10	1
9	R 5-pit	Air smpl	5	10	1
10	R 5-wall	Air smpl	17	10	1
11	R 6-pit	Air smpl	6	10	1
12	R 6-wall	Air smpl	18	10	1
13	R 7-pit	Air smpl	7	10	1
14	R 7-wall	Air smpl	19	10	1
15	R 8-pit	Air smpl	8	10	1
16	R 8-wall	Air smpl	20	10	1

This page defines the digital output (DO) control using one or two National Instrument Field Point FP-DO-401 modules, each with 16 DO channels.
- Ctrl #: automatically entered.
- Name: type in for control identification.
- Control type: keep all Air smpl before Other ctrl. Only one air sampling location is turned on by LabVIEW at any given time, but multiple other controls can be turned on at the same time.
- Seq (sampling sequence): select for automatic air sampling. Select a number only once. Select blank for Air smpl that does not need auto sampling and for all Other ctrl.
- Time (automatic sampling time in minute): enter 0 for Other ctrl and if the sampling location is to be skipped.
- Freq (sampling frequency): select 1 if the location is to be sampled every cycle, and 1/n if it needs to be sampled once every n cycles.
- FP-DO channel: select the channels that need to be turned on (in green).

Figure 9. An example of DO tab in AirDAC.

7.4. Running AirDAC (subsequent operation): Repeat Steps 7.3.1 and 7.3.18.

7.5. AirDAC status and DAC system monitoring

7.5.1. When AirDAC is running, go to tab “M/C” (Figure 10). In “Monitoring”, verify the AirDAC loop timing. The “DAC loop t” should be 1.000 ± 0.005 s. The “Display loop t” should be 0.500 ± 0.005 s, except when AirDAC is sending email.

7.5.2. In “Monitoring” verify the AirDAC sample timing at the “sFile smpl” (which should count 15 sample numbers at 1 sample per s) and “mFile smpl” (which should count 60 sample numbers).

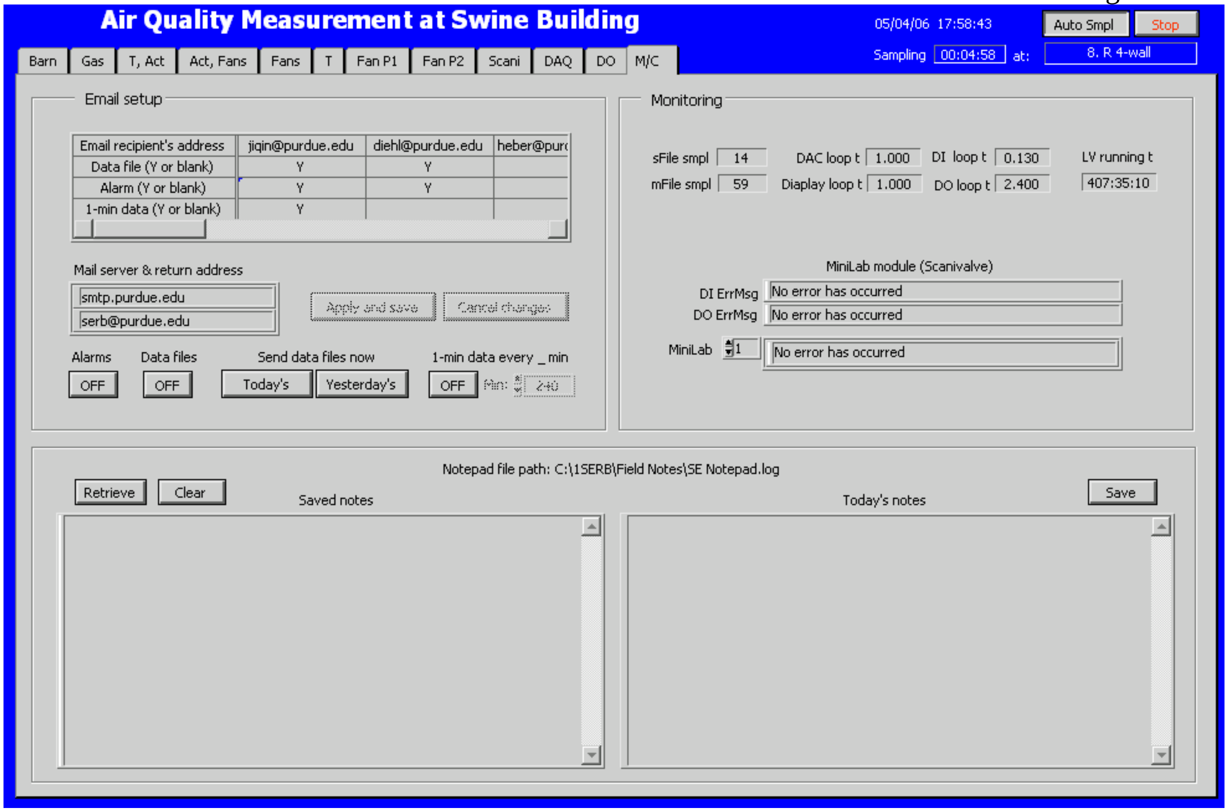
7.5.3. Verify the displays in the schematic representations of the barns (Figure 7).

7.5.4. Verify the other tabs for displayed measurement histories (Figure 11) to make sure that the DAC system is running properly.

7.6. Manual control of sampling locations

7.6.1. Click the Auto Smpl button at the upper right corner of the AirDAC front panel to switch to Manual Sampling. Click the Select... button that appears and select the location to be sampled (**Figure 12**).

7.6.2. To switch back to auto sampling, click the Manual Smpl button.



05/04/06 17:58:43

Sampling 00:04:58 at: 8. R 4-wall

Email recipient's address	jiqin@purdue.edu	diehl@purdue.edu	heber@pur
Data file (Y or blank)	Y	Y	
Alarm (Y or blank)	Y	Y	
1-min data (Y or blank)	Y		

Mail server & return address
smtp.purdue.edu
serb@purdue.edu

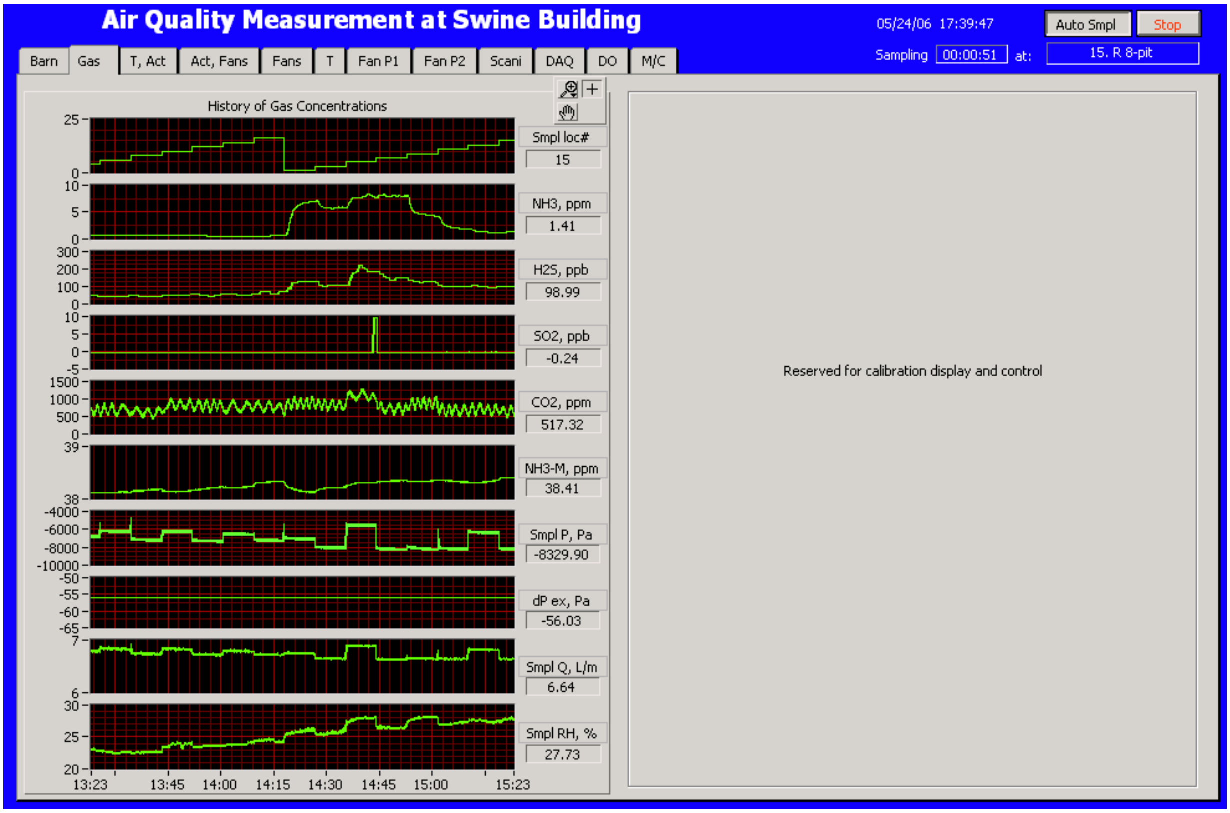
Min: 240

sFile smpl 14
mFile smpl 59
DAC loop t 1.000
Diaplay loop t 1.000
DI loop t 0.130
DO loop t 2.400
LV running t 407:35:10

DI ErrMsg No error has occurred
DO ErrMsg No error has occurred
MiniLab 1 No error has occurred

Notepad file path: C:\1SERB\Field Notes\SE Notepad.log

Figure 10. An example of M/C tab in AirDAC.



05/24/06 17:39:47

Sampling 00:00:51 at: 15. R 8-pit

Smpl loc# 15
NH3, ppm 1.41
H2S, ppb 98.99
SO2, ppb -0.24
CO2, ppm 517.32
NH3-M, ppm 38.41
Smpl P, Pa -8329.90
dP ex, Pa -56.03
Smpl Q, L/m 6.64
Smpl RH, % 27.73

Reserved for calibration display and control

Figure 11. An example of measurement history display in AirDAC.

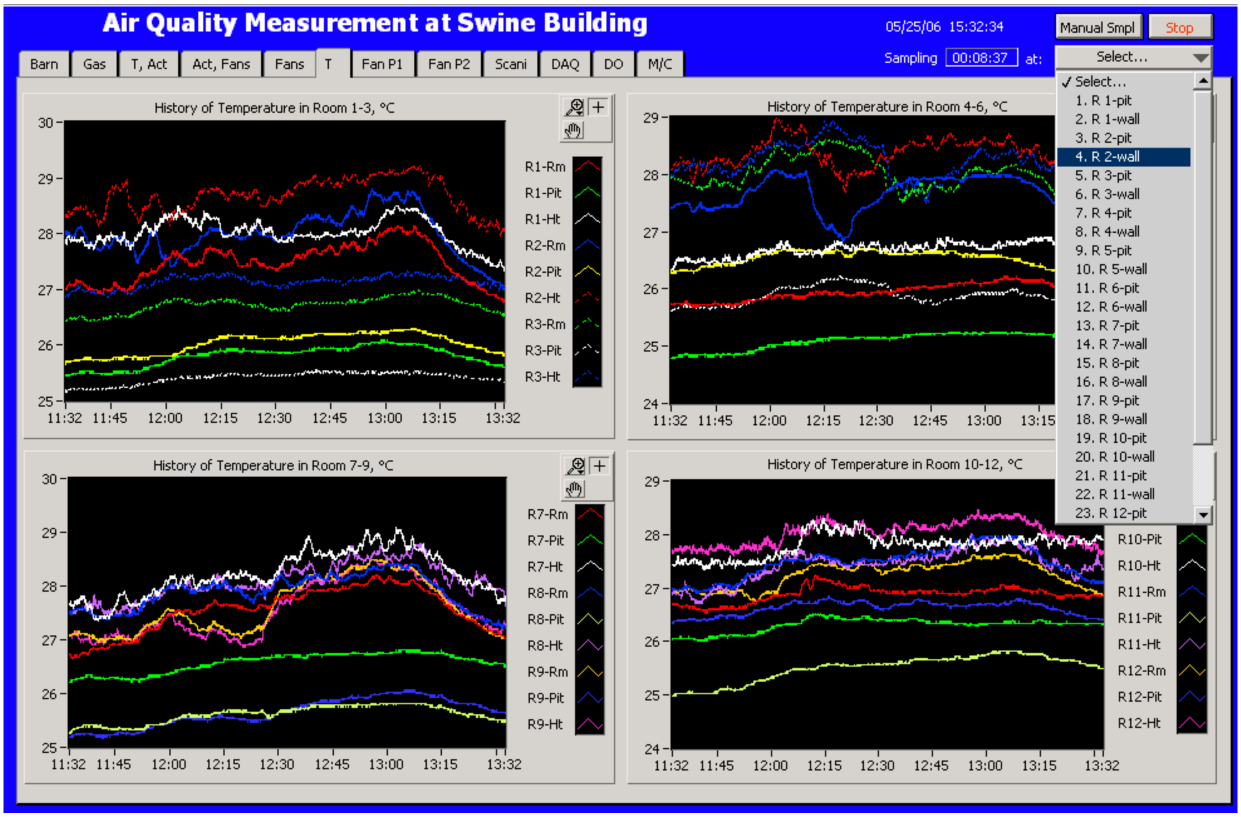


Figure 12. Manual control of sampling locations in AirDAC.

8. Data and Records Management

8.1. Save all AirDAC-related files in the folder C:*YY*site*n*\AirDAC\\.

8.2. AirDAC initial and hardware configuration files are automatically generated and saved in C:*YY*site*n*\AirDAC\Program\AirDAC ini.txt. All previous configurations are also kept in the same file for record keeping and data analysis purposes.

8.3. AirDAC data acquisition and control configuration data are updated and saved in AirDAC Config *YY*Site*n*.xls. All previous configurations are kept in the same file. It is recommended that this file be saved in C:*YY*site*n*\AirDAC\Program\\.

8.4. The daily data files will be saved in the folder C:\YYsiten\AirDAC\Data\\.

8.5. Manage all AirDAC-related files according to SOP B5.

9. Quality Control and Quality Assurance

9.1. Use the built-in features in AirDAC to ensure DAC consistency and quality.

9.2. Keep and backup old configuration files when creating new configuration files. When editing the files, avoid altering any configuration information related to real measurement.

9.3. Set up alarms (rows 11 to 13 in the DAC tab, Figure 8) for real-time monitoring of all primary measurement variables, and use the alarm email feature to provide an alert for any out-of-range values for these variables. Consult the QAPP to identify the primary measurement variables.

9.4. Because an absence of alarm emails does not necessarily mean that the system is running normally (especially when the internet connection or the computer fails, or the AirDAC is shut down), use the “1-min data file every _min” option (Figure 10) to constantly email partial measurement data at selected time intervals. Failure to receive these emails indicates internet or measurement system trouble.

9.5. Maintain all records in a worksheet of the designated electronic field notes spreadsheet. Record observations and changes that can affect the measurement data.

9.6. Save screen shots of the AirDAC front panel displays to a PowerPoint or MS Word file when any abnormality is noticed that would not be preserved in the 1-min data files. An example of this would be a certain temperature fluctuating more than a couple of degrees C every second. The information is vital to data analysis and interpretation, but non-reproducible. To copy screen, activate the AirDAC front panel, hold the “Alt” key and press the “Print Screen” key. To paste the screen, activate the PowerPoint or MS Word file. Hold the “Ctrl” key and press “V” key.

9.7. Include date at the end of file name in the following format: mm-dd-yy, ex: 01-09-06. Leading zeros in day and month can be omitted, ex. 1-9-06.

9.8. Check the DAC system at least daily, either during a site visit, or remotely.

  9.8.1. Always check for displayed alarms (Figure 7 and Figure 8).

  9.8.2. Use the Notepad function of AirDAC (Figure 10) to record important observations and findings, and to notify other research personnel.

9.9. Avoid running other software that utilizes significant CPU power and memory, because sampling by AirDAC might be slowed down.

9.10. Seek technical support from PAAQL for problems related to AirDAC.

9.11. Record and report all modifications made to electronic files. The note should include the time, name of personnel, observation, changes made, and the reason.

9.12. Verify the conversion and adjustment of data by AirDAC before starting data collection

  9.12.1. Apply a known voltage or current to an analog input channel in a FieldPoint module that is configured for voltage or current signals.

  9.12.2. Run AirDAC.

  9.12.3. Configure the signal range, measurement range, slope, and intercept in the DAC tab in AirDAC. Apply and Save the configuration.

  9.12.4. Watch the S, X, and Y values displayed in AirDAC, and check their mathematical relationship according to the equations provided in the DAC tab. If their relationship does not agree with the equations, contact PAAQL for troubleshooting.

  9.12.5. After saving the data for a few min, stop AirDAC and open the data file. Find the data column that includes the test data. Compare the saved data and the Y values displayed in AirDAC. If they are different, contact PAAQL for troubleshooting.

10. References

10.1. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.

10.2. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.

10.3. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.

10.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
10.5. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
10.6. SOP G1. 2006. Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
10.7. LabVIEW manuals. Available in C:\Program Files\National Instruments\LabVIEW 7.1\manuals\
10.8. Webmet. 2005.http://www.webmet.com/met_monitoring/621.html (accessed 06/2005)

11. Contact Information

11.1. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

11.2. National Instruments Corporation:
11500 N Mopac Expwy
Austin, TX 78759-3504
Technical Support: 800-531-5066.

11.3. Measurement Computing Corporation:
10 Commerce Way
Norton MA 02766
Phone: 508-946-5100
Fax: 508-946-9500
Email: info@mccdaq.com

11.4. Bugs found in the AirDAC program and suggested improvements can be directed by email (jiqin@purdue.edu) or phone (765-496-1733) to Ji-Qin Ni, Purdue University.

AIR DATA PRE-PROCESSING SOFTWARE
Standard Operating Procedure (SOP) B3

AIR DATA PRE-PROCESSING SOFTWARE

Standard Operating Procedure (SOP) B3

Prepared by

Ji-Qin Ni and Juan Carlos Ramirez

Reviewed by

Teng-Teeh Lim, Albert J. Heber and Bill W. Bogan

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

Page

1. Scope and Applicability

1.1. This method is used to inspect air emission data collected in livestock barns. Three levels of data review are used to ensure quality of barn air emission data.

1.1.1. Real-time data monitoring is performed by AirDAC during data acquisition, and by the field engineers or personnel accessing AirDAC, either at the site or remotely. Signals acquired from all analyzers and sensors are converted to engineering units, and compared with pre-determined normal ranges every second. Alarms can be shown immediately and sent via email by AirDAC to indicate any out-of-range data that might be collected (SOP B2).

1.1.2. Pre-processing of collected data into daily figures and mean value tables using Air Data Pre-Processing (ADPP) software is performed at any time after a day's data is collected. Data for related parameters are compared with each other; for instance, temperature versus barn airflow rate, and airflow versus pollutant concentrations. Hourly or daily means are compared with historical data.

1.1.3. Final processing of the complete dataset is conducted using CAPECAB (SOP B6).

1.2. This SOP describes only the second-level of data review (1.1.2) to provide timely feedback to field engineers to prevent and correct measurement errors or other problems.

1.3. This SOP applies specifically to the use of ADPP to preprocess data acquired and generated by the data acquisition and control software, AirDAC (SOP B2).

1.4. This SOP describes the June 2006 version of ADPP. Read update notes which will be supplies by PAAQL with updated versions of ADPP for additional instructions.

2. Summary of Method

The ADPP, a macro program contained in the Air Data Pre-Process.xls file, written in Visual Basic for Applications (Microsoft Corporation), was developed by PAAQL. The ADPP uses an Excel graph template to organize raw data, assemble one or more data files in a single day, and produce daily figures as defined in the template. The ADPP also uses precision check (or zero/span check) data (SOP G9) to adjust gas concentrations or other sensor data according to the degree of instrument drift determined by these checks. In addition, the program extracts equilibrium data from location-shared analyzers and sensors (LSAS), calculates daily mean values for rapid data evaluation, and assembles multi-day mean data in a result file (Fig. 1).

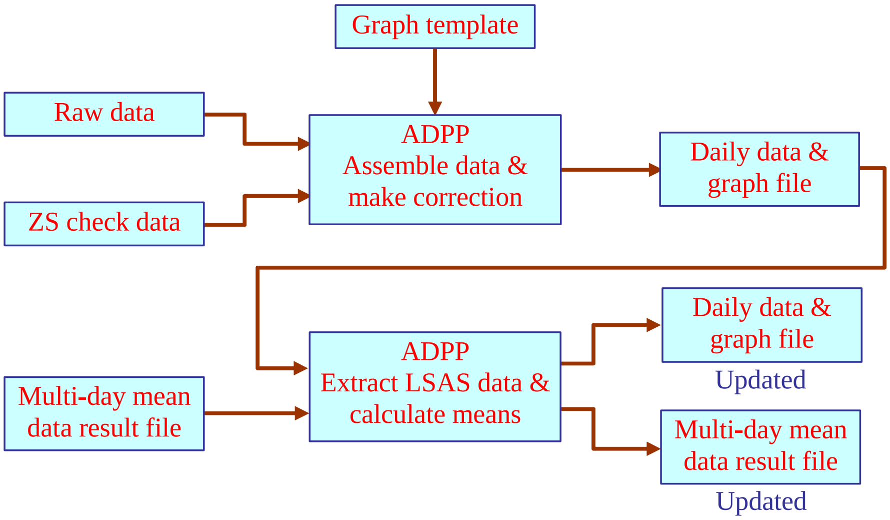


Figure 1. Data flow diagram when using ADPP to process data.

3. Definitions

3.1.	ADPP	Air Data Pre-Processing software, written in Visual Basic for Applications in MS Excel
3.2.	AirDAC	Air quality monitoring Data Acquisition and Control program, written in LabVIEW. The AirDAC program (SOP B2) is also used to display real-time data, deliver data via email, and provide information on the DAQ system's operation status to research personnel.
3.3.	DAQ	Data acquisition
3.4.	LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench. A platform and development environment for a visual programming language (a dataflow language), produced by National Instruments Corporation (Austin, TX)
3.5.	LSAS	Location-shared analyzers and sensors
3.6.	MS	Microsoft Corporation
3.7.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.8.	PC	Personal computer

4. Interferences

4.1. Interferences may occur if the computer running the ADPP is also running other software. This can result in a run-time error in the ADPP. If this occurs, it will be necessary to close other software before restarting ADPP.

5. Personnel Qualifications

5.1. Personnel must have good computer skills with MS Excel, including chart functions.

5.2. All personnel involved in data processing must read and understand this SOP, any updated information that has been supplied with newer versions of the software, and SOPs B1, B2, and B4 to know the methods of data acquisition and data processing.

5.3. Personnel involved in data inspection and review should have basic knowledge of AFO (animal feeding operation) emission measurement and the general ranges of measured variables, and understand the data patterns (e.g. diurnal and seasonal changes) and the relationship among the data (e.g. effect of ventilation on concentrations), so that they can correctly identify any field measurement problems.

6. Equipment and Supplies

6.1. PC with 1.5 GHz or higher CPU speed, 512 MB or more RAM, and 2 GB or more free hard disk space.

6.2. Software and files

6.2.1. Windows XP and MS Excel 2003

6.2.2. Air Data Pre-Process.xls file that contains the executable ADPP program

6.2.3. Site-specific graph template.xls, which is created by modifying the Graph template.xls file provided by PAAQL. This will store processed data and figures, and be used by ADPP for generating uniform daily data files.

6.2.4. Site-specific precision check data file, created by modifying the precision check data template.xls provided by PAAQL and containing precision check data generated during precision checks, to be used by ADPP for concentration data correction.

6.2.5. Site-specific Result.xls file, which is created by modifying the Result template.xls file provided by PAAQL, to store multi-day mean data processed by ADPP, and to store data graphs.

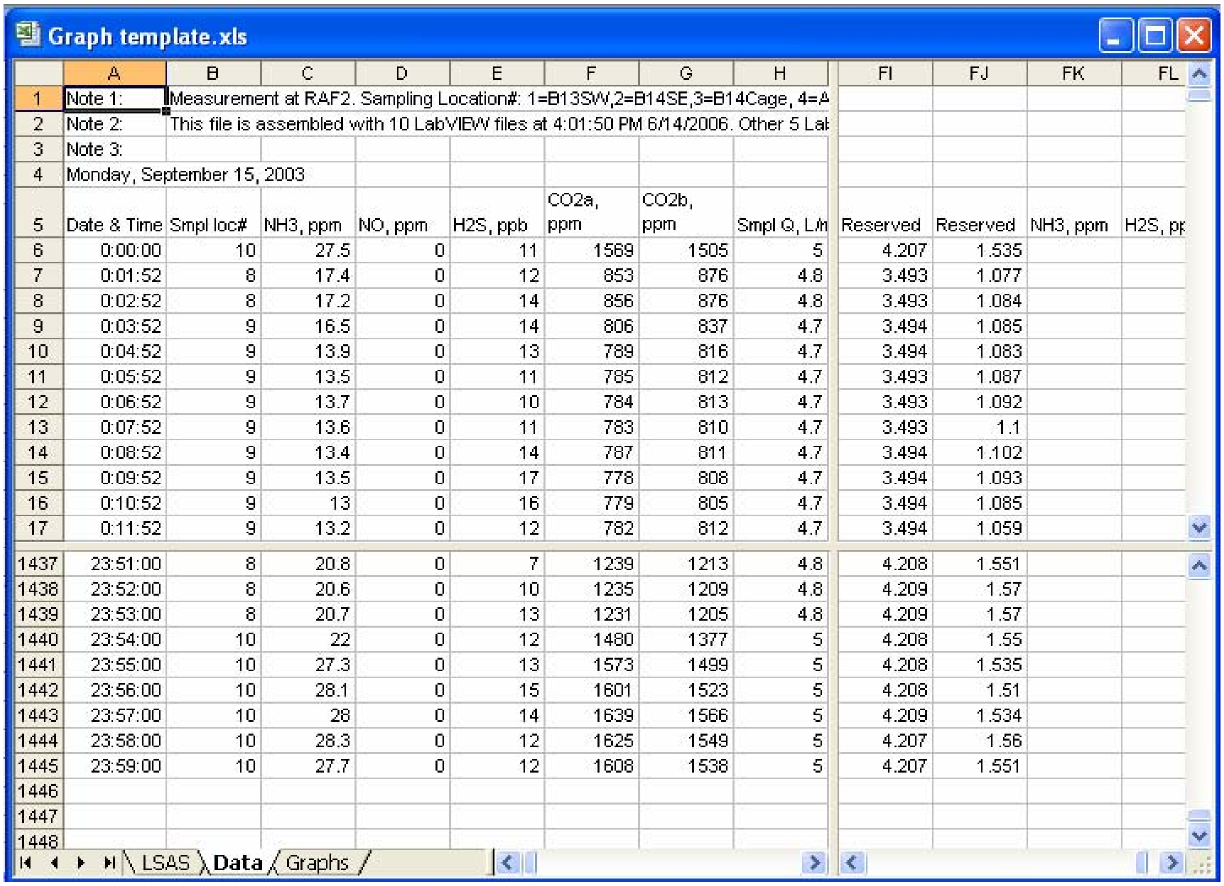
6.2.6. Raw data files in text format generated by AirDAC (SOP B2)

7. Procedure

7.1. Create a site-specific graph template Excel file

7.1.1. Every measurement site has a different data configuration. For example, some sites may have more air-sampling locations, and others may have more measured variables. The purpose of the site-specific template is to create graphs for all the important variables at a site, and organize them for easy review and comparison (for example, keeping all the LSAS data graphs close to the location code graph), while minimizing the number of graphs.

7.1.2. Create a new site-specific Excel template file, based on the existing template file Graph template.xls, which is provided by PAAQL (Fig. 2). Create a folder “ADPP” in C:*YYnX*\AirDAC\ and save the “Graph template.xls” as C:*YYnX*\AirDAC\ADPP\Graph *YYnX*.xls, where *YY* is the state abbreviation and *n* is the assigned site-specific number.

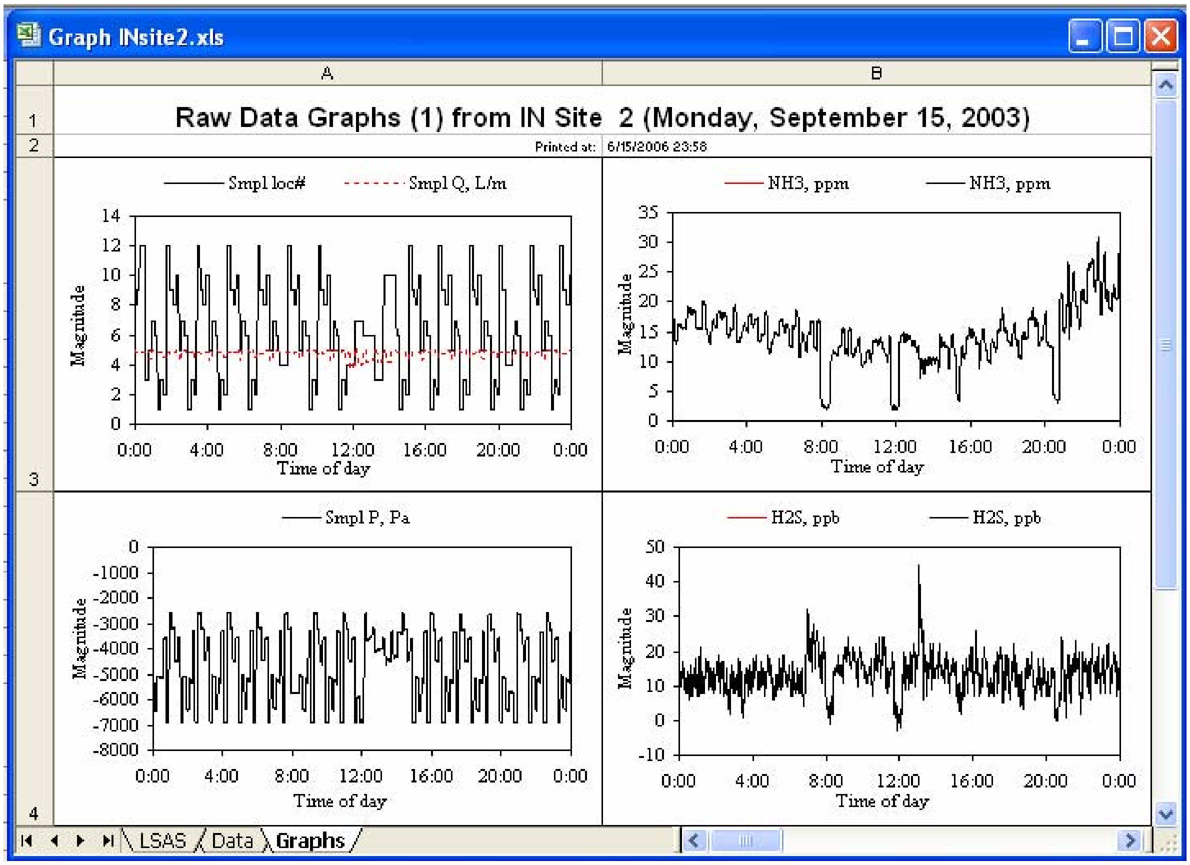


	A	B	C	D	E	F	G	H	FI	FJ	FK	FL
1	Note 1:	Measurement at RAF2. Sampling Location#: 1=B13SW,2=B14SE,3=B14Cage, 4=A										
2	Note 2:	This file is assembled with 10 LabVIEW files at 4:01:50 PM 6/14/2006. Other 5 Lal										
3	Note 3:											
4	Monday, September 15, 2003											
5	Date & Time	Smpl loc#	NH3, ppm	NO, ppm	H2S, ppb	CO2a, ppm	CO2b, ppm	Smpl Q, L/n	Reserved	Reserved	NH3, ppm	H2S, pp
6	0:00:00	10	27.5	0	11	1569	1505	5	4.207	1.535		
7	0:01:52	8	17.4	0	12	853	876	4.8	3.493	1.077		
8	0:02:52	8	17.2	0	14	856	876	4.8	3.493	1.084		
9	0:03:52	9	16.5	0	14	806	837	4.7	3.494	1.085		
10	0:04:52	9	13.9	0	13	789	816	4.7	3.494	1.083		
11	0:05:52	9	13.5	0	11	785	812	4.7	3.493	1.087		
12	0:06:52	9	13.7	0	10	784	813	4.7	3.493	1.092		
13	0:07:52	9	13.6	0	11	783	810	4.7	3.493	1.1		
14	0:08:52	9	13.4	0	14	787	811	4.7	3.494	1.102		
15	0:09:52	9	13.5	0	17	778	808	4.7	3.494	1.093		
16	0:10:52	9	13	0	16	779	805	4.7	3.494	1.085		
17	0:11:52	9	13.2	0	12	782	812	4.7	3.494	1.059		
1437	23:51:00	8	20.8	0	7	1239	1213	4.8	4.208	1.551		
1438	23:52:00	8	20.6	0	10	1235	1209	4.8	4.209	1.57		
1439	23:53:00	8	20.7	0	13	1231	1205	4.8	4.209	1.57		
1440	23:54:00	10	22	0	12	1480	1377	5	4.208	1.55		
1441	23:55:00	10	27.3	0	13	1573	1499	5	4.208	1.535		
1442	23:56:00	10	28.1	0	15	1601	1523	5	4.208	1.51		
1443	23:57:00	10	28	0	14	1639	1566	5	4.209	1.534		
1444	23:58:00	10	28.3	0	12	1625	1549	5	4.207	1.56		
1445	23:59:00	10	27.7	0	12	1608	1538	5	4.207	1.551		
1446												
1447												
1448												

Figure 2. Example of the “Data” worksheet in the “Graph template.xls” Excel file.

7.1.3. Select a range from cell B2 to cell in the last column of row 1442 of a complete raw data file. Copy this data range and paste it into the worksheet “Data” in the Graph *YYnX*.xls, starting from cell B5 (keeping the time in column A). Copy the date from cell A1 in the raw data file to cell A4 of the worksheet “Data” in the Graph *YYnX*.xls. In the first three rows in the template file, Note 1 is for sampling location codes, and will be copied from raw data files by ADPP. Note 2 will be generated automatically by ADPP. Note 3 is reserved for additional data processing information (Refer to Fig. 10 for an example).

7.1.4. Go to the worksheet “Graphs” of the Graph *YYnX*.xls. Make necessary modifications to the graphs, including the raw data graphs (Fig. 3) and the mean data graphs (Fig. 4), by creating new graphs, adding/deleting curves to be included in the graphs, adjusting graph format, and arranging the graphs for easy visual data inspection and comparison. Save the file.



Raw Data Graphs (1) from IN Site 2 (Monday, September 15, 2003)

Printed at: 6/15/2006 23:58

Figure 3. Example of the "Graphs" worksheet in graph template file.

7.1.5. The mean data graphs can also be modified after the LSAS mean data are generated in the worksheet "LSAS" by test-running the "Extract LSAS data & calculate means" feature in the ADPP (Section 7.5).

7.1.6. Create figures in the result file to plot mean data over days, weeks or months, so that variation can be monitored over all of these intervals.

7.2. Enable the "Print on Both Sides" function for raw graphs, if the printer has this option.

7.2.1. It is usually desirable to print the graphs as double-sided printouts to save paper and reduce the number of hardcopies. However, this command is not available in Visual Basic for Application. Sections 7.2.2 and 7.2.3 provide an example of enabling "print on both sides" in the template file using a HP Laser Jet 8000 Series PS printer.

7.2.2. Activate the Graph *YYnX*.xls file. Select File > Print.... to open the Print window (Fig. 5).

7.2.3. Select the printer Name. Click the "Properties…" button to activate the Properties window (Fig. 6). Select the "Layout" tab. Check "Portrait in Orientation" and "Flip on Long Edge" in "Print on Both Sides." Click "OK" to close the Properties window. Click "Close" to close the Print window. Save the Graph *YYnX*.xls file.

7.3. Prepare the analyzer precision check data file.

7.3.1. If gas concentration correction is to be performed by ADPP, prepare an Excel file for analyzer precision check data. This file can be created using the template file ZS check data template.xls provided by PAAQL (Fig. 7). Follow the Notes at the top of the sheet for the format requirements of the file. Data obtained during an analyzer precision check is described in SOP G9.

7.3.2. Save the file in the folder C:*YYnX*\Calibration\.

7.4. Perform "Assemble raw data and make correction."

7.4.1. Open the macro file (Air Data Pre-process.xls). If the Security Warning window (Fig. 8) appears, click "Enable Macros."

7.4.2. Click on the Start button in the "Start" worksheet when the Excel file opens. A user form "Select project and process" appears (Fig. 9).

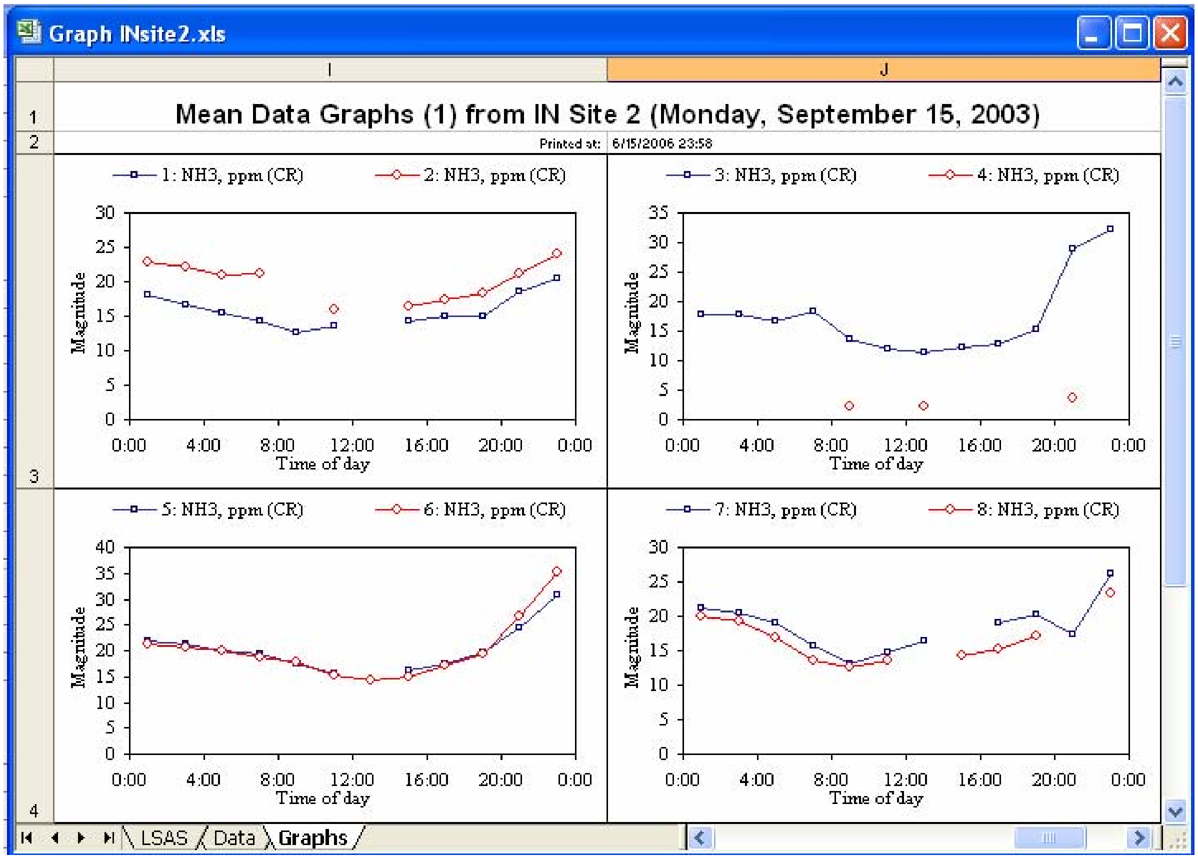
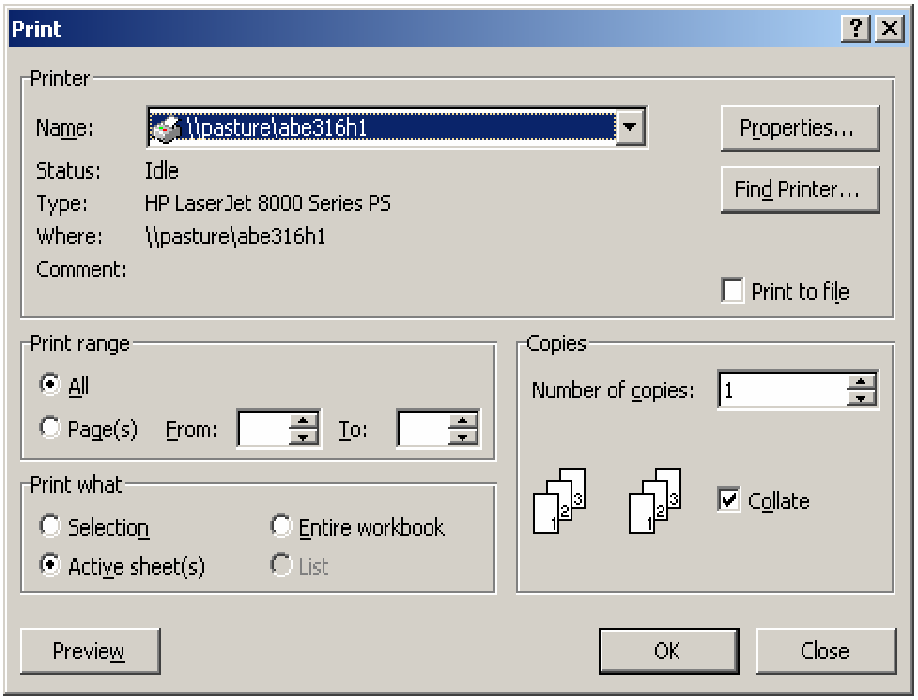


Figure 4. Example of the mean data graphs showing the calculated ammonia concentrations at sampling locations #1 - #8.



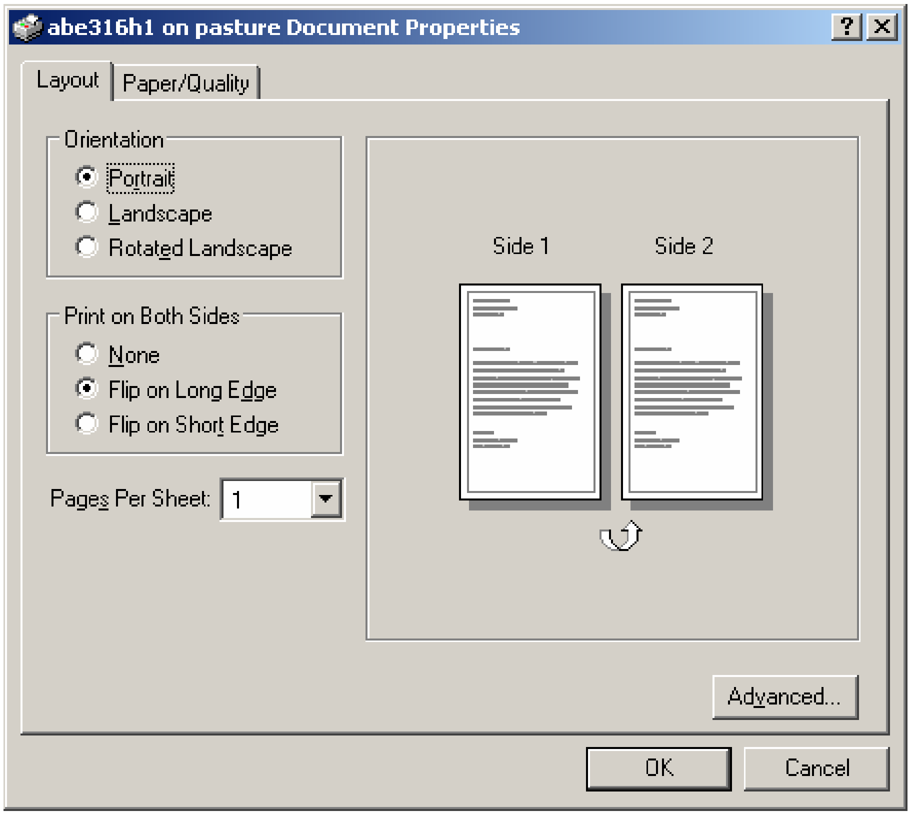
Name: \\pasture\abe316h1
Status: Idle
Type: HP LaserJet 8000 Series PS
Where: \\pasture\abe316h1
Comment:
☐ Print to file

● All
○ Page(s) From: To:

Number of copies: 1
☑ Collate

○ Selection
● Active sheet(s)
○ Entire workbook
○ List

Figure 5. An example of the Print window to setup printer properties.

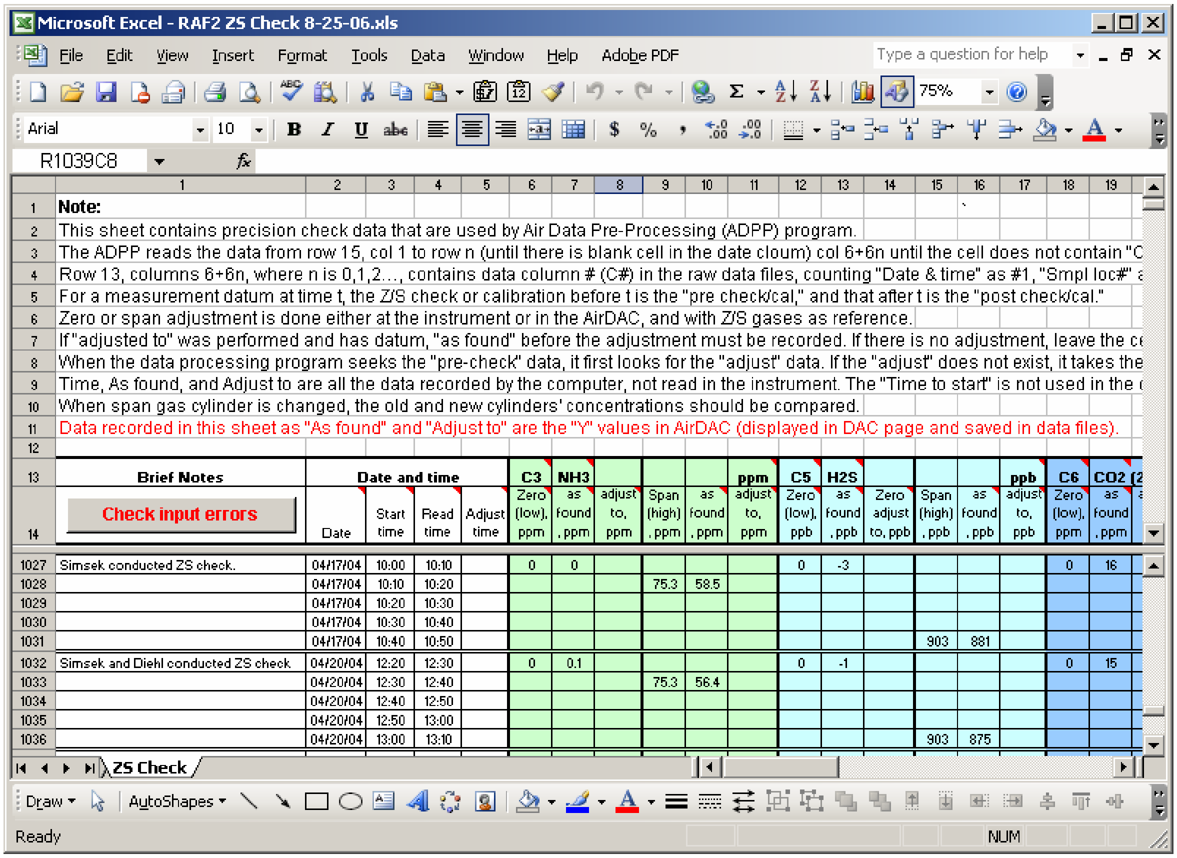


● Portrait
○ Landscape
○ Rotated Landscape

○ None
● Flip on Long Edge
○ Flip on Short Edge

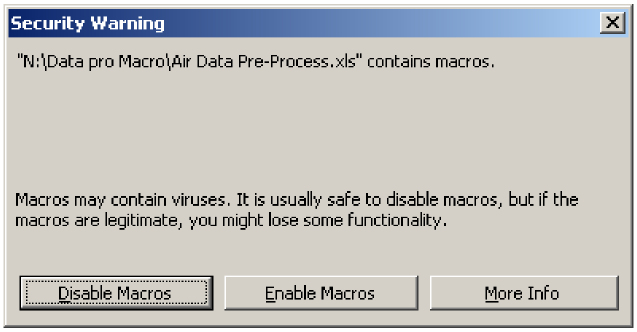
Pages Per Sheet: 1

Figure 6. An example of setting up the printer properties window.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	**Note:**																		
2	This sheet contains precision check data that are used by Air Data Pre-Processing (ADPP) program.																		
3	The ADPP reads the data from row 15, col 1 to row n (until there is blank cell in the date cloum) col 6+6n until the cell does not contain "C																		
4	Row 13, columns 6+6n, where n is 0,1,2..., contains data column # (C#) in the raw data files, counting "Date & time" as #1, "Smpl loc#" a																		
5	For a measurement datum at time t, the Z/S check or calibration before t is the "pre check/cal," and that after t is the "post check/cal."																		
6	Zero or span adjustment is done either at the instrument or in the AirDAC, and with Z/S gases as reference.																		
7	If "adjusted to" was performed and has datum, "as found" before the adjustment must be recorded. If there is no adjustment, leave the ce																		
8	When the data processing program seeks the "pre-check" data, it first looks for the "adjust" data. If the "adjust" does not exist, it takes the																		
9	Time, As found, and Adjust to are all the data recorded by the computer, not read in the instrument. The "Time to start" is not used in the (																		
10	When span gas cylinder is changed, the old and new cylinders' concentrations should be compared.																		
11	Data recorded in this sheet as "As found" and "Adjust to" are the "Y" values in AirDAC (displayed in DAC page and saved in data files).																		
12																			
13	**Brief Notes**	**Date and time**				**C3**	**NH3**				**ppm**	**C5**	**H2S**				**ppb**	**C6**	**CO2 (2**
14	Check input errors	Date	Start time	Read time	Adjust time	Zero (low), ppm	as found , ppm	adjust to, ppm	Span (high) , ppm	as found , ppm	adjust to, ppm	Zero (low), ppb	as found , ppb	Zero adjust to, ppb	Span (high) , ppb	as found , ppb	adjust to, ppb	Zero (low), ppm	as found , ppm
1027	Simsek conducted ZS check.	04/17/04	10:00	10:10		0	0					0	-3					0	16
1028		04/17/04	10:10	10:20					75.3	58.5									
1029		04/17/04	10:20	10:30															
1030		04/17/04	10:30	10:40															
1031		04/17/04	10:40	10:50											903	881			
1032	Simsek and Diehl conducted ZS check	04/20/04	12:20	12:30		0	0.1					0	-1					0	15
1033		04/20/04	12:30	12:40					75.3	56.4									
1034		04/20/04	12:40	12:50															
1035		04/20/04	12:50	13:00															
1036		04/20/04	13:00	13:10											903	875			

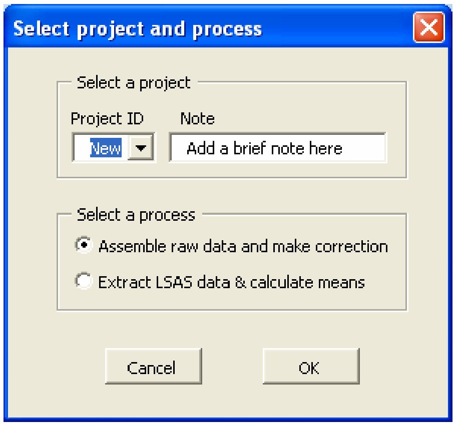
Figure 7. Example of the analyzer precision check or zero/span check data file.



"N:\Data pro Macro\Air Data Pre-Process.xls" contains macros.

Macros may contain viruses. It is usually safe to disable macros, but if the macros are legitimate, you might lose some functionality.

Figure 8. The Security Warning window after opening the macro file.



Select project and process

Select a project

Project ID: New

Note: Add a brief note here

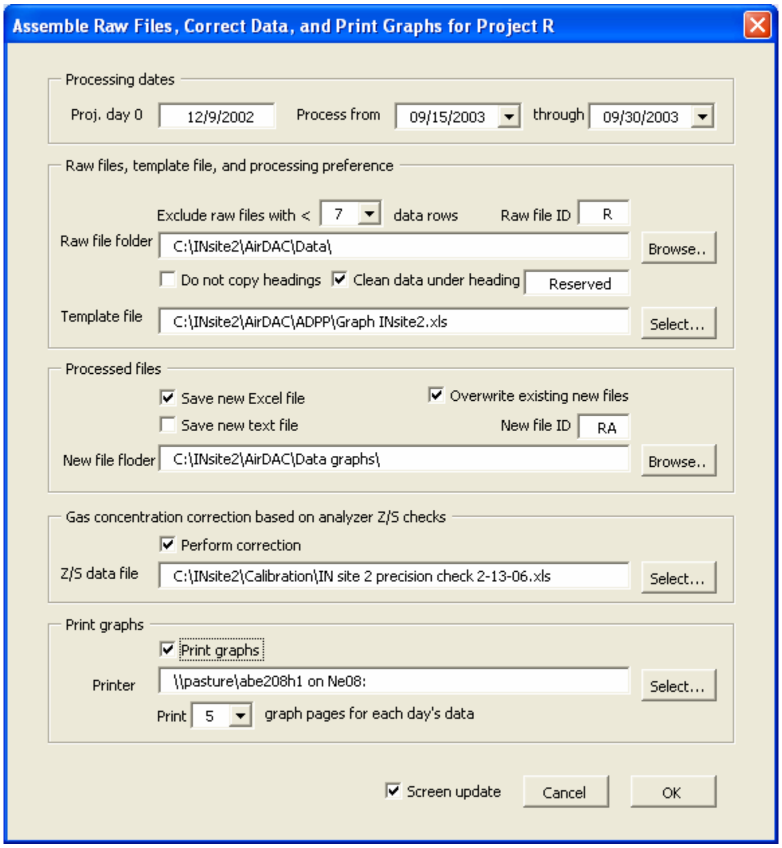
Select a process

● Assemble raw data and make correction

○ Extract LSAS data & calculate means

Figure 9. The "Select a project and process" user form.

7.4.3. At the initial use, select "New" in "Project ID" and type in a 2-letter and 1-digit site ID (for example "IN2"). Type in a brief note in the "Note" (for example "Indiana Site at RAF2") in the "Select a project." Select "Assemble raw data and make correction" in the "Select a process" and click OK. A new user form "Assemble Raw Files, Correct Data, and Print Graphs" appears (Fig. 10). In subsequent uses, the project ID and note entered in this step will appear as default values.



Assemble Raw Files, Correct Data, and Print Graphs for Project R

Processing dates

Proj. day 0: 12/9/2002 Process from: 09/15/2003 through: 09/30/2003

Raw files, template file, and processing preference

Exclude raw files with < 7 data rows Raw file ID: R

Raw file folder: C:\INsite2\AirDAC\Data\

☐ Do not copy headings ☑ Clean data under heading: Reserved

Template file: C:\INsite2\AirDAC\ADPP\Graph INsite2.xls

Processed files

☑ Save new Excel file ☑ Overwrite existing new files

☐ Save new text file New file ID: RA

New file floder: C:\INsite2\AirDAC\Data graphs\

Gas concentration correction based on analyzer Z/S checks

☑ Perform correction

Z/S data file: C:\INsite2\Calibration\IN site 2 precision check 2-13-06.xls

Print graphs

☑ Print graphs

Printer: \\pasture\abe208h1 on Ne08:

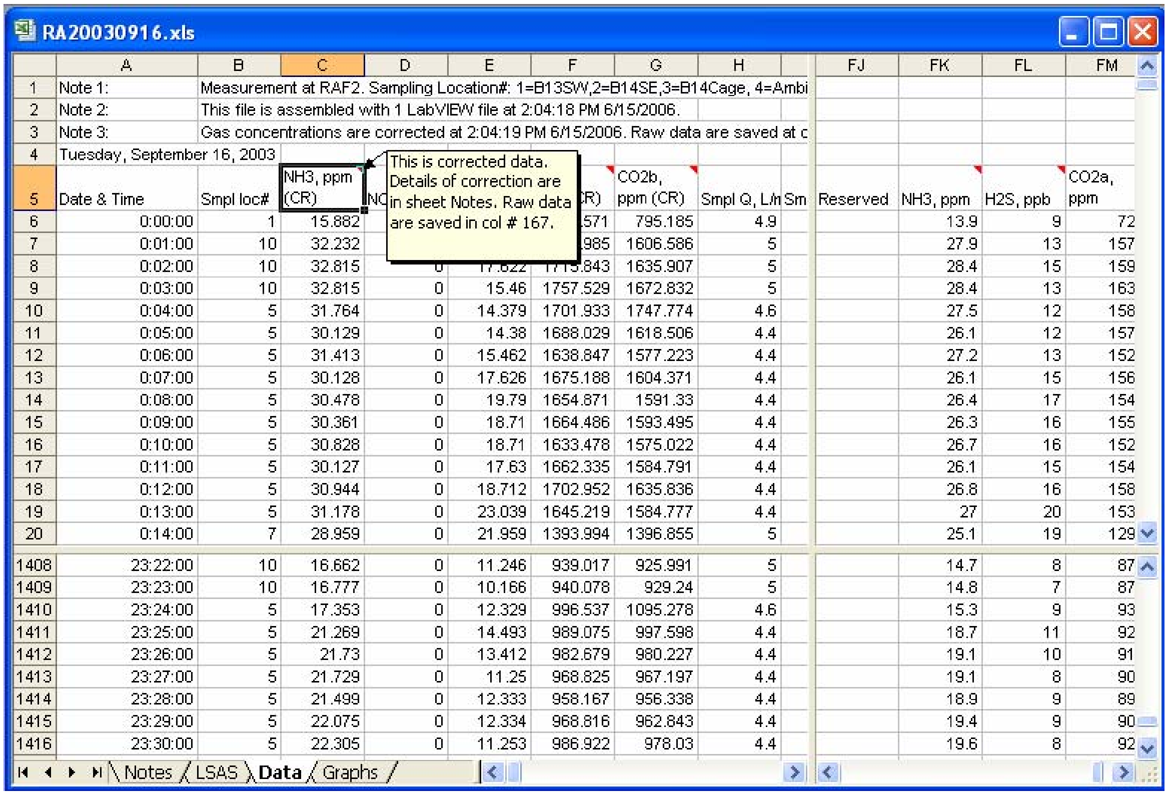
Print 5 graph pages for each day's data

☑ Screen update

Figure 10. The "Assemble Raw Files, Correct Data, and Print Graphs" user form.

7.4.4. Configure processing settings in the “Assemble Raw Files, Correct Data, and Print Graphs” form.

- 7.4.4.1. Processing dates
  - 7.4.4.1.1. Type in the project’s starting day (day 0) using format “m/d/yyyy.”
  - 7.4.4.1.2. Select the dates to process in “Process from” and “through” list boxes.
- 7.4.4.2. Raw files, template files, and processing preference
  - 7.4.4.2.1. Select the minimum number of data rows required, in order to exclude from processing any raw data files that contain too few data.
  - 7.4.4.2.2. Type a data file ID in “Raw file ID” (for example, “RA” for raw data files RA*yyyymmddx*.txt, where *yyyymmdd* are year, month and date, and *x* is the file serial letter of the day).
  - 7.4.4.2.3. Select the raw data file folder by clicking the “Browse…” button.
  - 7.4.4.2.4. Check “Do not copy headings” to keep the data headings in the template file. Otherwise, the headings of the first file of the day will be used.
  - 7.4.4.2.5. Check “Clean data under heading”, and type in the heading to remove useless data and reduce processed data file size.
  - 7.4.4.2.6. Find the template file by clicking the “Select…” button.
- 7.4.4.3. Processed files
  - 7.4.4.3.1. Check “Save new Excel file” and “Save new text file” if these files are to be saved. The new Excel file will contain daily graphs and processed results. The new text file will only contain 1-min data from the “Data” worksheet.
  - 7.4.4.3.2. Enter the “New file ID”, which should be a 2-letter ID if the new text files are to be further processed by the CAPECAB data processing software (SOP B6).
  - 7.4.4.3.3. Check “Overwrite existing new files” if desired.
  - 7.4.4.3.4. Select the folder to save the new files by clicking “Browse…”
- 7.4.4.4. Gas concentration correction based on analyzer precision checks
  - 7.4.4.4.1. Check “Perform correction” if gas concentrations are to be corrected.
  - 7.4.4.4.2. Select the precision data file by clicking “Select…” Corrected gas concentrations will be saved in the original data column, and the raw data will be moved to the right side of the sheet in the new Excel graph data file. Comments will be added in the headings of the relevant data columns (Fig. 11) and a sheet “Notes” will be added during processing.
  - 7.4.4.4.3. Gas concentration data correction requires two sets of precision check data, as only measurements made between two checks can be adjusted. Since gas analyzer precision checks are usually not conducted daily, gas concentration data cannot be corrected until the post-measurement precision check is conducted. If necessary, process the data twice using the ADPP. The first of these provides a quick data review/feedback; the second, with two complete precision check datasets, provides actual data assessment.



	A	B	C	D	E	F	G	H		FJ	FK	FL	FM
1	Note 1:	Measurement at RAF2. Sampling Location#: 1=B13SW,2=B14SE,3=B14Cage, 4=Ambi											
2	Note 2:	This file is assembled with 1 LabVIEW file at 2:04:18 PM 6/15/2006.											
3	Note 3:	Gas concentrations are corrected at 2:04:19 PM 6/15/2006. Raw data are saved at c											
4	Tuesday, September 16, 2003												
5	Date & Time	Smpl loc#	NH3, ppm (CR)	NC		R)	CO2b, ppm (CR)	Smpl Q, L/m	Sm	Reserved	NH3, ppm	H2S, ppb	CO2a, ppm
6	0:00:00	1	15.882			571	795.185	4.9			13.9	9	72
7	0:01:00	10	32.232			985	1606.586	5			27.9	13	157
8	0:02:00	10	32.815	0	17.622	1715.843	1635.907	5			28.4	15	159
9	0:03:00	10	32.815	0	15.46	1757.529	1672.832	5			28.4	13	163
10	0:04:00	5	31.764	0	14.379	1701.933	1747.774	4.6			27.5	12	158
11	0:05:00	5	30.129	0	14.38	1688.029	1618.506	4.4			26.1	12	157
12	0:06:00	5	31.413	0	15.462	1638.847	1577.223	4.4			27.2	13	152
13	0:07:00	5	30.128	0	17.626	1675.188	1604.371	4.4			26.1	15	156
14	0:08:00	5	30.478	0	19.79	1654.871	1591.33	4.4			26.4	17	154
15	0:09:00	5	30.361	0	18.71	1664.486	1593.495	4.4			26.3	16	155
16	0:10:00	5	30.828	0	18.71	1633.478	1575.022	4.4			26.7	16	152
17	0:11:00	5	30.127	0	17.63	1662.335	1584.791	4.4			26.1	15	154
18	0:12:00	5	30.944	0	18.712	1702.952	1635.836	4.4			26.8	16	158
19	0:13:00	5	31.178	0	23.039	1645.219	1584.777	4.4			27	20	153
20	0:14:00	7	28.959	0	21.959	1393.994	1396.855	5			25.1	19	129
1408	23:22:00	10	16.662	0	11.246	939.017	925.991	5			14.7	8	87
1409	23:23:00	10	16.777	0	10.166	940.078	929.24	5			14.8	7	87
1410	23:24:00	5	17.353	0	12.329	996.537	1095.278	4.6			15.3	9	93
1411	23:25:00	5	21.269	0	14.493	989.075	997.598	4.4			18.7	11	92
1412	23:26:00	5	21.73	0	13.412	982.679	980.227	4.4			19.1	10	91
1413	23:27:00	5	21.729	0	11.25	968.825	967.197	4.4			19.1	8	90
1414	23:28:00	5	21.499	0	12.333	958.167	956.338	4.4			18.9	9	89
1415	23:29:00	5	22.075	0	12.334	968.816	962.843	4.4			19.4	9	90
1416	23:30:00	5	22.305	0	11.253	986.922	978.03	4.4			19.6	8	92

This is corrected data. Details of correction are in sheet Notes. Raw data are saved in col # 167.

Figure 11. Original and adjusted gas concentrations in the Excel graph file.

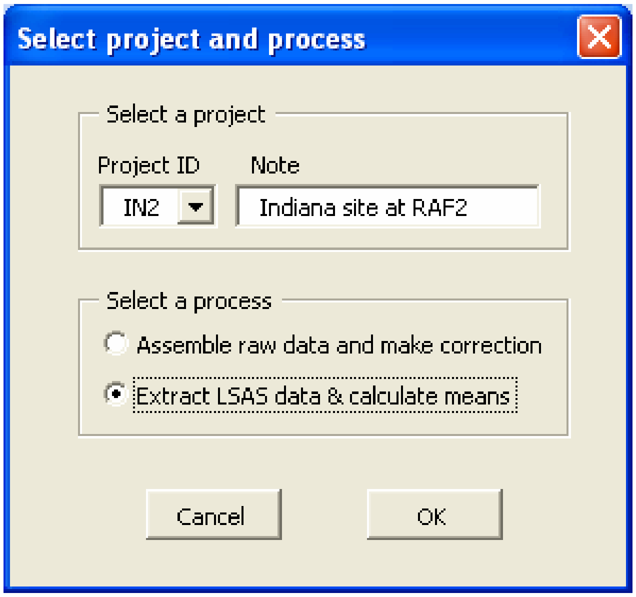
7.4.4.5. Printing graphs:
  7.4.4.5.1. Check “Print graphs” if the figures in the “Graphs” sheet are to be printed.
  7.4.4.5.2. Select the printer by clicking the “Select…” button.
  7.4.4.5.3. Select the number of pages to be printed, based on the template file configuration.

7.4.5. Check “Screen update” if the processing is to be monitored. More time will be required to finish the data pre-processing if this option is selected. When all settings are correctly made, click “OK” to start processing.

7.5. Perform “Extract LSAS data and calculate means.”

7.5.1. After the “Assemble raw data and make correction” process is completed, ADPP can be used to extract the equilibrated data from LSAS (mainly gas analyzers and sensors in the GSS) and to calculate mean data.

7.5.2. Repeat the steps in Sections 7.4.1 (if the macro file is to be opened) and 7.4.2. The “Select project and process” user form appears (Fig. 12).



Project ID: IN2

Note: Indiana site at RAF2

○ Assemble raw data and make correction

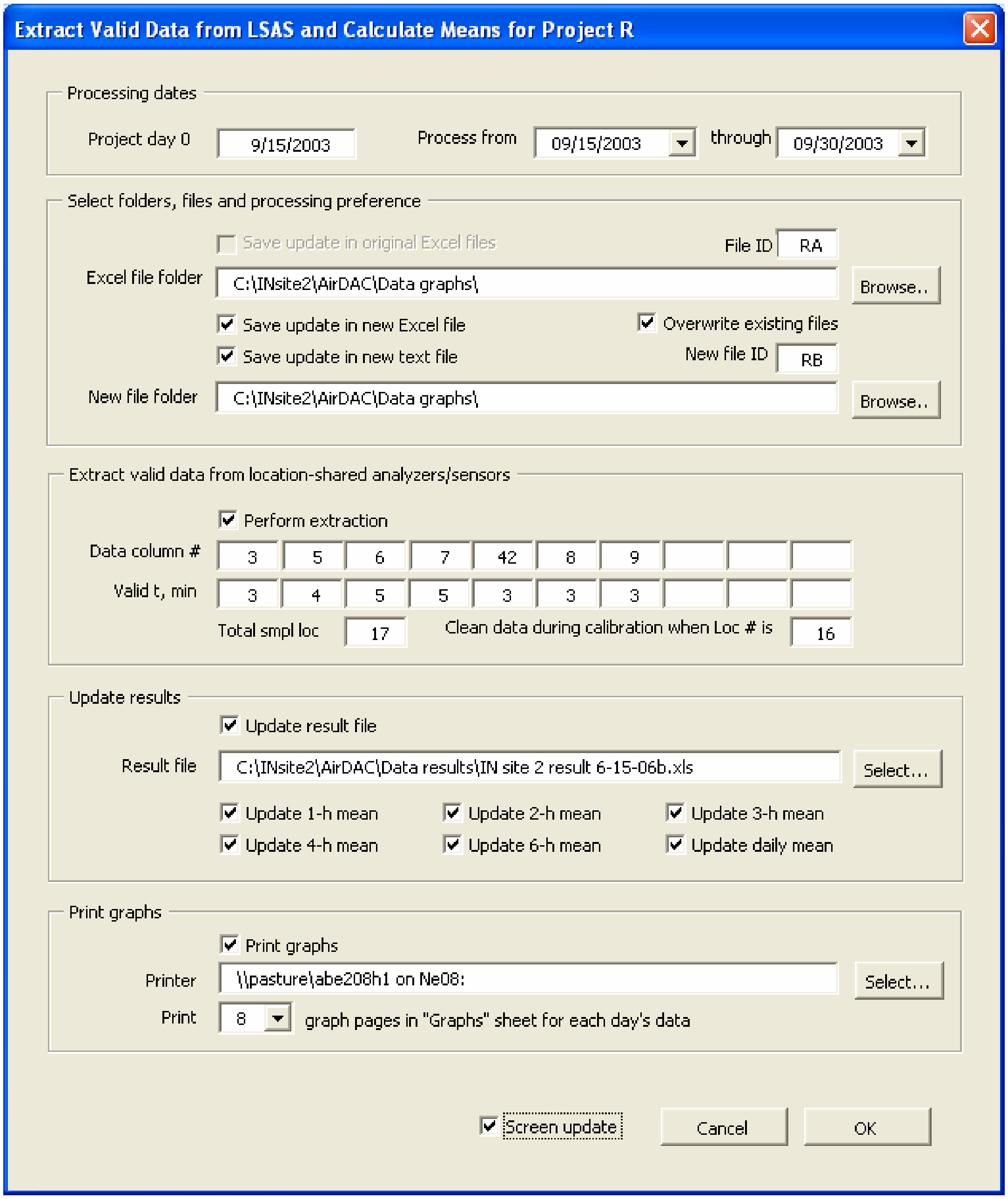
● Extract LSAS data & calculate means

Figure 12. Select project and process for extract LSAS and get mean data.

7.5.3. Select the Project ID, check "Extract LSAS and calculate means," and click OK. A user form "Extract Data from LSAS and Calculate Means" appears (Fig. 13).

7.5.4. Configure processing settings in the "Extract Data from LSAS and Calculate Means" form.

- 7.5.4.1. Processing dates
  - 7.5.4.1.1. Type in the project starting day (day 0) using the "m/d/yyyy" format. This date will also be used by ADPP to determine the starting row of the mean data in the result file (Section 7.5.4.4).
  - 7.5.4.1.2. Select the range of dates to process in "Process from" and "through" list boxes.
- 7.5.4.2. Select folders, files and processing preference
  - 7.5.4.2.1. Select the file folder where the processed Excel files were saved during the "Assemble raw data and make corrections" processing by clicking "Browse…" Enter the "File ID".
  - 7.5.4.2.2. Select between "Save update in original Excel files" and "Save update in new Excel file." If the latter is selected, enter the "New file ID" and select the new file folder.
  - 7.5.4.2.3. Check "Overwrite existing files" and "Save update in new text file" as desired.
- 7.5.4.3. Extract valid data from LSAS
  - 7.5.4.3.1. Check "Perform extraction" and enter the "Data Column #", which is the column # in the raw data file (column # 1 is date & time, column # 2 is sampling location code, and so on), and "Valid t, min", which is the last n minutes in the same sampling location (for example, in the 10-min sampling, entering "3" in the "Valid t, min" will extract the 8th – 10th min data). Refer to SOP B4 for amount of data (i.e. the number of minutes) which are taken as valid for different gases



Extract Valid Data from LSAS and Calculate Means for Project R

Processing dates

Project day 0: 9/15/2003
Process from: 09/15/2003
through: 09/30/2003

Select folders, files and processing preference

☐ Save update in original Excel files
File ID: RA
Excel file folder: C:\INsite2\AirDAC\Data graphs\
☑ Save update in new Excel file
☑ Overwrite existing files
☑ Save update in new text file
New file ID: RB
New file folder: C:\INsite2\AirDAC\Data graphs\

Extract valid data from location-shared analyzers/sensors

☑ Perform extraction

Data column #	3	5	6	7	42	8	9			
Valid t, min	3	4	5	5	3	3	3			

Total smpl loc: 17
Clean data during calibration when Loc # is: 16

Update results

☑ Update result file
Result file: C:\INsite2\AirDAC\Data results\IN site 2 result 6-15-06b.xls
☑ Update 1-h mean
☑ Update 2-h mean
☑ Update 3-h mean
☑ Update 4-h mean
☑ Update 6-h mean
☑ Update daily mean

Print graphs

☑ Print graphs
Printer: \\pasture\abe208h1 on Ne08:
Print 8 graph pages in "Graphs" sheet for each day's data

☑ Screen update

Figure 13. User form to set the LSAS data extraction and mean data calculation.

7.5.4.3.2. Enter the number of sampling locations in the “Total smpl loc”; this is used by the software to determine the size of the mean data table.

7.5.4.3.3. Enter the location number of analyzer calibration if the data during calibration should be cleared.

7.5.4.4. Update results

7.5.4.4.1. Check “Update result file” if the mean data in daily files are to be copied into a separate result file by the ADPP.

7.5.4.4.2. Check the different mean data as desired. New worksheets will be added into the result file by the ADPP based on these selections.

7.5.4.5. Printing graphs

7.5.4.5.1. Check "Print graphs" if the figures in the "Graphs" sheet are to be printed.

7.5.4.5.2. Select the printer by clicking the "Select…" button, and select the number of pages to be printed based on the template file configuration.

7.5.5. Check the "Screen update" if the process is to be monitored. Click the OK button to start processing when all settings are correctly made.

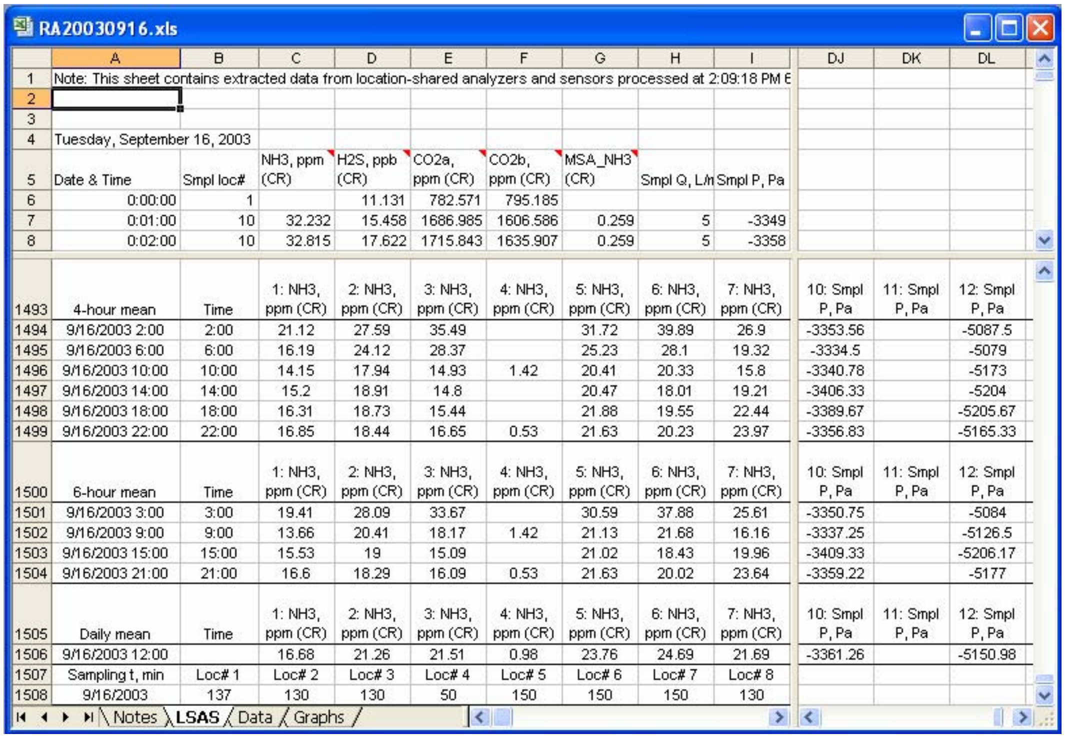
7.5.6. An example of extracted data from LSAS in daily Excel files is provided in Fig. 14, and an example of a processed result file containing multi-day data is illustrated in Fig. 15.

7.6. Troubleshooting

7.6.1. If the program displays an error message, first check the raw data files. The format of the raw data files should be the same as the one generated by AirDAC (Fig. 16), in which cell 1A contains the date, cell 1D stores the sampling location codes, row 2 has data headings, and data are saved from row 3 on. Delete the empty raw data files or correct the file format, and try running the program again.

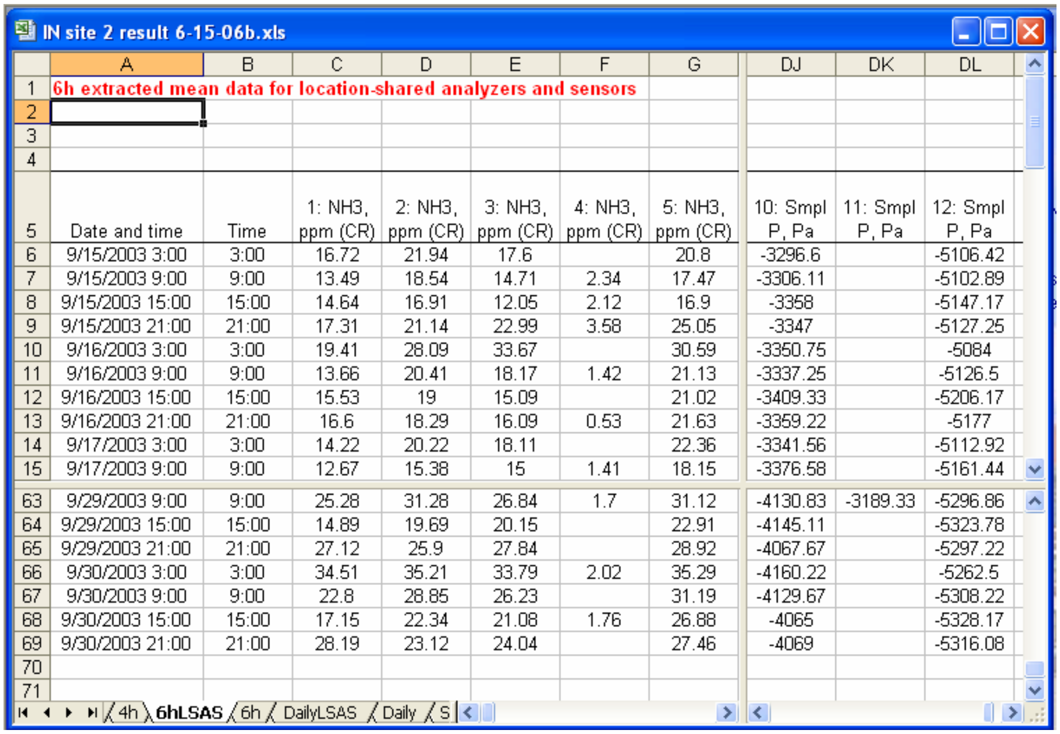
7.6.2. Excel spreadsheets allow a maximum of 256 columns. A run-time error will occur if the number of data columns exceeds 256. Reduce the number of columns and try running the program again.

7.6.3. For errors that cannot be solved, contact jiqin@purdue.edu for troubleshooting.



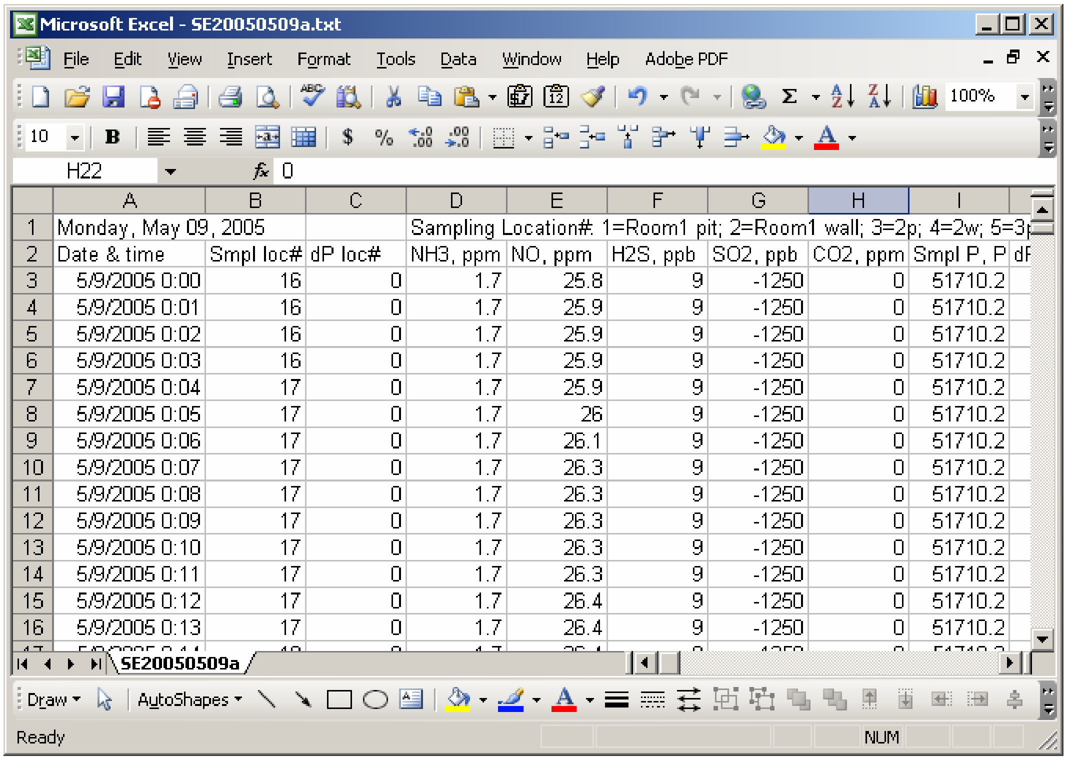
	A	B	C	D	E	F	G	H	I	DJ	DK	DL
1	Note: This sheet contains extracted data from location-shared analyzers and sensors processed at 2:09:18 PM 6											
2												
3												
4	Tuesday, September 16, 2003											
5	Date & Time	Smpl loc#	NH3, ppm (CR)	H2S, ppb (CR)	CO2a, ppm (CR)	CO2b, ppm (CR)	MSA_NH3 (CR)	Smpl Q, L/n	Smpl P, Pa			
6	0:00:00	1		11.131	782.571	795.185						
7	0:01:00	10	32.232	15.458	1686.985	1606.586	0.259	5	-3349			
8	0:02:00	10	32.815	17.622	1715.843	1635.907	0.259	5	-3358			
1493	4-hour mean	Time	1: NH3, ppm (CR)	2: NH3, ppm (CR)	3: NH3, ppm (CR)	4: NH3, ppm (CR)	5: NH3, ppm (CR)	6: NH3, ppm (CR)	7: NH3, ppm (CR)	10: Smpl P, Pa	11: Smpl P, Pa	12: Smpl P, Pa
1494	9/16/2003 2:00	2:00	21.12	27.59	35.49		31.72	39.89	26.9	-3353.56		-5087.5
1495	9/16/2003 6:00	6:00	16.19	24.12	28.37		25.23	28.1	19.32	-3334.5		-5079
1496	9/16/2003 10:00	10:00	14.15	17.94	14.93	1.42	20.41	20.33	15.8	-3340.78		-5173
1497	9/16/2003 14:00	14:00	15.2	18.91	14.8		20.47	18.01	19.21	-3406.33		-5204
1498	9/16/2003 18:00	18:00	16.31	18.73	15.44		21.88	19.55	22.44	-3389.67		-5205.67
1499	9/16/2003 22:00	22:00	16.85	18.44	16.65	0.53	21.63	20.23	23.97	-3356.83		-5165.33
1500	6-hour mean	Time	1: NH3, ppm (CR)	2: NH3, ppm (CR)	3: NH3, ppm (CR)	4: NH3, ppm (CR)	5: NH3, ppm (CR)	6: NH3, ppm (CR)	7: NH3, ppm (CR)	10: Smpl P, Pa	11: Smpl P, Pa	12: Smpl P, Pa
1501	9/16/2003 3:00	3:00	19.41	28.09	33.67		30.59	37.88	25.61	-3350.75		-5084
1502	9/16/2003 9:00	9:00	13.66	20.41	18.17	1.42	21.13	21.68	16.16	-3337.25		-5126.5
1503	9/16/2003 15:00	15:00	15.53	19	15.09		21.02	18.43	19.96	-3409.33		-5206.17
1504	9/16/2003 21:00	21:00	16.6	18.29	16.09	0.53	21.63	20.02	23.64	-3359.22		-5177
1505	Daily mean	Time	1: NH3, ppm (CR)	2: NH3, ppm (CR)	3: NH3, ppm (CR)	4: NH3, ppm (CR)	5: NH3, ppm (CR)	6: NH3, ppm (CR)	7: NH3, ppm (CR)	10: Smpl P, Pa	11: Smpl P, Pa	12: Smpl P, Pa
1506	9/16/2003 12:00		16.68	21.26	21.51	0.98	23.76	24.69	21.69	-3361.26		-5150.98
1507	Sampling t, min	Loc# 1	Loc# 2	Loc# 3	Loc# 4	Loc# 5	Loc# 6	Loc# 7	Loc# 8			
1508	9/16/2003	137	130	130	50	150	150	150	130			

Figure 14. Example of the extracted LSAS data and the mean data separated by sampling locations. The "Time" column is for graph plotting.



	A	B	C	D	E	F	G	DJ	DK	DL
1	6h extracted mean data for location-shared analyzers and sensors									
2										
3										
4										
5	Date and time	Time	1: NH3, ppm (CR)	2: NH3, ppm (CR)	3: NH3, ppm (CR)	4: NH3, ppm (CR)	5: NH3, ppm (CR)	10: Smpl P, Pa	11: Smpl P, Pa	12: Smpl P, Pa
6	9/15/2003 3:00	3:00	16.72	21.94	17.6		20.8	-3296.6		-5106.42
7	9/15/2003 9:00	9:00	13.49	18.54	14.71	2.34	17.47	-3306.11		-5102.89
8	9/15/2003 15:00	15:00	14.64	16.91	12.05	2.12	16.9	-3358		-5147.17
9	9/15/2003 21:00	21:00	17.31	21.14	22.99	3.58	25.05	-3347		-5127.25
10	9/16/2003 3:00	3:00	19.41	28.09	33.67		30.59	-3350.75		-5084
11	9/16/2003 9:00	9:00	13.66	20.41	18.17	1.42	21.13	-3337.25		-5126.5
12	9/16/2003 15:00	15:00	15.53	19	15.09		21.02	-3409.33		-5206.17
13	9/16/2003 21:00	21:00	16.6	18.29	16.09	0.53	21.63	-3359.22		-5177
14	9/17/2003 3:00	3:00	14.22	20.22	18.11		22.36	-3341.56		-5112.92
15	9/17/2003 9:00	9:00	12.67	15.38	15	1.41	18.15	-3376.58		-5161.44
63	9/29/2003 9:00	9:00	25.28	31.28	26.84	1.7	31.12	-4130.83	-3189.33	-5296.86
64	9/29/2003 15:00	15:00	14.89	19.69	20.15		22.91	-4145.11		-5323.78
65	9/29/2003 21:00	21:00	27.12	25.9	27.84		28.92	-4067.67		-5297.22
66	9/30/2003 3:00	3:00	34.51	35.21	33.79	2.02	35.29	-4160.22		-5262.5
67	9/30/2003 9:00	9:00	22.8	28.85	26.23		31.19	-4129.67		-5308.22
68	9/30/2003 15:00	15:00	17.15	22.34	21.08	1.76	26.88	-4065		-5328.17
69	9/30/2003 21:00	21:00	28.19	23.12	24.04		27.46	-4069		-5316.08
70										
71										

Figure 15. Example of a result file in which mean values were calculated for different sampling locations. The "Time" column is for sorting data to evaluate diurnal patterns.



	A	B	C	D	E	F	G	H	I
1	Monday, May 09, 2005			Sampling Location#. 1=Room1 pit; 2=Room1 wall; 3=2p; 4=2w; 5=3p					
2	Date & time	Smpl loc#	dP loc#	NH3, ppm	NO, ppm	H2S, ppb	SO2, ppb	CO2, ppm	Smpl P, P
3	5/9/2005 0:00	16	0	1.7	25.8	9	-1250	0	51710.2
4	5/9/2005 0:01	16	0	1.7	25.9	9	-1250	0	51710.2
5	5/9/2005 0:02	16	0	1.7	25.9	9	-1250	0	51710.2
6	5/9/2005 0:03	16	0	1.7	25.9	9	-1250	0	51710.2
7	5/9/2005 0:04	17	0	1.7	25.9	9	-1250	0	51710.2
8	5/9/2005 0:05	17	0	1.7	26	9	-1250	0	51710.2
9	5/9/2005 0:06	17	0	1.7	26.1	9	-1250	0	51710.2
10	5/9/2005 0:07	17	0	1.7	26.3	9	-1250	0	51710.2
11	5/9/2005 0:08	17	0	1.7	26.3	9	-1250	0	51710.2
12	5/9/2005 0:09	17	0	1.7	26.3	9	-1250	0	51710.2
13	5/9/2005 0:10	17	0	1.7	26.3	9	-1250	0	51710.2
14	5/9/2005 0:11	17	0	1.7	26.3	9	-1250	0	51710.2
15	5/9/2005 0:12	17	0	1.7	26.4	9	-1250	0	51710.2
16	5/9/2005 0:13	17	0	1.7	26.4	9	-1250	0	51710.2

Figure 16. Format of the raw data file.

8. Records Management

8.1. Manage data files according to SOP B5.
8.2. ADPP automatically records the date and time of processing and the number of raw data files used in the daily Excel file that it generates.
8.3. ADPP automatically records the name of the precision check file, the name of the worksheet where precision data are used for concentration correction, and the date and time the correction was made in the "Notes" worksheet in the daily Excel file.
8.4. Record other information including date, analyst name, site name, and narrative in the data processing notebook or computer file.

9. Quality Control and Quality Assurance

9.1. Verify the results of the data processing to make sure that all results are correct at the initial use of the software. This can be done by processing a few days worth of data, and compare the results (adjusted vs. original gas concentrations, extracted vs. original data for LSAS, and minute vs. averaged data) for any inconsistencies.
9.2. Be sure to modify the graph template file, result file, and ADPP configuration to meet the new data processing requirement and avoid incorrect presentation of the data if any change is made to the measurement configuration and data file format (e.g. adding a new sensor or changing DAQ channel(s)),.
9.3. Provide timely feedback to the personnel maintaining the measurement site whenever an error is found and/or corrective action is needed.

10. References

10.1. USEPA. 2001. Guidance for Preparing Standard Operating Procedures (SOPs) EPA QA/G-6, EPA, EPA/240/B-01/004, Appendix E. Available at http://www.epa.gov/QUALITY/qs-docs/g6-final.pdf. Accessed on May 2005.
10.2. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.
10.3. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
10.4. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.
10.5. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
10.6. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
10.7. SOP G9. 2006. Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.

11. Contact Information

11.1. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.
11.2. For troubleshooting of ADPP: jiqin@purdue.edu

CALCULATION AND REPORTING OF AIR EMISSIONS FROM BARNS

Standard Operating Procedure (SOP) B4

CALCULATION AND REPORTING OF AIR EMISSIONS FROM BARNS

Standard Operating Procedure (SOP) B4

Prepared by

Teng-Teeh Lim and Bill W. Bogan

Reviewed by

Ji-Qin Ni and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This standard operating procedure (SOP) describes the methods for calculating and reporting gas and particulate matter (PM) concentrations and emission rates from livestock barns.

1.2. This method applies to continuous measurements of gas and PM emission data from livestock barns.

1.3. Several emission equations, along with their derivations, are included. Some discussion of CAPECAB functions that are used to perform the calculations is also included, although this is discussed in much more detail in SOP B6.

1.4. The equations and report formats in this SOP are used in the data processing software CAPECAB (SOP B6). They can also be used for manual calculations and report generation, or by or other computer software (e.g. MS Excel).

2. Summary of Method

The emission rate for a barn or similar structure is calculated by multiplying ventilation rate (the volume of air exiting the barn per unit time) by the contaminant concentration (specifically, the concentration difference between exhaust and inlet air). In the emission rate calculations for gases, volumetric gas concentrations (ppmv or ppbv), reported by most of the gas analyzers, are converted to mass concentrations (mg/m^3 or $\mu g/m^3$), which are then multiplied by an exhaust airflow rate (m^3/time) that is based on the same air volume density. For TSP and $PM_{2.5}$ emission rates, since the concentration is given in the form of a mass concentration based on the as-found sampling flow rate, the calculation of emission rate is straightforward. However, the PM_{10} concentration, as measured by the TEOM, is reported based on 25ºC, and 1 atm of sampling flow rate; thus, this must be converted to standard temperature and pressure conditions (20ºC, 1 atm) in the emission rate calculation. The ventilation rate for PM_{10} emission rate calculation is also converted to dry STP conditions.

3. Definitions of Terms and Acronyms

3.1.	AirDAC	Air Data Acquisition and Control program
3.2.	ASABE	American Society of Agricultural and Biological Engineers
3.3.	atm	atmosphere, 746 mBar or 101,325 Pa
3.4.	Average daily mean	Average of valid daily means over a certain period of time, such as a week, month, season or year
3.5.	Complete Data Day	A day in which the collected and valid data cover >70% of the time (>16.8 h)
3.6.	Daily mean	Average of all valid and interpolated data records during a Complete Data Day
3.7.	Data record	A single data point recorded in data files by AirDAC. A data record consists of an average of 1-s readings collected over the data recording interval. AirDAC takes a reading for each measurement every s, and writes a data record 60 s, after

		averaging 60 readings. AirDAC also writes 15-s data records, based on the averages of 15 readings.
3.8.	GSS	Gas sampling system
3.9.	Overall test mean	Average of all valid data over the entire test
3.10.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.11.	Period mean	Average of valid data records during the sampling period
3.12.	PM	Particulate matter
3.13.	PM_{10}	PM with a diameter $\leq$10 µm
3.14.	QAPP	Quality Assurance Project Plan
3.15.	Reading	One data point acquired by the data acquisition or data logging program
3.16.	RH	Relative humidity
3.17.	Sampling cycle	The amount of time that the GSS takes to scan through all sampling locations, and return back to the starting location. For example, in a project with 12 locations, which are sampled for 10 min each, the sampling cycle is 2 h (120 min).
3.18.	SLG	Sampling location group
3.19.	SOP	Standard Operating Procedure
3.20.	STP	Standard Temperature and Pressure. For this SOP, STP is defined as 20°C and 1 atm. "Moist STP" refers to moist air at STP conditions, while "dry STP" refers to dry air at STP conditions.
3.21.	TEOM	Tapered Element Oscillating Microbalance
3.22.	TM	Total mass

4. Interferences

4.1. Gas concentrations in volumetric units (e.g. ppmv and ppbv) and emission rates in mass/time units (e.g. g/s) are independent of air density (as influenced by temperature, pressure, humidity and barometric pressure). However, concentrations in mass units (mg/m^3 or $\mu g/m^3$) are dependent on density, and whether the volume unit refers to an air–water vapor mixture (moist air) or dry air.

4.1.1. When reporting airflow rate and mass concentrations, base the air volume on dry air (0.0% RH) at STP (20°C and 1 atm).

4.1.2. Overall (including both seasonal and geographical variations) outdoor temperatures in the U.S. vary from -30ºC to +40°C. Barn temperatures range from 10ºC to 40°C.

4.1.3. The relationship between standard mass concentrations and actual concentrations also depends on air pressure. Atmospheric pressure varies from 88,000 to 104,000 Pa, or up to a 13% difference from standard pressure. Pressure can change geographically by 1000 Pa in a few hundred km.

4.1.3.1. The static pressure differential between the inside and outside of mechanically-ventilated barns ranges from 0 to 80 Pa, or 0 to 0.08% of standard atmospheric pressure. Thus, the maximum variation of building static pressure relative to atmospheric pressure is typically only 0.01%, and is considered negligible.

4.1.4. EPA Method 4 specifies that PM concentrations should be reported based on dry air. The percentage of moisture in the exhaust air from livestock and poultry barns is typically 1-3%.

5. Personnel Qualifications

5.1. Most of these procedures assume a familiarity with the use of personal computers, general computer application software (e.g. MS Office), and the data analysis software CAPECAB (SOP B6).

5.2. Personnel should understand the Ideal Gas Law and its applications in concentration measurements. Personnel should also have basic knowledge of AFO (Animal feeding operation) emission measurement and expected ranges of measured variables.

5.3. Only personnel who are explicitly authorized to access the research data will be allowed to modify or write to the files.

6. Procedures

6.1. Data reporting

6.1.1. Concentrations

6.1.1.1. Report concentrations using the units listed in Table 1.

Table 1. Units of gas and PM concentrations at different conditions.

Concentrations	Gas, in ppbv	Gas, in ppmv	PM
Volumetric	Ppb	ppm	---
Mass (actual)	µg/m^3	mg/m^3	µg/m^3
Mass (standard)	µg/sm^3	mg/sm^3	µg/sm^3
Mass (dry standard)	µg/dsm^3	mg/dsm^3	µg/dsm^3

6.1.1.2. Report concentrations with a maximum of three (3) significant digits (e.g. 1.22, 20.2, 1220, etc.).

6.1.1.2.1. Round concentrations over 1000 ppm to the nearest 10 ppm (e.g. 2050 ppm, 5010 ppm, etc.).

6.1.1.2.2. Include the decimal for a concentration less than 100 ppm (e.g. report 20 ppm as 20.0 ppm), but drop it if over 100 (e.g. 122 ppm, not 122.0 ppm).

6.1.1.2.3. Supersede this rule in any case where it would imply greater accuracy than the instruments are capable of achieving. For example, ambient concentrations might be less than 1 ppm (e.g. 0.322 ppm). However, this would give the impression that the measurement is accurate to 1 ppb. If this is not the case, report the measurement as 0.32 or 0.3 ppm, depending on the sensitivity of the particular analyzer.

6.1.2. Emission rates

6.1.2.1. Report emission rates using the units listed in Table 2.

6.1.2.2. Report emission rates with a maximum of three (3) significant digits.

6.1.2.3. Emissions on a per-second basis are used to present diurnal emissions (hourly, per min, etc.). Baseline emissions are typically given on a daily or annual basis.

Table 2. Units of gas and PM emission rates.

Emission rate	Gas measured in ppbv	Gas measured in ppmv	PM
Per barn	kg/d mg/s kg/yr	kg/d g/s kg/yr	kg/d g/s kg/yr
Per unit floor area	µg/s-m^2 µg/d-m^2 g/yr-m^2	mg/s-m^2 g/d-m^2 g/yr-m^2	mg/s-m^2 g/d-m^2 g/yr-m^2
Per animal	µg/s-hd µg/d-hd g/yr-hd	mg/s-hd g/d-hd g/yr-hd	mg/s-hd g/d-hd g/yr-hd
Per live mass (AU=500 kg)	µg/s-AU mg/d-AU kg/yr-AU µg/h-kg	mg/s-AU kg/d-AU kg/yr-AU mg/h-kg	mg/s-AU kg/d-AU kg/yr-AU mg/h-kg

6.2. Graphs and tables
- 6.2.1. Graphs should follow a particular style as defined by a prominent journal (e.g. Transactions of ASABE), which defines a specific format (font, labels, etc.).
- 6.2.2. Use the variables and format presented in Appendix A of this SOP to present data.
- 6.2.3. Use the "CreateTable" function of CAPECAB software (SOP B6) to create the monthly tables.

6.3. Calculation methods
- 6.3.1. Standardizing gas concentrations
  - 6.3.1.1. Use the Ideal Gas Law ($PV = nRT$), expanded as in Equation 1, to convert volumetric gas concentrations to actual mass concentrations:

$$C = \frac{P \cdot c \cdot M}{R \cdot (273 + T_O)} \tag{1}$$

Where:
C Actual mass concentration of gas (mg/m^3 or µg/m^3)
P Atmospheric pressure at sampling location (atm)
c Volumetric concentration of gas (ppm or ppb)
M Molecular weight of gas (g/mol)
R Universal Gas Constant (0.08206 L-atm/mol-°K)
T_O Temperature at sampling location (°C)

  - 6.3.1.2. Use the Ideal Gas Law to standardize the volumetric gas concentration of any pollutant (PM, gas) to the standard mass concentration on a moist-air basis (C′), as in Equation 2:

$$C^{'} = \frac{P^{'} \cdot c \cdot M}{R \cdot (273 + T^{'})} \tag{2}$$

Where:

C' Standard mass concentration, moist-air basis (mg/sm^3 or µg/sm^3)

P' Standard pressure (1 atm)

T' Standard temperature (20°C)

6.3.1.3. Calculate the dry standard concentration according to Equation 3:

$$C'' = \frac{C'}{(1 - W)} \tag{3}$$

Where:

C'' Dry standard mass concentration dry basis (mg/dsm^3 or µg/dsm^3)

W Humidity ratio (See Appendix D)

6.4. Standardizing airflow rates

6.4.1. Equation 4 standardizes actual airflow (m3/s) to the moist standard airflow (sm3/s):

$$Q^{'} = \frac{Q_O \cdot P \cdot (273.15 + T^{'})}{P^{'} \cdot (273 + T_O)} \tag{4}$$

Where:

Q' Moist standard airflow (sm^3/s)

Q_O Outlet airflow rate at T (m^3/s)

P Pressure at sampling location (atm)

T' Standard temperature (20°C)

P' Standard pressure (1 atm)

T_O Temperature at sampling location (°C)

6.4.2. Equation 5 standardizes actual airflow (m3/s) to dry standard airflow (dsm3/s):

$$Q^{''} = (1 - W) \cdot Q^{'} = (1 - W) \cdot \frac{Q_O \cdot P \cdot (273.15 + T^{'})}{P^{'} \cdot (273 + T_O)} \tag{5}$$

Where:

Q'' Dry standard airflow (dsm^3/s)

W Humidity ratio (See Appendix D)

6.5. Gas concentration corrections

6.5.1. The sensitivity of a gas analyzer may drift over time, introducing errors into the measurement. Correct these errors by using the precision check results (SOP G9) before and after the measurement, and by assuming that the drift is linear between the two precision checks. Fig. 1 illustrates how this correction works.

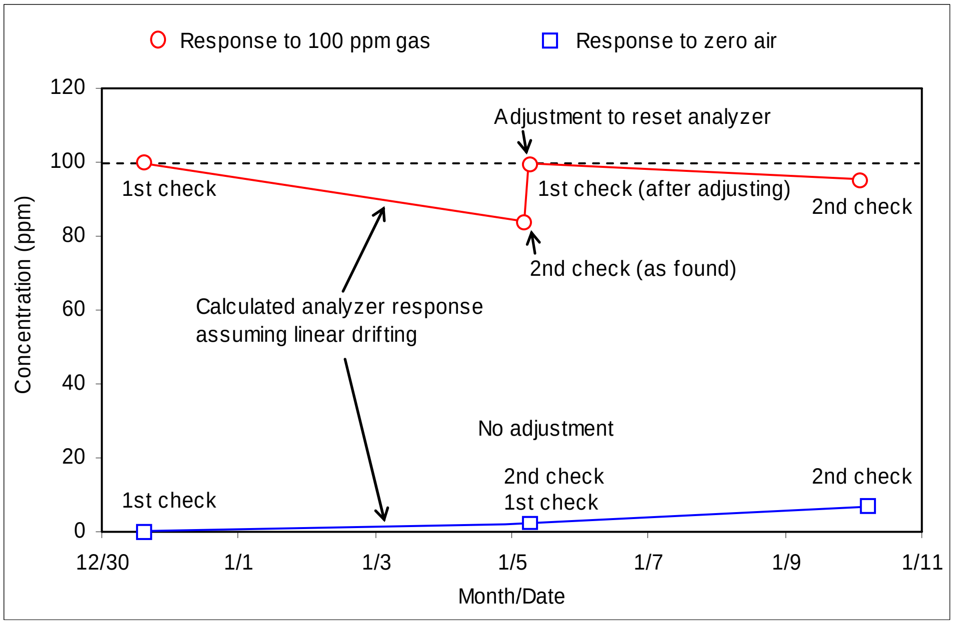


Figure 1. Linearly interpolated analyzer responses between the 1st and 2nd checks are used for correcting the data between the two checks.

6.5.2. The equations to correct gas concentrations based on two precision checks and linear interpolation are as follows:

$$c_m = Y_m - Xz_m - \left[\left(Xs_m - Xz_m\right) - \left(c_s - c_z\right)\right] \frac{(Y_m - Xz_m)}{(Xs_m - Xz_m)} \qquad (6)$$

$$Xz_m = Xz_1 + \left(Xz_2 - Xz_1\right) \frac{(t_m - tz_1)}{(tz_2 - tz_1)} \qquad (7)$$

$$Xs_m = Xs_1 + \left(Xs_2 - Xs_1\right) \frac{(t_m - ts_1)}{(ts_2 - ts_1)} \qquad (8)$$

Where:

c	Corrected concentration measured at times between two precision checks (ppm or ppb)
c_s	Span gas concentration (ppm or ppb)
c_z,	Zero air concentration (ppm or ppb)
t	Time of measurement
t_s	Time of span check
t_z,	Time of zero check
X_s	PC as-found reading at span gas check
X_z	PC as-found reading at zero check
Y	PC-recorded concentration measured at times between two precision checks
$_1$	Time of first precision check (subscript)
$_2$	Time of second precision check (subscript)
$_m$	Time of measurement (subscript)

6.5.2.1. Units of concentrations can be volumetric (ppm or ppb) or mass (mg/m^3 or µg/m^3) as long as only a single unit is used in the calculation.

6.6. Gas emission calculations

6.6.1. Calculate the net emission rate (i.e. building generation rate) by subtracting the inlet mass flow from outlet emission.

6.6.2. Two assumptions are implicit in the following discussion of emission rate calculations:

6.6.2.1. The inlet dry standard mass airflow rate is equal to the sum of all outlet dry standard mass airflow rates.

6.6.2.2. All gases obey the Ideal Gas Law.

6.6.3. The calculation of emission with a single ventilation exhaust sampling location is:

$$E = Q_O \cdot \frac{P_O \cdot M}{R \cdot (273 + T_O)} \cdot (c_O - c_i) \tag{9}$$

Where:

E	Barn emission rate (mg/s or µg/s)
Q_O	Barn outlet moist airflow rate at T_o (m^3/s)
P_O	Pressure at the exhaust sampling location (atm)
M	Gas molecular weight (g/mol)
R	Universal Gas Constant (0.08206 L-atm/mol-°K)
T_O	Temperature at the exhaust sampling location (°C)
c_o	Exhaust air concentration (ppm or ppb)
c_i	Ambient or ventilation air inlet concentration (ppm or ppb)

The derivation of Equation 9 is detailed in Appendix B.

6.6.3.1. Do not base emission calculations on dry standard concentration C_o'' and dry standard airflow Q_o''. The reason is related to the fact that while moist standard incoming and outgoing flow rates are equal, the dry standard incoming and outgoing flow rates are not equal, because moisture is added to the ventilation air in the barn.

6.6.4. Equation 9 can be used for each emission stream, since ci (the inlet air concentration) is common to each stream. The barn emission rate with n sampling locations (corresponding to n ventilation exhausts) is:

$$E = \sum_{k=1}^{n} \left[Q_{o,k} \bullet \left(C_{o,k} - C_i \right) \right] \tag{10}$$

Where:

E	Gas emission rate from the barn (mg/s or µg/s)
$C_{o,k}$	Mass concentration at ventilation exhaust location k (mg/m^3 or µg/m^3)
C_i	Mass concentration in incoming ventilation air (mg/m^3 or µg/m^3)
$Q_{o,k}$	Ventilation rate at ventilation exhaust location k (m^3/s)

6.7. PM emission calculations

6.7.1. Use Equation 11 to calculate PM emission with a single ventilation exhaust sampling location.

$$E = \left\{ \left[Q_O \cdot P_O \cdot \frac{(273+25)}{(273+T_O)} \right] \cdot \left(C_O^* - C_i^* \right) \right\} \tag{11}$$

Where:

E	Net PM emission rate (µg/s)
Q_O	Exhaust airflow rate at T_o (m^3/s)
P_O	Pressure of exhaust air (atm)
C_O^*	PM concentration of exhaust air (µg/m^3)
C_i^*	Ambient PM concentration (µg/m^3)
T_O	Temperature of exhaust air (°C)

The derivation of Equation 11 is detailed in Appendix C.

6.7.2. Also use Equation 11 for multiple emission stream emission calculation. However, if there is only one PM sampling location, substitute QO with the total barn ventilation rate, and Equation 11 will then yield the barn PM emission rate.

6.8. Concentration data extraction, averaging and interpolation

6.8.1. Gas concentration extraction and averaging

6.8.1.1. Gas concentrations of each SLG are generally measured continuously during a 10-min sampling period. Ambient air generally has a 30-min sampling period. Consult the QAPP to verify these sampling periods.

6.8.1.2. Depending on the response time and condition of different gas analyzers, each type of gas requires several min of pre-equilibrium data to be excluded from valid data sets for period mean calculation.

6.8.1.2.1. Some examples of the equilibrium time for several common analyzers are:

Ammonia (TEI 17C)	7 min invalid, 3 min valid
Hydrogen sulfide (TEI 450C)	5 min invalid, 5 min valid
Carbon dioxide (MSA 3600)	3 min invalid, 7 min valid

6.8.1.2.2. Observe analyzer traces during sampling and during precision checks to verify the equilibration period of each analyzer. The equilibrium time for the ambient measurement data will be longer than the above-stated durations, because some analyzers require more time to reach equilibrium when switching from measuring high (exhaust location) to low (ambient) concentrations.

6.8.1.3. Pre-equilibration gas concentration readings during each sampling period are automatically flagged as invalid by the CAPECAB data processing software (SOP B6).

6.8.1.4. Assuming the data recording interval is 60 s, each valid reading is an actual minute average. Average the valid readings to obtain the sampling period mean.

6.8.2. Gas concentration interpolation

6.8.2.1. Estimate gas concentrations in the intervals between valid readings by linearly interpolating the means of two or three groups of valid readings.

6.8.2.2. The interpolation function utilizes the averages of the last *x* min of the most recent previous set of valid data, and of the first *x* min of the next set of valid data.

6.8.2.2.1. The value of *x* depends on the variance of the gas concentration

6.8.2.2.2. Interpolate to the midpoint of the interval with the *x* readings.

6.8.2.3. The maximum interval of missing data that should be interpolated will be project-specific, depending on the data quality objectives of the project. Consult the project QAPP for maximum allowable interpolation intervals.

7. Data and Records Management

7.1. Refer to SOP B5 for data and records management.

8. Quality Control and Quality Assurance

8.1. Completeness of data sets

8.1.1. Only calculate and report average daily means (ADM) for complete-data days (CDD), days in which over 70% of the data are valid.

8.1.1.1. This is necessary in order to avoid errors introduced into calculated average values due to partial-data days (*e.g.* only a few hours of valid data) that would result in biased time weights.

8.1.2. Similarly, only report hourly averages if more than 70% of the data during that hour are valid, and monthly averages only if more than 70% of the days are valid.

9. References

9.1. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

9.2. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab

9.3. SOP G9. 2006. Precision Checks of Gas Analyzers. Standard Operating Procedure B6. Purdue Ag Air Quality Lab

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Appendix A. Formats for Reporting Daily Mean Data at Two Barns

In this example, data are reported (±s.d.) for Barns A and B at site Y. Month, 200j.

Table 1. Daily means (±s.d.) of weather parameters and animal characteristics for barns A and B at Site Y for Month, 200j.																		
	Weather variables						Animal characteristics											
							Barn A				Barn B							
Day	T, °C	RH, %	Wind speed, m/s	Wind direction, degrees	Solar energy, J	Bar. P, kPa	Barn inventory	Mass, Kg	Density, kg/m^2	Activity, mV	Barn inventory	Mass, kg	Density, kg/m^2	Activity, mV				
Table 2. Daily means (±s.d.) of environmental parameters for barns A and B at Site Y. Month, 200j..																		
	Barn A									Barn B								
	Ventilation		Inlet		Indoor		Exhaust			Ventilation		Inlet		Indoor		Exhaust		
Day	ΔP, Pa	Airflow, dsm^3/s	T, °C	RH, %	T, °C	RH, %	T, °C	RH, %	open	ΔP, Pa	Airflow, dsm^3/s	T, °C	RH, %	T, °C	RH, %	T, °C	RH, %	open
Table 3. Daily means (±s.d.) of gas X concentrations for barns A and B at Site Y. Month, 200j. Maximums refer to one-minute readings..																		
Day	Outdoor		Barn A								Barn B							
			Inside Barn A				Barn A Exhaust				Inside Barn B				Barn B Exhaust			
			Mean		Maximum		Mean		Maximum		Mean		Maximum		Mean		Maximum	
	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3	ppm	mg/dsm^3
Table 4. Daily means (±s.d.) of particulate matter concentrations and emission rates for barns A and B at Site Y. Month, 200j. Maximums refer to one-minute readings.																		
Day	Particulate Matter Concentrations, µg/dsm^3							Particulate Matter Emission Rates										
	Outdoor	Barn A Exhaust			Barn B Exhaust													
	PM$_{10}$	PM$_{10}$		TSP			TSP											
	Mean	Mean	Max	Mean (n)	Mean	Max	Mean (n)			kg/d	g/d•m^2	g/d•hd	g/d•AU					
Table 5. Daily means (±s.d.) of gases X and Z emission rates from barns A and B at Site Y for Month, 200j.																		
Day	Gas X Emission Rates								Gas Y Emission Rates									
	Barn A				Barn B				Barn A				Barn B					
	kg/d	g/d•m^2	g/d•hd	g/d•AU	kg/d	g/d•m^2	g/d•hd	g/d•AU	kg/d	g/d•m^2	g/d•hd	g/d•AU	kg/d	g/d•m^2	g/d•hd	g/d•AU		
1																		
.																		
31																		
Mean																		
S. D.																		
Min																		
Max																		

Appendix B. Derivation of Gas Emission Equations

9.3.1. The calculation of emission with a single ventilation exhaust sampling location is:

$$E=(Q_O C_O - Q_i C_i)=(Q_O^{'} C_O^{'} - Q_i^{'} C_i^{'}) \tag{B1}$$

Where:

E	Barn emission rate (mg/s or µg/s)
C_O	Mass concentration at the barn air inlet (mg/m^3 or $\mu g/m^3$)
Ci	Mass concentration at the barn air exhaust (mg/m^3 or $\mu g/m^3$)
$C_i^{'}$	Standardized (STP) mass concentration at air inlet (mg/sm^3 or $\mu g/sm^3$)
$C_O^{'}$	Standardized (STP) mass concentration at exhaust (mg/sm^3 or $\mu g/sm^3$)
Q_O	Barn outlet moist airflow rate at T_o (m^3/s)
Q_i	Barn inlet moist airflow rate at T_i (m^3/s)
$Q_i^{'}$	Moist standard (STP) ventilation rate at air inlet (sm^3/s)
$Q_O^{'}$	Moist standard (STP) ventilation rate at exhaust (sm^3/s)

9.3.2. Since there is conservation of mass, and $P_o/P_i \approx 1$, the airflow rate at T_o can be converted to airflow rate based on T_i, as follows:

$$Q_i=\left[Q_O \cdot \frac{P_O}{P_i} \cdot \frac{(273+T_i)}{(273+T_O)}\right] \approx \left[Q_O \cdot \frac{(273+T_i)}{(273+T_O)}\right] \tag{B2}$$

Where:

P_o	Pressure at the exhaust sampling location (atm)
P_i	Pressure of incoming air (atm)
T_o	Temperature at the exhaust sampling location (°C)
T_i	Temperature of incoming air (°C)

9.3.3. Combining Equations 1, B1, and B2, the net gas emission rate is:

$$E=\left\{\left[Q_O \cdot c_O \cdot \frac{P_O \cdot M}{R \cdot (273+T_O)}\right]-\left[Q_O \cdot \frac{273+T_i}{(273+T_O)} \cdot c_i \cdot \frac{P_O \cdot M}{R \cdot (273+T_i)}\right]\right\} \tag{B3}$$

$$E = Q_O \cdot \frac{P_O \cdot M}{R \cdot (273 + T_O)} \cdot (c_O - c_i) \tag{B4}$$

Where:

M	Gas molecular weight (g/mol)
c_o	Outlet (exhaust sampling location) gas concentration (ppm)
c_i	Inlet (ambient sampling location) gas concentration (ppm)
M	Gas molecular weight
R	Universal Gas Constant (0.08206 L-atm/mol-°K)

Appendix C. Correcting PM_{10} Concentrations from the TEOM

The net PM emission rate is calculated as:

$$E = \left\{ \left[Q_O \cdot P_O \cdot \frac{(273+25)}{(273+T_O)} \right] \cdot \left(C_O^* - C_i^* \right) \right\} \tag{C1}$$

Where:

E	Net PM emission rate (µg/s)
Q_O	Exhaust airflow rate at T_o (m^3/s)
P_O	Pressure of exhaust air (atm)
C_o^*	PM concentration of exhaust air (µg/m^3)
C_i^*	Ambient PM concentration (µg/m^3)
T_O	Temperature of exhaust air (°C)

Derivation of Equation C1

The default setting in the TEOM automatically converts the concentration C to C* (based on 25^oC, 1 atm). The TEOM converts the actual sample airflow rate Q_s to Q_s^* based on 25 ^oC and 1 atm, and calculates the concentration C* from the mass collected on the filter. However, C* needs to be converted to C′ at STP (20^oC, 1 atm) for calculating emissions and to C″ for reporting emissions on a dry standard air basis. No adjustment for pressure is needed because the TEOM is already corrected to standard pressure (1 atm) internally. We know that:

$$C' = \frac{\Delta m_f}{t \bullet Q'_s} \tag{C2}$$

whereas the TEOM sampler output is:

$$C^* = \frac{\Delta m_f}{t \bullet Q_s^*} \tag{C3}$$

Where:

Δm_f	PM mass on the filter collected during sampling time t (ug)
C’	PM concentration at STP (µg/m^3)
C*	PM concentration (reported by TEOM) at 1 atm and 25^oC (µg/m^3)
t	Time of sampling during which Δm_f was collected (s)
Q'_s	TEOM sample airflow rate at STP (m^3/s)
Q_s^*	TEOM sample airflow rate at 1 atm and 25^oC (m^3/s)

To get C′, we know

$$Q'_s = Q^*_s \bullet \frac{(273+T')}{(273+T^*)} \tag{C4}$$

Where:

$T^{'}$	Standard temperature (20ºC)
T^{*}	Temperature basis of TEOM reported concentrations (25°C)

And equation C2 becomes:

$$C' = \frac{\Delta m_f}{t \bullet Q'_s} = \frac{\Delta m_f}{t \bullet Q^*_s \bullet \dfrac{(273+T')}{(273+T^*)}} = \frac{\Delta m_f}{t \bullet Q^*_s} \bullet \frac{(273+T^*)}{(273+T')} \tag{C5}$$

Substituting from equation C3 yields

$$C^{'} = C^{*} \cdot \frac{(273+T^{*})}{(273+T^{'})} \tag{C6}$$

The reportable concentration C″ is based on dry air:

$$C'' = \frac{C'}{(1-W)} \tag{C7}$$

The barn airflow rate is used as follows in the calculation of net emission rate:

$$E = (Q_O C_O - Q_i C_i) = (Q_O^{'} C_O^{'} - Q_i^{'} C_i^{'}) \tag{C8}$$

Note that:

$$Q_O^{'} = Q_O \cdot \frac{P_O}{P^{'}} \cdot \frac{(273+T^{'})}{(273+T_i)} \tag{C9}$$

$$C_O^{'} = C_O^{*} \cdot \frac{(273+T_O^{*})}{(273+T^{'})} \qquad \text{C10)}$$

$$Q_i^{'} = Q_i \cdot \frac{P_i}{P^{'}} \cdot \frac{(273+T^{'})}{(273+T_O)} \tag{C11}$$

$$C_i' = C_i^* \cdot \frac{(273+T_i^*)}{(273+T')} \tag{C12}$$

Substituting Equations C9 to C12 into Equation C8, yields:

$$E = \left\{ \left[Q_O \cdot \frac{P_O}{P'} \cdot \frac{(273+T')}{(273+T_O)} \cdot C_O^* \cdot \frac{(273+T_O^*)}{(273+T')} \right] - \left[Q_i \cdot \frac{P_i}{P'} \cdot \frac{(273+T')}{(273+T_i)} \cdot C_i^* \cdot \frac{(273+T_i^*)}{(273+T')} \right] \right\} \tag{D13}$$

$$E = \left\{ \left[Q_O \cdot \frac{P_O}{P'} \cdot \frac{(273+T_O^*)}{(273+T_O)} \cdot C_O^* \right] - \left[Q_i \cdot \frac{P_i}{P'} \cdot \frac{(273+T_i^*)}{(273+T_i)} \cdot C_i^* \right] \right\} \tag{D14}$$

9.3.4. Since there is conservation of mass, and $P_o / P_i \approx 1$, the airflow rate at T_o can be converted to airflow rate based on T_i, as follows:

$$Q_i = \left[Q_O \cdot \frac{P_O}{P_i} \cdot \frac{(273+T_i)}{(273+T_O)} \right] \approx \left[Q_O \cdot \frac{(273+T_i)}{(273+T_O)} \right] \tag{C15}$$

Where:

P_o	Pressure at the exhaust sampling location (atm)
P_i	Pressure of incoming air (atm)
T_o	Temperature at the exhaust sampling location (°C)
T_i	Temperature of incoming air (°C)

Substituting Equation C15 into Equation C14, and simplifying, yields:

$$E = \left\{ \left[Q_O \cdot \frac{P_O}{P'} \cdot \frac{(273+T_O^*)}{(273+T_O)} \right] \cdot \left(C_O^* - C_i^* \right) \right\} \tag{C16}$$

Since P' = 1 atm, and T_O^* = 25°C, then:

$$E = \left\{ \left[Q_O \cdot P_O \cdot \frac{(273+25)}{(273+T_O)} \right] \cdot \left(C_O^* - C_i^* \right) \right\} \tag{C1}$$

Appendix D. Humidity Ratio Calculation

The humidity ratio (W) is calculated with Equation D1:

$$W = 0.62198 \bullet \frac{e^{f(T)}\varphi}{P_{act} - e^{f(T)}\varphi} \tag{D1}$$

Where:
W Humidity ratio (kg/kg)
P Pressure at the sampling location (Pa)
φ Relative humidity, decimal

Note that, for cases where T < 273.15°K:

$$f(T) = \frac{C_1}{T} + C_2 + C_3 T + C_4 T^2 + C_5 T^3 + C_6 T^4 + C_7 \ln T \tag{D2}$$

And, for cases where T > 273.16°K:

$$f(T) = \frac{C_8}{T} + C_9 + C_{10} T + C_{11} T^2 + C_{12} T^3 + C_{13} \ln T \tag{D3}$$

In Equations D2 and D3:

$C_1 = -5.675\text{x}10^3$	$C_2 = 6.392$	$C_3 = -9.678\text{x}10^{-3}$	$C_4 = 6.222\text{x}10^{-7}$
$C_5 = 2.075\text{x}10^{-9}$	$C_6 = -9.484\text{x}10^{-13}$	$C_7 = 4.163$	$C_8 = -5.800\text{x}10^3$
$C_9 = 1.391$	$C_{10} = -4.864\text{x}10^{-2}$	$C_{11} = 4.176\text{x}10^{-5}$	$C_{12} = -1.445\text{x}10^{-8}$
$C_{13} = 6.545$			

DATA MANAGEMENT FOR BARNS

Standard Operating Procedure (SOP) B5

DATA MANAGEMENT FOR BARNS

Standard Operating Procedure (SOP) B5

Prepared by
Ji-Qin Ni and Juan Carlos Ramirez

Reviewed by
Albert J. Heber and Bill W. Bogan

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. The objective of data management is to ensure data security, easy data identification and retrieval, and efficient publication.

1.2. This SOP applies to the management of air emission data collected at commercial livestock barns. It applies to all affiliated personnel who conduct research, assist in the research, or perform duties that bring them in contact with the following data:

- 1.2.1. Measurement variables that are monitored by the data acquisition computer.
- 1.2.2. Data from off-line sample analysis, including manure characteristics and particulate matter weights, by various laboratories.
- 1.2.3. Data from the nearest weather station.
- 1.2.4. Livestock characteristics obtained from the producer.
- 1.2.5. Field test notes and visual observations.
- 1.2.6. Data analyzed to calculate air emission rates.
- 1.2.7. Farm and barn design and operational characteristics.

2. Summary of Method

Electronic files are classified according to their importance and recoverability. All project-related files in the on-site computer are arranged in a single folder with a default structure of subfolders. An administrative server on campus stores data from on-site computers and data after processing. Files in the on-site computers are backed-up regularly. Acquired 24-h measurement data are emailed to the administrative server and site PI daily. Field notes and other electronic files (e.g. digital photos) are emailed to recipients daily when they are updated. The project data files are kept for at least six years.

3. Definitions

3.1.	ABE	Agricultural and Biological Engineering.
3.2.	AirDAC	Air Data Acquisition and Control program.
3.3.	CAPECAB	Calculation of Air Pollutant Emissions from Confined Animal Buildings, a custom computer program.
3.4.	Data recipients	Individuals designated to receive emailed data.
3.5.	Site PI	Site principal investigator.
3.6.	SMP	Site monitoring plan.

4. Personnel Qualifications and Responsibilities

4.1. Most of these procedures assume a familiarity with the use of personal computers, general computer application software, e.g. MS Office, and the data acquisition and control software, AirDAC (SOP B2) or the data analysis software CAPECAB (SOP B6).

4.2. The site PI will follow the procedures of data recording, organization, and safeguards and should ensure that all members of the research team (including appropriate administrative personnel) understand and follow the procedures for the site.

4.3. Only those individuals explicitly authorized to access the research data will be allowed to write to the files. The person creating the daily field notes will be identified in the notes.

4.4. Those authorized to access research data will use strong passwords that are difficult to crack. Passwords will not be written down or shared with others. Passwords will be changed on a regular basis (every two months at minimum).

4.5. The authorized personnel are site PI, site engineer, project managers, and data analysts.

- 4.5.1. The site PI and site engineer have keys to the on-farm instrument shelter and access to the site computer.
- 4.5.2. The site PI and site engineer have the password to remotely connect to the site computer.
- 4.5.3. The site PI and site engineer have read/write access to the site data.
- 4.5.4. The project managers and data analysts have passwords to the computers that are connected to the administrative server.
- 4.5.5. The project managers and data analysts have read/write access to the administrative server data.
- 4.5.6. No one is authorized to change original raw data files (Sections 6.4 and 6.5).

5. Procedures

5.1. Classification of electronic files

- 5.1.1. Classify all electronic files according to the following four categories:
  - 5.1.1.1. Category 1. Research information and data. These files, if lost, cannot be rebuilt or recovered.
    - 5.1.1.1.1. Measurement data including data logged by instruments with internal data storage
    - 5.1.1.1.2. Data acquisition and control configuration data
    - 5.1.1.1.3. Calibration data recorded by AirDAC, electronic calibration forms
    - 5.1.1.1.4. Field notes
    - 5.1.1.1.5. Email messages
    - 5.1.1.1.6. Image files (digital photos or computer screen shots)
    - 5.1.1.1.7. Farm production data (excluding copies obtained from farm management)
  - 5.1.1.2. Category 2. Project-specific configurations that could be rebuilt or recovered, if lost.
    - 5.1.1.2.1. Hardware configuration files (e.g. FieldPoint configuration file *.iak)
    - 5.1.1.2.2. Configurations of firewalls, virus protection, etc.
    - 5.1.1.2.3. Email accounts, address books, message rules
    - 5.1.1.2.4. Favorite lists
  - 5.1.1.3. Category 3. Project-specific software and documents
    - 5.1.1.3.1. Files provided by vendors such as instrument manuals and quotations
    - 5.1.1.3.2. Data acquisition and control software (e.g. C:\MCC)
    - 5.1.1.3.3. Instrument communication software
  - 5.1.1.4. Category 4. Operation system and general PC software
    - 5.1.1.4.1. Windows
    - 5.1.1.4.2. MS Office

5.1.1.4.3. pcAnywhere
5.1.1.4.4. Other software

5.2. File organization

5.2.1. In the on-site data acquisition computer, arrange all project-specific files in a single default folder called YYnX where YY is a two-letter abbreviation for the state and n is a number and X is a letter. For example, a site in Indian would be identified as NC1B. Organize the subfolders of YYnX in the C drive as shown in Fig. 1:

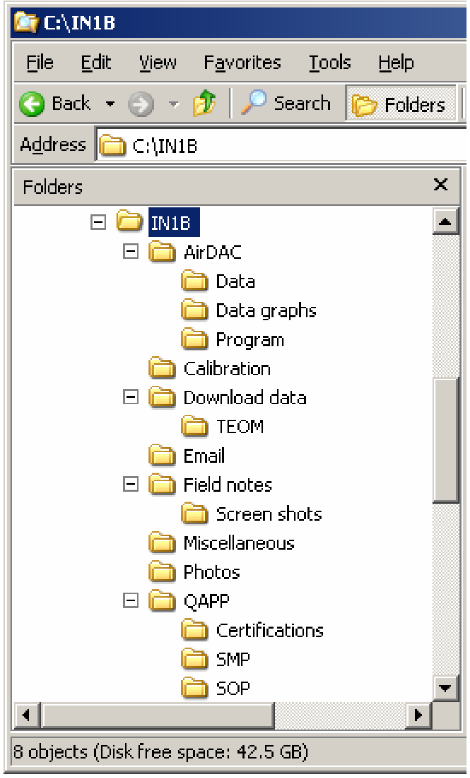


Figure 1. An example of default project folder structure in the on-site computer.

5.2.1.1. AirDAC. Contains air data acquisition and control.
5.2.1.1.1. Data. Stores raw text data collected by the data acquisition program.
5.2.1.1.2. Data graphs. Contains daily plots of raw data.
5.2.1.1.3. Program. Contains AirDAC program and configuration files for AirDAC.
5.2.1.2. Calibration. Contains calibration sheets, gas cylinder logs, control charts, and other records.
5.2.1.3. Download data. Contains data downloaded from instrument internal data loggers.
5.2.1.4. Email. Contains email messages and attachments. Name the email account YYnX@zzz.zzz where zzz.zzz is the internet service provider’s domain. Outlook Express is the preferred email program.
5.2.1.5. Field notes. Contains typed logs of activities and observations.
5.2.1.5.1. Screen shots. Contains interesting trend histories consisting of 1-s readings.
5.2.1.6. Miscellaneous. Contains site equipment inventory including gas cylinders, producer supplied information (e.g. Producer Event Forms), etc.

    - 5.2.1.7. Photos. Stores digital pictures of field setup and observations.
    - 5.2.1.8. QAPP. Saves the latest copy of the Quality Assurance Project Plan.
      - 5.2.1.8.1. Certifications
      - 5.2.1.8.2. SMP. Site monitoring plan
      - 5.2.1.8.3. SOP. Standard operating procedures (SOP).
  - 5.2.2. The administrative server on campus contains the following information:
    - 5.2.2.1. YYnX. A copy of the files received from the on-site DAC computers.
    - 5.2.2.2. Data emailed from YYnX and automatically saved in this folder.
    - 5.2.2.3. CAPECAB data and configuration files.
    - 5.2.2.4. Excel files of data exported from CAPECAB during processing.
    - 5.2.2.5. PowerPoint slides for presentations
    - 5.2.2.6. Drawings of barns and equipment
    - 5.2.2.7. Data tables (see SOP B4) for reports and manuscripts.
    - 5.2.2.8. Reports
    - 5.2.2.9. Manuscripts
- 5.3. Data safety and security
  - 5.3.1. The on-site computer will be equipped with two parallel hard drives, so that all files will be backed up to the second drive. Execute a progressive back-up of the project folder (YYnX), from the primary hard drive of the on-site computer to the secondary hard drive, such that all files modified in a given day will be backed up at the conclusion of that day. This will be done automatically on a daily basis.
  - 5.3.2. Select data recipients and configure the AirDAC (SOP B2) to email data to. The data recipients include Site PI, Site post-doc, and the administrative server (odorair@purdue.edu).
  - 5.3.3. Program the AirDAC to email the 24-h data files to the data recipients defined in Section (5.3.2) at midnight (SOP B2).
  - 5.3.4. Send calibration data and control charts to recipients defined in Section (5.3.2) after calibrations or precision checks.
  - 5.3.5. Email field notes to recipients defined in Section (5.3.2) at the end of each work day during which the field notes are edited or added to (i.e. any day that work is done on-site), before leaving the site or logging out of a remote connection to the on site computer. The individual who creates the daily field notes (whose name is recorded in the notes as per Section 4.3) will be contacted in any case of missing data and the site PI will also be contacted or notified so corrective action will be taken.
    - 5.3.5.1. Any photos which need to be included into the field notes will be taken with a digital camera (kept on site), transferred to the computer, and e-mailed along with the electronic field notes for the corresponding day.
    - 5.3.5.2. Any paper drawings which need to be included into the field notes will be scanned (kept on site), transferred to the computer, and e-mailed along with the electronic field notes for the corresponding day.
  - 5.3.6. Email AirDAC configuration files to recipients after updating them.
  - 5.3.7. Back up the entire project folder YYnX, which include all the Category 1 files, from on-site computer onto an external backup device (e.g. hard drive, DVD, or CD) every 2 wks or when there are changes in Category 2 or 3 files.
  - 5.3.8. Keep the external backup device off-site for storage by the site PI or site post-doc.

5.3.9. Back up operating system to the secondary hard drive when there are significant changes, e.g. new project-related software installed or updated.

5.3.10. Back up the project administrative server files to the Purdue University Engineering Computing Network's backup system daily and automatically. The computer administrator of the ABE Dept., Purdue University has the authority to retrieve the backup data from the Purdue University backup system.

5.3.11. The passwords are updated the same day upon termination of a person's work with the project.

5.4. Management of producer-supplied data

5.4.1. As described in SOP S1, producers are expected to keep a "Producer Event Form", which must document all production levels, changes in inventory, significant mortalities, manure removals, cleanings, and any other factors which would be expected to influence emissions.

5.4.2. Collect Event Forms from the producer on a weekly basis.

5.4.2.1. Keep hard copies of Event Forms on site in a bound notebook.

5.4.2.2. Scan and save Event Forms to the on-site computer (See Section 5.3.5.2), and e-mail to the data recipients on a weekly basis.

5.5. Retention of data

5.5.1. At the conclusion of the project, remove the primary hard disk (C drive) from the site computer and erase all files from the secondary hard disk so that the data can be protected if the site computer is to be used for other purposes.

5.5.2. Keep the removed hard disk, producer-supplied data (Section 5.4), and other hard copies, along with the "off-site" backup device, for at least six (6) years by the site PI. The site PI has access and control of the files.

5.5.3. Keep all project related files in the administrative server, including the files received from the site computers, for at least six (6) years by PAAQL, Purdue University. The PAAQL personnel involved in this project has access and control of these data.

5.5.4. Establish digital signatures of data using LabVIEW and its DSC (Data Supervision and Control) module, so that it is compliant with FDA regulation 21 CFR Part 11.

6. Quality Control and Quality Assurance

6.1. Make and follow the schedule of file backups described in Section 5.3.

6.2. Record in the field notes any manual backup that has been performed.in the field notes in a worksheet called "Backup."

6.3. Designate a person from the authorized personnel (Section 4.5) to back up files.

6.4. Check field computer and the relevant software, and take immediate measures to solve the related problem if the daily data file email, or emails with other files are not received.

6.5. Back up all raw data in their original form.

6.6. If corrections and changes are needed in the created raw files, including the manually entered original data files (e.g. manure sampling locations), perform the following:

6.6.1. Make a copy of the original file and keep the original file unchanged, including the file saving date and time.

6.6.2. Work only on the copied file.

6.6.3. Record in the new file who made the corrections/changes and when and why the data were corrected/changed. For Excel files, make the record in a new worksheet "Notes." Records can also be made as comments in the relevant cells.

6.6.4. Rename the new file by adding or updating the date at the end of the original file name in the following format: mm-dd-yy, e.g. "B1 manure samples 01-09-06.xls" for an original file named "B1 manure samples.xls." Leading zeros in date and month can be omitted, e.g. 1-9-06.

6.7. Establish electronic audit trails of data using LabVIEW and its DSC (Data Supervision and Control) module, so that it is compliant with FDA regulation 21 CFR Part 11.

7. References

7.1. EPA (2001). Guidance for Preparing Standard Operating Procedures (SOPs) EPA QA/G-6, EPA, EPA/240/B-01/004, Available at http://www.epa.gov/QUALITY/qs-docs/g6-final.pdf. Accessed October, 2005.
7.2. EPA (2003). Standard Operating Procedure for (PM2.5) Database Operations, US EPA, Environmental Health and Safety Division. Available at http://www.epa.gov/ttnamti1/files/ambient/pm25/spec/database.pdf. Accessed on December 20, 2005.
7.3. IUPUI/Clarian Standard Operating Procedure for Data Management, v 05/05. Available at http://www.iupui.edu/~respoly/human-sop/SOP%20-%20Data%20Management.htm. Accessed on December 21, 2005.
7.4. SOP B2. 2005. Standard Operating Procedure for Data Acquisition and Control Software (AirDAC). Purdue Ag Air Quality Lab.
7.5. SOP B4. 2005. Standard Operating Procedure for Calculation and Reporting of Air Emissions. Purdue Ag Air Quality Lab.
7.6. SOP B6. 2005. Standard Operating Procedure for Data Processing Software (CAPECAB). Purdue Ag Air Quality Lab.

DATA PROCESSING PROGRAM (CAPECAB)
Standard Operating Procedure (SOP) B6

DATA PROCESSING PROGRAM (CAPECAB)

Standard Operating Procedure (SOP) B6

Prepared by

Teng-Teeh Lim and Erin L. Cortus

Reviewed by

Albert J. Heber and Bill W. Bogan

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This SOP applies specifically to the custom software, Calculation of Air Pollutant Emissions from Confined Animal Buildings (CAPECAB). The program was developed to assemble and review data, and final-process air emission measurement variables collected from confined animal feeding operations (CAFO).

1.2. The CAPECAB program was originally written in Visual Basic 6 programming language. The program language is being converted to Visual Basic.Net, resulting in different user interfaces, and slight variations to some procedures. However, the focus of this SOP will be the use of CAPECAB to generate the final air emission measurement variables. Hereafter, the original program will be referred to as the VB6 version, and the revised program will be referred to as the .NET version.

1.3. The program converts measurement variables mainly acquired and generated by the data acquisition and control software, AirDAC (SOP B2), into the CAPECAB database. Other data files, including animal and feed consumption information, weather station data, stand-alone measurement data, and data logged by instruments (TEOM, SOP P1) with internal data storage, can also be sorted and combined into the database.

1.4. This method concatenates and displays graphical and tabular data over any desired interval between 10 min to 60 d for review and verification.

1.5. Basic statistics calculated by CAPECAB for user-defined intervals of data include frequency, maximum, minimum, and mean.

1.6. This method utilizes binary files that are processed much faster than spreadsheet files.

1.7. Other important functions of the software are to exclude pre-equilibrium and invalid data, and conduct airflow and emission rate calculations.

1.8. The software can also be used to provide original and processed data in table format for report writing.

2. Summary of Method

The CAPECAB program consists of four application subprograms: 1. Convert; 2. Display; 3. Flagging; and 4. ImportExport. A flowchart (Fig. 1) shows the program’s data processing procedures. Tabular data (15-s or 60-s averages) collected by AirDAC (SOP B2) are first converted using the “Convert” program into a binary database where each column of data from AirDAC (representing a single measurement) becomes a separate file. Separate files are created for each month of data collection. Each datum is associated with the time stamp (1-min interval), the sampling location as specified by the AirDAC, and a flag value. Users are allowed to create hundreds of files to store raw (from AirDAC), imported (e.g., Producer Event Form data), and calculated data values. The “Display” program is capable of presenting graphical and tabular data consisting of minute-data or means over any user-specified time interval (hourly, daily, monthly, etc). When reporting mean values, users will identify the data completeness percentage of the mean values. This function is set up to prevent reporting incomplete data to avoid bias. The “Flagging” program is used to inspect and assess data validity, using a graphical interface. For example, data can be manually or automatically flagged invalid based on field notes, user-specified ranges, ventilation-stage dependent measurement, or when the user is inspecting the data. The “ImportExport” program is used to incorporate data from other sources, and to execute various calculations for data processing such as adjustment of gas concentration data (due to analyzer drifts) based on precision checks, extraction of equilibrium data, calculation of ventilation rates, and finally, calculation of emission rates. At the end of data processing, the calculated mean values are exported into tabular format using the “Display” program.

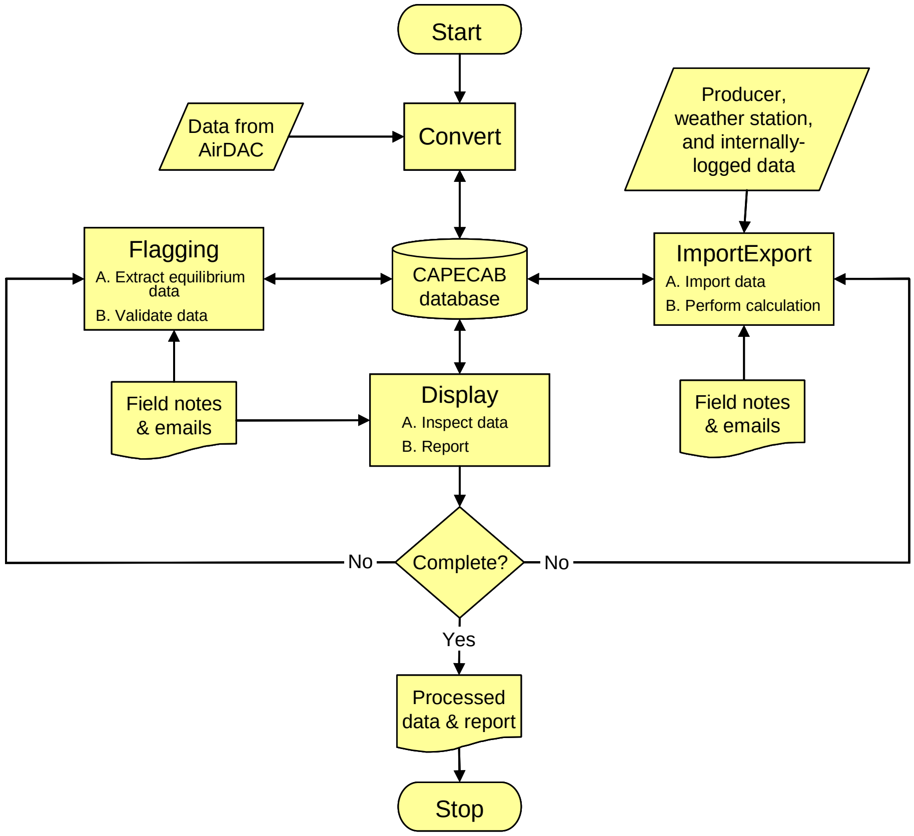


Figure 1. Data flow diagram of CAPECAB data processing.

3. Definitions

3.1.	ADPP	Air Data Pre-Processing program, written in Visual Basic for Applications in MS Excel
3.2.	CAFO	Confined animal feeding operations
3.3.	AirDAC	Air Data Acquisition and Control program written in LabVIEW (SOP B2).
3.4.	CAPECAB	Calculation of Air Pollutant Emissions from Confined Animal Buildings, a custom computer program
3.5.	LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench. A platform and development environment for a visual programming

		language (a dataflow language), produced by National Instruments Corporation (Austin, TX)
3.6.	LSAS	Location-shared analyzers and sensors
3.7.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.8.	QAPP	Quality Assurance Project Plan
3.9.	XXYB	Site-specific reference where XX represents the state, Y represents the animal type, and B represents a barn source

4. 4. Personnel Qualifications and Responsibilities

4.1. Personnel are expected to have good computer skills, including Microsoft Excel.
4.2. All personnel involved in data processing must read and understand this SOP, and SOPs B2, B3, B4, and B5 to know the details of data acquisition and data processing.
4.3. Personnel involved in data inspection and processing are required to have basic knowledge of CAFO emission measurements, and the general ranges of measured variables. Personnel are expected to understand the data patterns (e.g. diurnal and seasonal changes), and the relationship among the data (e.g. effect of ventilation on concentrations), so that data can be inspected with expert judgment.
4.4. A training course by someone familiar with the CAPECAB software is recommended to supplement the information provided in this SOP.

5. Equipment and Supplies

5.1. Personal computer with minimum 1.5 GHz CPU speed, 512 MB RAM, and 4 GB free hard disk space, and installed with Windows XP and spreadsheet software
5.2. Calculation of Air Pollutant Emissions from Confined Animal Buildings (CAPECAB) software
5.3. Tabular data recorded or generated by AirDAC (SOPs B2, B3, and B5). These data files will be emailed to the appropriate user(s) daily, or can be transferred from the monitoring sites.
5.4. Analyzer precision check data files, which describes analyzer drifts (SOP B5), and will be used for gas concentration corrections
5.5. Field notes (in emails, or electronic copy in computer or network) and emails

6. Procedures

6.1. Set up CAPECAB configuration files.
  6.1.1. Prepare an array of configuration files for each monitoring site database group. The file type is “comma separated.” It is recommended to start from existing template files and incorporate the site-specific details into the files.
  6.1.2. Several important configuration files include ana_info_XXYB.csv, convert_info_XXYB.csv, and flagging_info_XXYB.csv. All of these files will be kept in the same site-specific folder, such as C:\Site_XXYB\CC6_XXYB\dif_XXYB, where XXYB is the site-specific CAPECAB database prefix name.

6.1.3. Modify the ana_info_XXYB file first to include details of the name, type and group, unit, and column number of each measurement variable.

6.1.3.1. Every measurement site has a unique data configuration. A good practice is to group the similar measurement variables, such as concentration data columns together, and assemble the other types accordingly.

6.1.3.2. Users can use either Flagging or Display function to check the database. Errors such as repeated column numbers, undefined columns, etc, will be indicated by individual windows when starting the program.

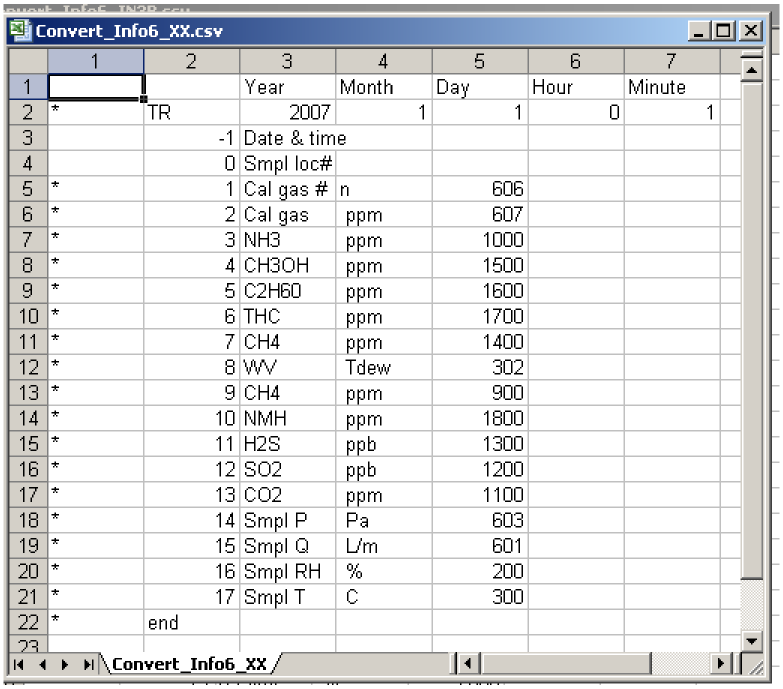
6.1.3.3. All of the configuration files can be created and edited using an MS Excel spreadsheet. Verify the line breaks in the configuration files using WordPad.

6.2. Convert tabular data into the CAPECAB database using the Convert program.

6.2.1. The main function of the Convert program is to assemble the AIRDAC data into the CAPECAB database. Setup the convert_info_XXYB file to indicate the column numbers for both the AirDAC tabular data and the CAPECAB database, Fig. 2. The CAPECAB database numbers essentially represent different files, but are referred to as columns for easier comparison with the original AirDAC data.

6.2.1.1. The heading row from an AirDAC data file can be copied and pasted in column 3 using MSExcel function Paste Special – Transpose. Doing this helps to assign the appropriate CAPECAB column numbers to the AirDAC column data.

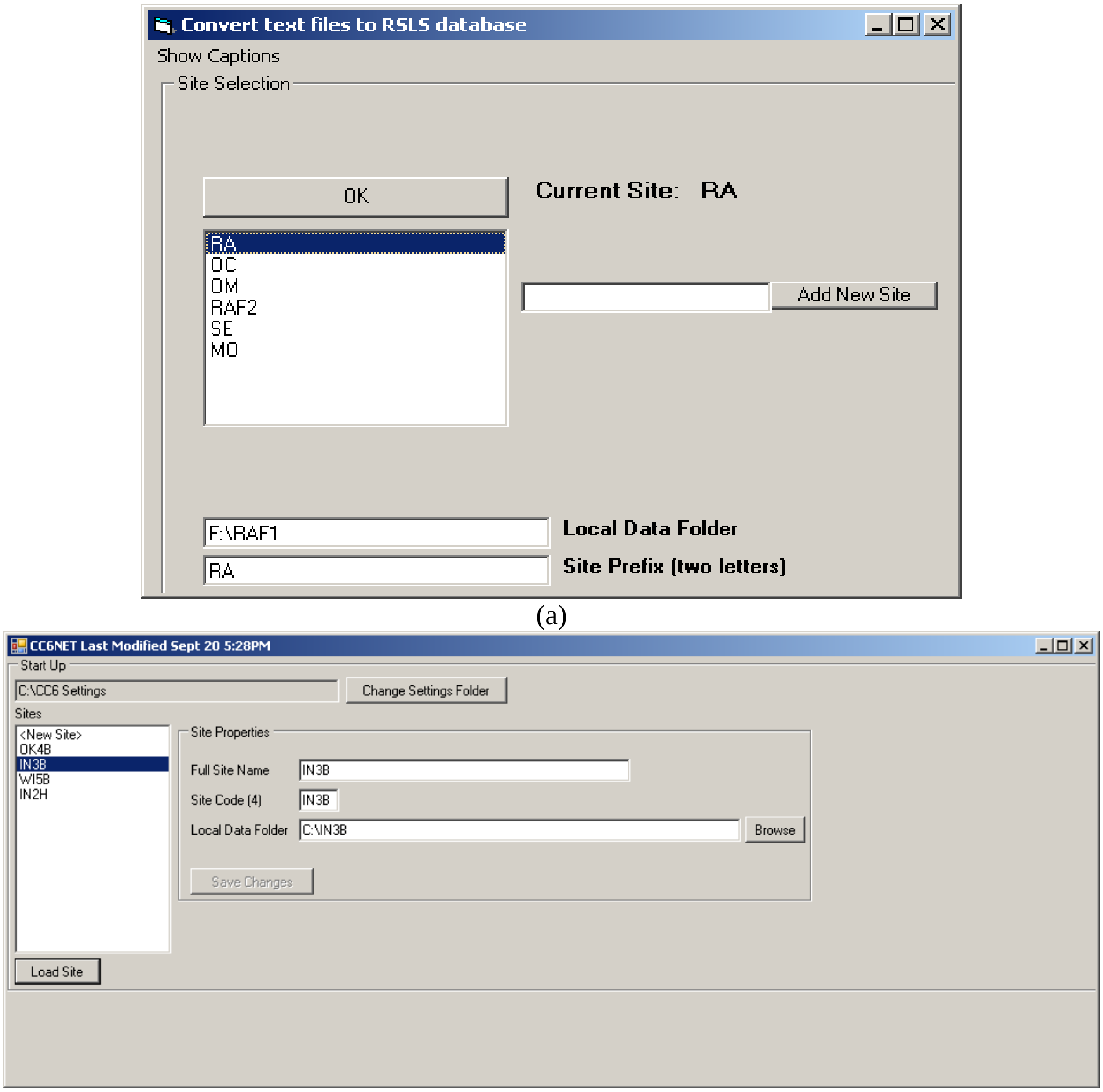
6.2.1.2. In the case of a column in the AirDAC data that is not used for a measurement (i.e. “Reserved”), assign a CAPECAB column number of -1.



	1	2	3	4	5	6	7
1			Year	Month	Day	Hour	Minute
2	*	TR	2007	1	1	0	1
3		-1	Date & time				
4		0	Smpl loc#				
5	*	1	Cal gas #	n	606		
6	*	2	Cal gas	ppm	607		
7	*	3	NH3	ppm	1000		
8	*	4	CH3OH	ppm	1500		
9	*	5	C2H60	ppm	1600		
10	*	6	THC	ppm	1700		
11	*	7	CH4	ppm	1400		
12	*	8	WV	Tdew	302		
13	*	9	CH4	ppm	900		
14	*	10	NMH	ppm	1800		
15	*	11	H2S	ppb	1300		
16	*	12	SO2	ppb	1200		
17	*	13	CO2	ppm	1100		
18	*	14	Smpl P	Pa	603		
19	*	15	Smpl Q	L/m	601		
20	*	16	Smpl RH	%	200		
21	*	17	Smpl T	C	300		
22	*	end					

Figure 2. Example of a convert_info_XXYB.csv file; column 2 indicates the source column numbers of AirDAC data file (starting with the date and time column as -1); column 5 indicates the destination column numbers in the CAPECAB database.

6.2.2. Open the Convert program (Fig. 3), and verify the information shown in the site selection window. If the program is used for the first time or has been re-installed, enter the corresponding local data folder and site prefix name, and save the information.



Current Site: RA

RA
OC
OM
RAF2
SE
MO

Local Data Folder: F:\RAF1

Site Prefix (two letters): RA

(a)

C:\CC6 Settings

<New Site>
OK4B
IN3B
WI5B
IN2H

Full Site Name: IN3B

Site Code (4): IN3B

Local Data Folder: C:\IN3B

(b)

Figure 3. Example of a site-selection window of the Convert program using the VB6 version (a) and the .NET version (b).

6.2.2.1. When the Convert form (Fig. 4) appears, click “Select txt file” (VB6) or “Browse” (.NET) from the menu bar and open a folder containing the text file(s) to be converted. Select one of the text files and click “Open”. Select one of the text files in the convert program window. Change the number in the text box on the left hand side of the form to “2”, and click “Look at a Line”. Line 2 in the text files contains the AirDAC data column headings. Click “Set as Captions”, and then click “Show Transfer Array” (VB6) or “See Transfer Into” (.NET). The conversion can be verified by comparing the AirDAC (or LV for LabView) column headings to the column names for the destination files in the CAPECAB database (CC6 Column; names are assigned in the Ana_Info6_XXYB.csv file) in the middle window for the VB6 version, and the right-hand side window for the .NET version. Verify the data column numbers to be assembled. If there are any errors, review the Ana_Info6_XXYB and/or Convert_Info6_XXYB files.

6.2.2.2. Select the files to be assembled into the CAPECAB database and press “Process all selected files” (VB6) or “Convert Selected Files” (.NET) (Fig. 4).

6.2.2.3. Check the individual monthly CAPECAB folders to verify that the data are imported. The monthly files will be saved at the same folder level similar to the dif folder, which is C:\Site_XXYB\CC6_XXYB\. The monthly files will be named YYYY_MM_XXYB where YYYY is the year, MM is the month, and XXYB is the site prefix.

6.2.2.4. Verify the site-specific folder location and name of each sub-window.

6.3. Validating and extracting data using the Flagging program.

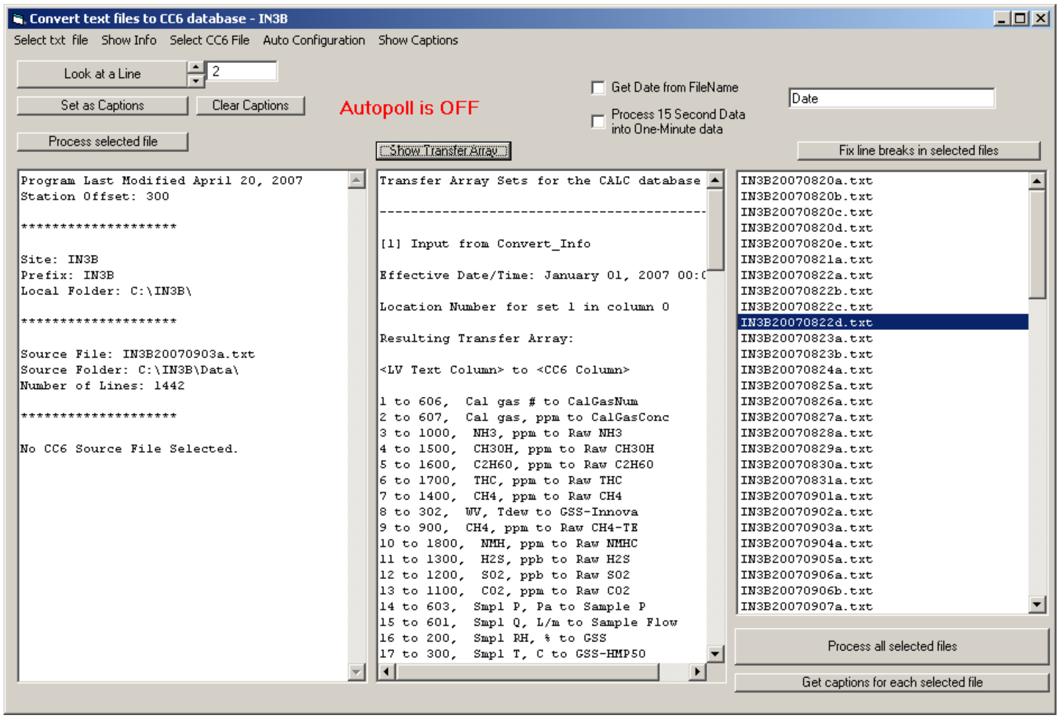
6.3.1. The main purposes of the Flagging program are to inspect and validate data, and extract equilibrium data. The flag values in the CABECAB database range from 0 to 255. Any unflagged data is considered invalid and will not be reported, thus forcing users to inspect all data prior to analyzing it. Validated data have flag values of 0 or 100. All others are considered invalid.

6.3.2. When data is first converted into the CAPECAB database, each datum is assigned a flag of 255, meaning “unflagged”. It is possible to initially assign a flag of 0 (Valid) to certain data columns.

6.3.3. CAPECAB will suggest a flag to each data point, based on information in the Flagging_Info6_XXYB.csv file for LSAS variables, or by default, flags of 0 and 1 for perceptible and missing data, respectively.

6.3.3.1. Select a measurement variable and a range of time to inspect and flag. A reasonable interval of time to inspect data is 1 or 2 d. Users can zoom into a small section of data to inspect, and only accept the valid flags if no error is found.

6.3.3.2. Click “Show/Hide Minute Editor”. The top row of the Minute Editor Form will show the suggested flags (Fig. 5a). If these flags are acceptable, click “Transfer Flags” and the new flag values will appear for each data point (Fig. 5b).

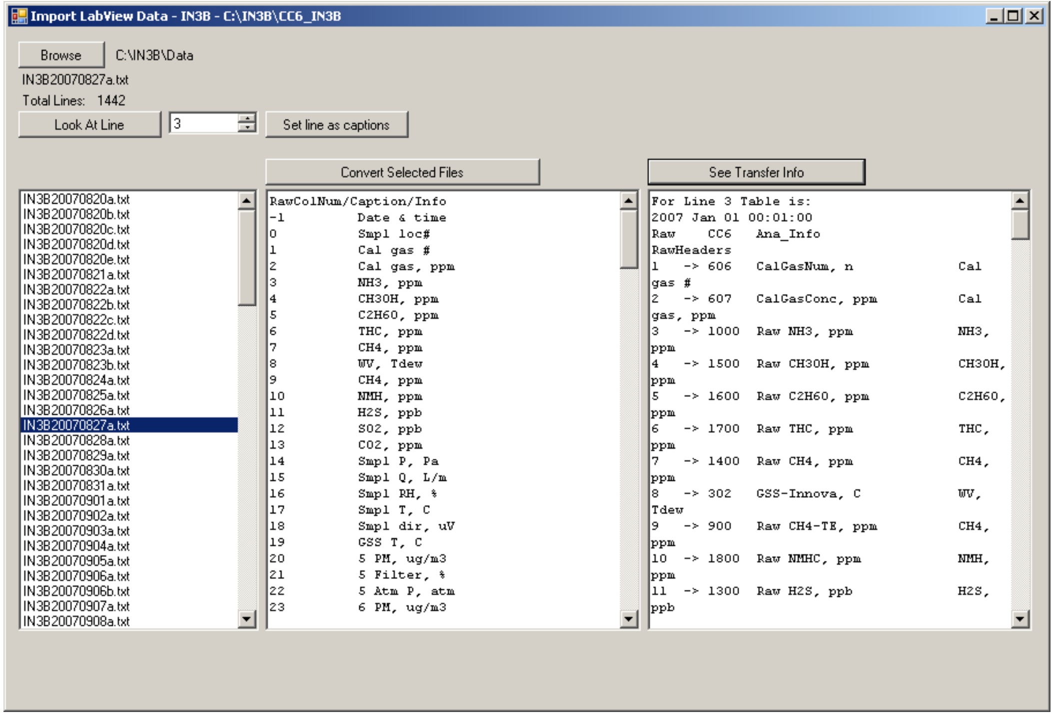


```
Program Last Modified April 20, 2007
Station Offset: 300

********************

Site: IN3B
Prefix: IN3B
Local Folder: C:\IN3B\

********************

Source File: IN3B20070903a.txt
Source Folder: C:\IN3B\Data\
Number of Lines: 1442

********************

No CC6 Source File Selected.
```

```
Transfer Array Sets for the CALC database

------------------------------------------

[1] Input from Convert_Info

Effective Date/Time: January 01, 2007 00:0

Location Number for set 1 in column 0

Resulting Transfer Array:

<LV Text Column> to <CC6 Column>

1 to 606,  Cal gas # to CalGasNum
2 to 607,  Cal gas, ppm to CalGasConc
3 to 1000,  NH3, ppm to Raw NH3
4 to 1500,  CH3OH, ppm to Raw CH3OH
5 to 1600,  C2H6O, ppm to Raw C2H6O
6 to 1700,  THC, ppm to Raw THC
7 to 1400,  CH4, ppm to Raw CH4
8 to 302,  WV, Tdew to GSS-Innova
9 to 900,  CH4, ppm to Raw CH4-TE
10 to 1800,  NMH, ppm to Raw NMHC
11 to 1300,  H2S, ppb to Raw H2S
12 to 1200,  SO2, ppb to Raw SO2
13 to 1100,  CO2, ppm to Raw CO2
14 to 603,  Smpl P, Pa to Sample P
15 to 601,  Smpl Q, L/m to Sample Flow
16 to 200,  Smpl RH, % to GSS
17 to 300,  Smpl T, C to GSS-HMP50
```

```
IN3B20070820a.txt
IN3B20070820b.txt
IN3B20070820c.txt
IN3B20070820d.txt
IN3B20070820e.txt
IN3B20070821a.txt
IN3B20070822a.txt
IN3B20070822b.txt
IN3B20070822c.txt
IN3B20070822d.txt
IN3B20070823a.txt
IN3B20070823b.txt
IN3B20070824a.txt
IN3B20070825a.txt
IN3B20070826a.txt
IN3B20070827a.txt
IN3B20070828a.txt
IN3B20070829a.txt
IN3B20070830a.txt
IN3B20070831a.txt
IN3B20070901a.txt
IN3B20070902a.txt
IN3B20070903a.txt
IN3B20070904a.txt
IN3B20070905a.txt
IN3B20070906a.txt
IN3B20070906b.txt
IN3B20070907a.txt
```

(a)



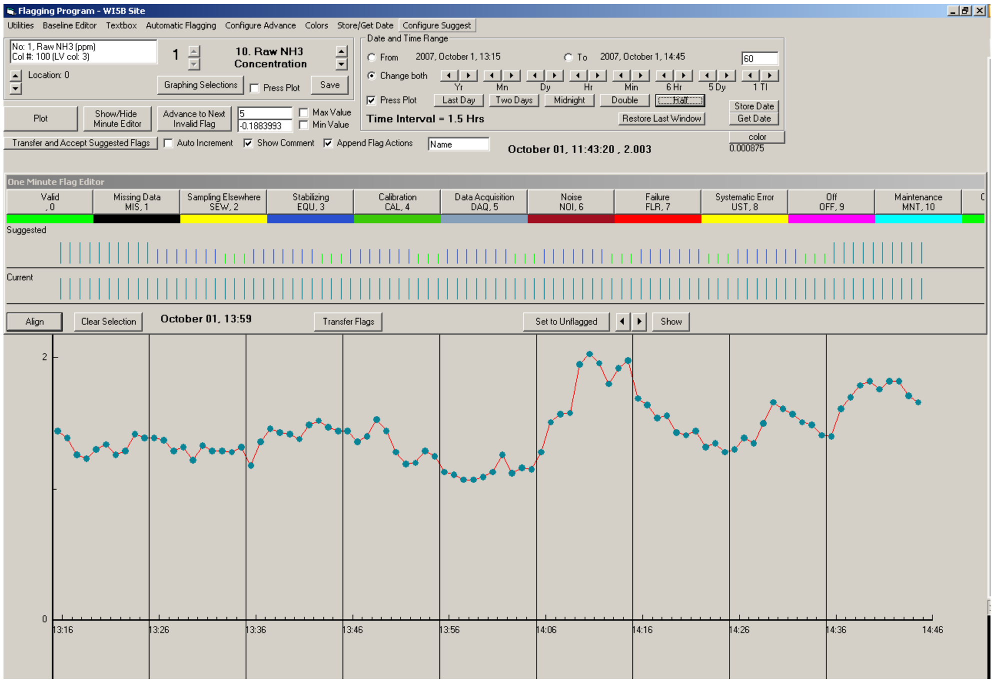
```
IN3B20070820a.txt
IN3B20070820b.txt
IN3B20070820c.txt
IN3B20070820d.txt
IN3B20070820e.txt
IN3B20070821a.txt
IN3B20070822a.txt
IN3B20070822b.txt
IN3B20070822c.txt
IN3B20070822d.txt
IN3B20070823a.txt
IN3B20070823b.txt
IN3B20070824a.txt
IN3B20070825a.txt
IN3B20070826a.txt
IN3B20070827a.txt
IN3B20070828a.txt
IN3B20070829a.txt
IN3B20070830a.txt
IN3B20070831a.txt
IN3B20070901a.txt
IN3B20070902a.txt
IN3B20070903a.txt
IN3B20070904a.txt
IN3B20070905a.txt
IN3B20070906a.txt
IN3B20070906b.txt
IN3B20070907a.txt
IN3B20070908a.txt
```

```
RawColNum/Caption/Info
-1          Date & time
0           Smpl loc#
1           Cal gas #
2           Cal gas, ppm
3           NH3, ppm
4           CH3OH, ppm
5           C2H6O, ppm
6           THC, ppm
7           CH4, ppm
8           WV, Tdew
9           CH4, ppm
10          NMH, ppm
11          H2S, ppb
12          SO2, ppb
13          CO2, ppm
14          Smpl P, Pa
15          Smpl Q, L/m
16          Smpl RH, %
17          Smpl T, C
18          Smpl dir, uV
19          GSS T, C
20          5 PM, ug/m3
21          5 Filter, %
22          5 Atm P, atm
23          6 PM, ug/m3
```

```
For Line 3 Table is:
2007 Jan 01 00:01:00
Raw    CC6   Ana_Info
RawHeaders
1   -> 606   CalGasNum, n             Cal
gas #
2   -> 607   CalGasConc, ppm          Cal
gas, ppm
3   -> 1000  Raw NH3, ppm             NH3,
ppm
4   -> 1500  Raw CH3OH, ppm           CH3OH,
ppm
5   -> 1600  Raw C2H6O, ppm           C2H6O,
ppm
6   -> 1700  Raw THC, ppm             THC,
ppm
7   -> 1400  Raw CH4, ppm             CH4,
ppm
8   -> 302   GSS-Innova, C            WV,
Tdew
9   -> 900   Raw CH4-TE, ppm          CH4,
ppm
10  -> 1800  Raw NMHC, ppm            NMH,
ppm
11  -> 1300  Raw H2S, ppb             H2S,
ppb
```

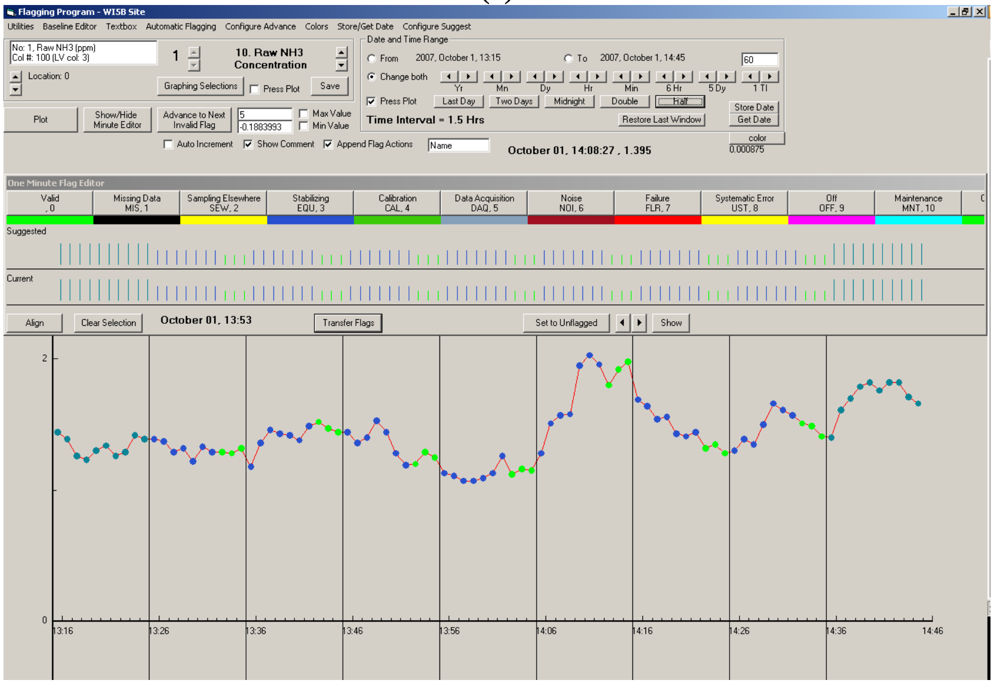
(b)

Figure 4. Example of a VB6 Convert program interface (a) and a .NET Convert program interface (b) with individual windows showing CAPECAB database folder information, column numbers, and data files to be assembled.



No: 1, Raw NH3 (ppm)
Col #: 100 (LV col: 3)
Location: 0
1
10. Raw NH3 Concentration
From 2007, October 1, 13:15
To 2007, October 1, 14:45
60
Time Interval = 1.5 Hrs
5
-0.1883993
Name
0.000875
October 01, 11:43:20 , 2.003
October 01, 13:59

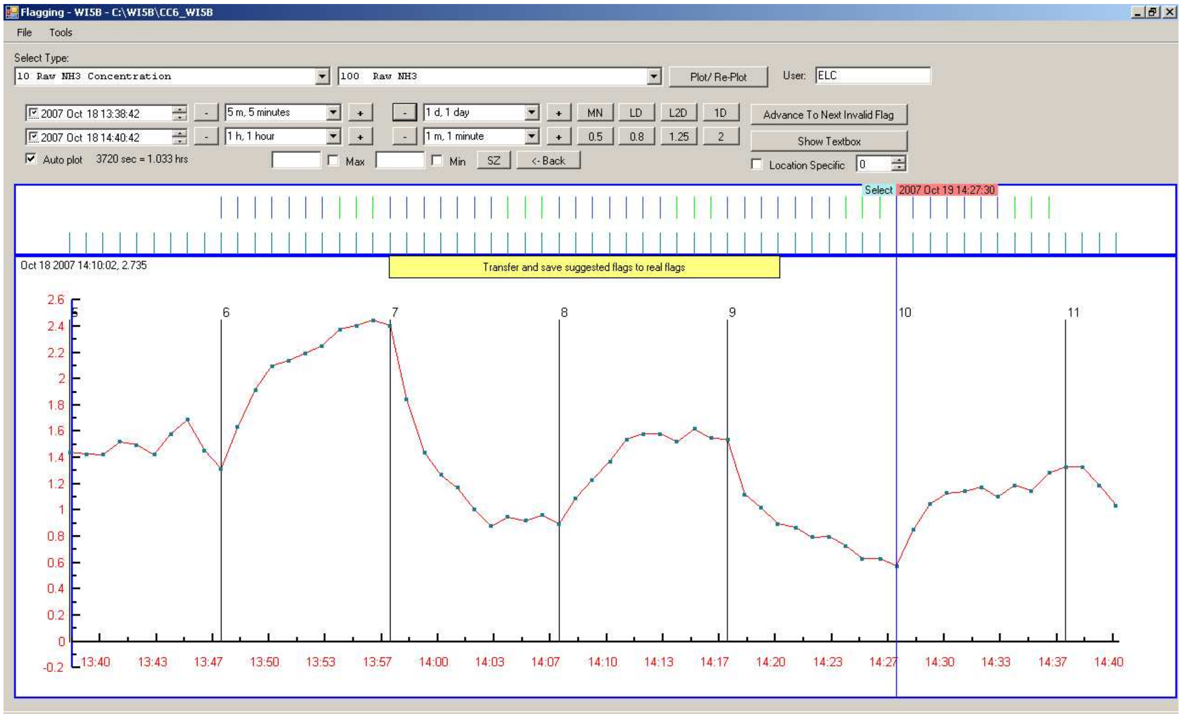
(a)



No: 1, Raw NH3 (ppm)
Col #: 100 (LV col: 3)
Location: 0
1
10. Raw NH3 Concentration
From 2007, October 1, 13:15
To 2007, October 1, 14:45
60
Time Interval = 1.5 Hrs
5
-0.1883993
Name
0.000875
October 01, 14:08:27 , 1.395
October 01, 13:53

(b)

Figure 5. Example (VB6 version) of using the Flagging program with ammonia measurements. Unflagged data (a) can be flagged using the suggested flags in the One Minute Flag Editor (b). The first 7 min of sampling period are invalidated (blue dots) because the analyzer is stabilizing, while the last 3 min of sampling period are valid (green dots).



Flagging - WI5B - C:\WI5B\CC6_WI5B

Select Type: 10 Raw NH3 Concentration | 100 Raw NH3

User: ELC

☑ 2007 Oct 18 13:38:42 | 5 m, 5 minutes | 1 d, 1 day

☑ 2007 Oct 18 14:40:42 | 1 h, 1 hour | 1 m, 1 minute

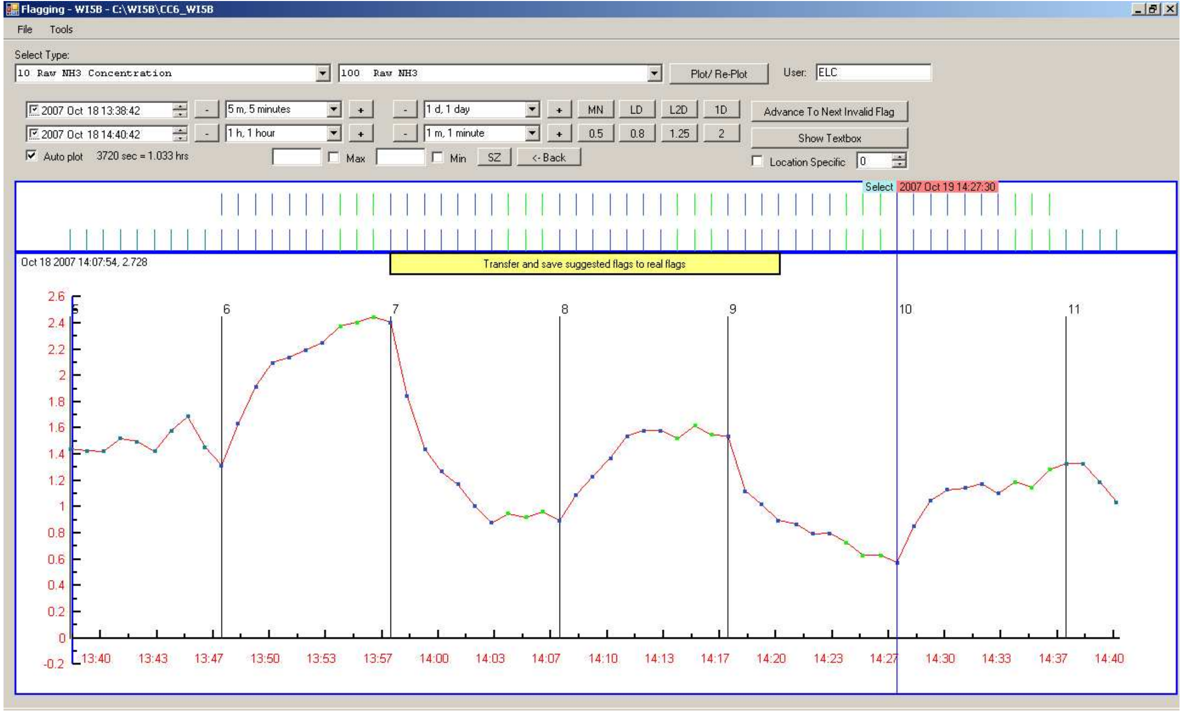
☑ Auto plot 3720 sec = 1.033 hrs

☐ Location Specific 0

Select 2007 Oct 19 14:27:30

Oct 18 2007 14:10:02, 2.735

(c)



Flagging - WI5B - C:\WI5B\CC6_WI5B

Select Type: 10 Raw NH3 Concentration | 100 Raw NH3

User: ELC

☑ 2007 Oct 18 13:38:42 | 5 m, 5 minutes | 1 d, 1 day

☑ 2007 Oct 18 14:40:42 | 1 h, 1 hour | 1 m, 1 minute

☑ Auto plot 3720 sec = 1.033 hrs

☐ Location Specific 0

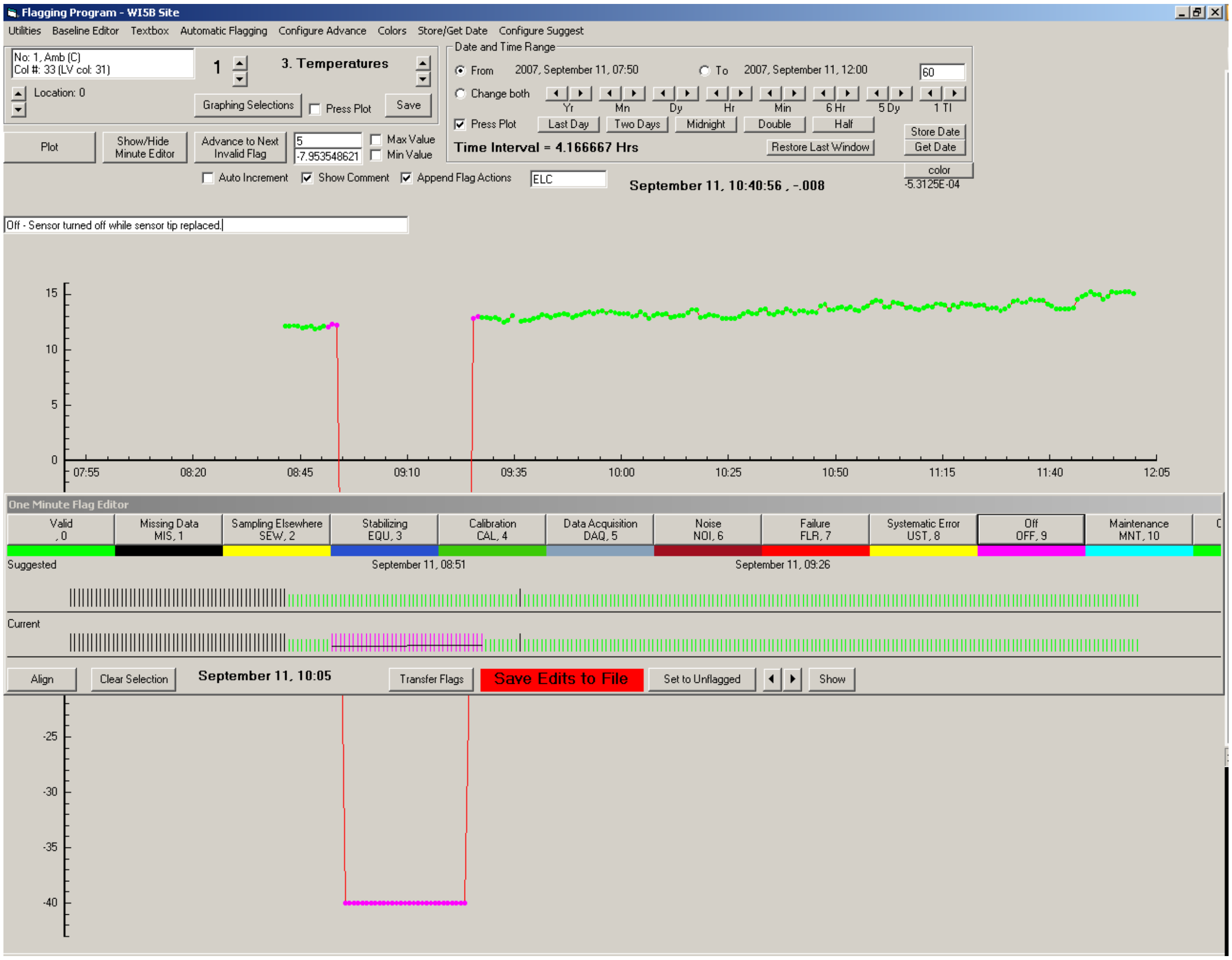
Select 2007 Oct 19 14:27:30

Oct 18 2007 14:07:54, 2.728

(d)

Figure 6 (cont). Example (.NET version) of using the Flagging program with ammonia measurements. As above, unflagged (c) and flagged (d) data are shown.

6.3.4. To manually flag data , click the “Show/Hide Minute Editor” button. Hold down the the left button of the mouse and drag a line across the desired range of data points. Click on the appropriate flag and add any appropriate comments in the text box on the upper left hand side of the form. Also, ensure that your name or initials are displayed in the text box in the middle of the form. Click “Save Edits to File” (Fig. 6). A record of manual flagging events containing the name of the user, the date and time the flag was made, and the flagged data information is stored in the flagevents.txt file in the dof_XXYB folder.



No: 1, Amb (C)
Col #: 33 (LV col: 31)

Location: 0

1 3. Temperatures

☐ Press Plot

● From 2007, September 11, 07:50 ○ To 2007, September 11, 12:00 60

○ Change both

☑ Press Plot

Time Interval = 4.166667 Hrs

5
-7.953548621
☐ Max Value
☐ Min Value

☐ Auto Increment ☑ Show Comment ☑ Append Flag Actions ELC

September 11, 10:40:56 , -.008

color
-5.3125E-04

Off - Sensor turned off while sensor tip replaced.

September 11, 08:51

September 11, 09:26

September 11, 10:05

Figure 6. An example of manually flagging data using the One Minute Flag Editor.

6.4. Perform calculations and import data using ImportExport program.

6.4.1. Open the program; Click “Go To” on the menu bar and select the “Calculate” function.

6.4.1.1. Select the file that has the equations to be used for data processing (Fig. 7).
6.4.1.2. Select the worksheet that contains the equations, each file can have multiple equation worksheets, for different measurement data analysis.

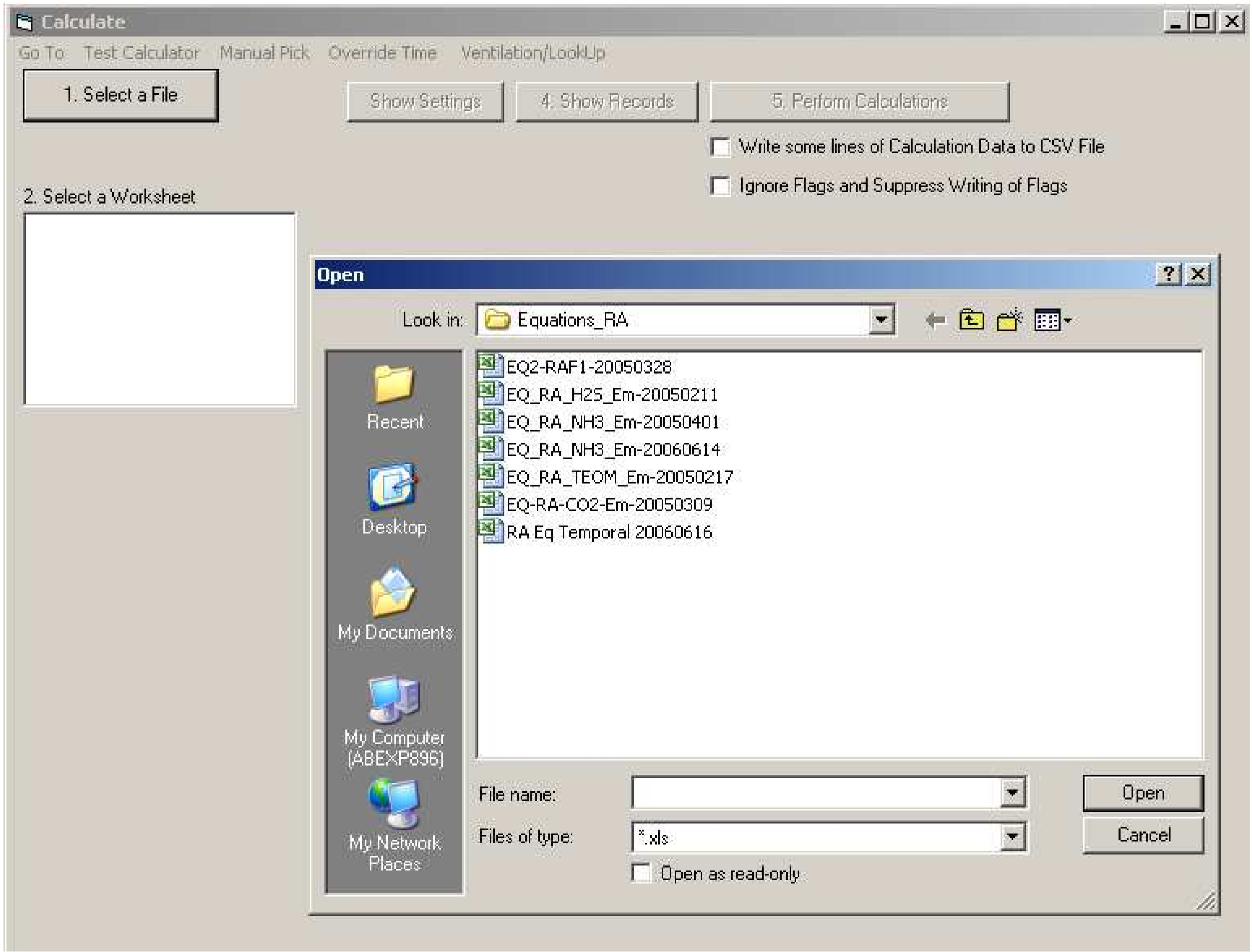


Figure 7. An example of ImportExport program, showing the screenshot of selecting the equation files to execute calculation.

6.4.1.3. An equation similar to the following will be used to adjust gas concentration measurement based on precision check data:

3/6/06 13:55; 3/8/06 13:34; c172=c170*A1; A1s =0.97; A1e=0.99

where the two sets of date and time specify the calculation period; c172 is the adjusted gas concentrations; c170 is the gas measurement data; and A1 is the linearly interpolated values based on the precision checks: A1s is the beginning precision check ratio (span/as-found ratio), and A1e is the ending precision check ratio.

6.4.1.4. An equation similar to the following will be used to calculate emission rate for a specific air stream:

3/6/06 13:55; 3/8/06 13:34;
c223=EmissionV(c18,17.03,c41,c143,valid(c180,ave1(c177,c181)),c183,1000)

where c223 is the calculated ammonia (NH3) emission rate and.EmissionV is a custom function that utilizes many required variables, including atmospheric pressure(c18), molecular weight of NH3 (17.03), exhaust air stream temperature (c41), airflow rate (c143), exhaust or neighboring exhaust concentrations (c189, c177 and c181), incoming airflow (background) concentration, and a multiplication factor of 1000. The valid function selects the value within the parenthesis when the first column (c180) of data is missing or invalid. The ave1 function return the mean value of c177 and c181, and returns the other value when either one is missing or invalid).

6.4.2. ImportExport is also used to import non-AirDac data from various sources (e.g., manure properties data).
6.4.2.1. Prepare a comma-separated data file from a template file. Do not change the format of the cells in the first 5 rows and 4 columns. However, change the CAPECAB database column number to indicate the destination of the data.
6.4.2.2. Copy and paste the date and time, and data values into the corresponding cells. The duration between each date and time values is flexible, and the values between these two times can be based on a step change, linearly interpolated, or no change.
6.4.2.3. Save and exit the comma separated file before importing the data.
6.4.2.4. Start the ImportExport program, and select the “Misc Import” function.
6.4.2.5. Click on “Pick a file” to select the data file for the program to read data.
6.4.2.6. Click on “Get Transfer Array” to check the details of the format and data to be imported.
6.4.2.7. Click on “Process the File” to import the data.

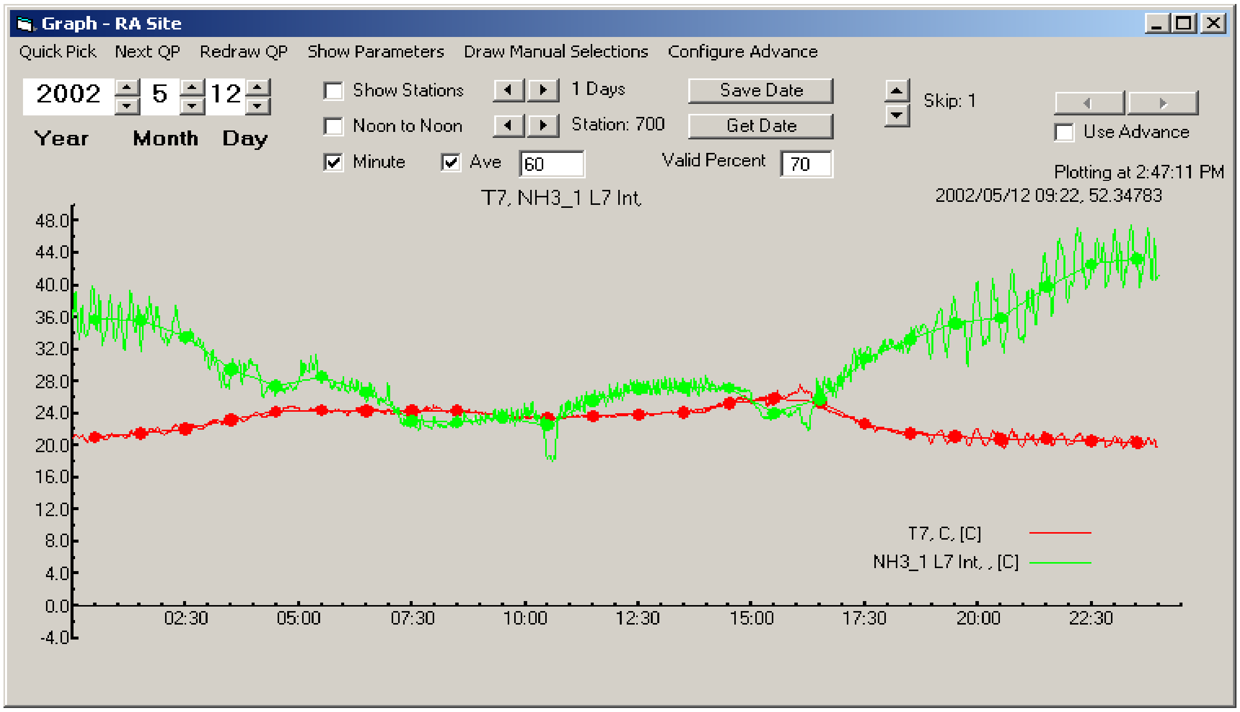
6.4.3. ImportExport can also be used to import non-AirDac date using pre-configured import settings. This function is generally reserved for animal data collected from the producer (e.g. animal inventory, feed consumption).
6.4.3.1. Prepare an ImEx_Info6_XX.csv file, using a previous file as a template.
6.4.3.2. Fill in the required information pertaining to the source columns of data in an Excel spreadsheet, and the destination columns of the CAPECAB database.

6.5. Check and export data using the Display program.

6.5.1. The program consists of two major functions: ShowGraph and ShowTextBox. They share many features. Use ShowGraph to display results as graphs, and ShowTextBox to display data in tabular format.

6.5.2. An important feature of the Display program is allowing a user-defined data completeness percentage such as 75% when calculating period means to avoid bias. Only mean values which meet or exceed the user-defined data completeness percentage for valid data are presented. This is typically 75%, but will be specified in the QAPP

6.5.3. ShowGraph allows plotting one to four columns of data (Fig. 8).



Graph - RA Site

2002 Year 5 Month 12 Day

☐ Show Stations

☐ Noon to Noon

☑ Minute ☑ Ave 60

1 Days

Station: 700

Valid Percent 70

Skip: 1

☐ Use Advance

Plotting at 2:47:11 PM

T7, NH3_1 L7 Int,

2002/05/12 09:22, 52.34783

Figure 8. An example of Display-ShowGraph program, displaying the correlation between ammonia concentration and exhaust temperature.

6.5.3.1. The program displays one-minute averages and/or any user-specified averages. For example, to check and export three-hour averages of data, set the number of minutes to read to 180. Fig. 8 shows temperatures and NH_3 concentrations of sampling location 7; in this figure, the thin lines are one-minute averages, while the dots indicate 60-min averages.

6.5.3.2. When viewing smaller samples of data, the individual points are shown in colors that indicate valid or invalid flags.

6.5.4. ShowTextBox presents and exports any number (or all) of data columns.

6.5.4.1. Users can see and export unlimited number of rows of data (Fig. 9).

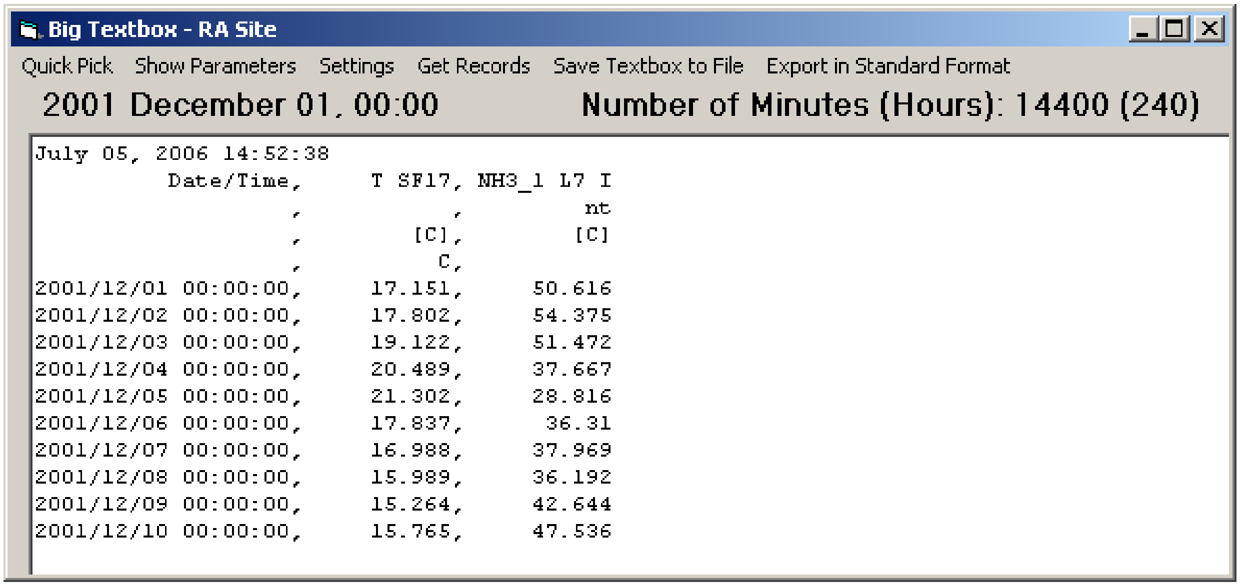
6.5.4.2. The program also allows users to define average periods (Fig. 10). Other useful functions include selecting the minimum percent data completeness for mean calculations, and showing blank when there is not enough valid data to meet the required completeness level.

7. Records Management

7.1. Manage data files according to SOP B5.

7.2. Whenever data is flagged as invalid in the flagging or data-inspection process, record the reason and period in the data processing notebook (or electronic file).

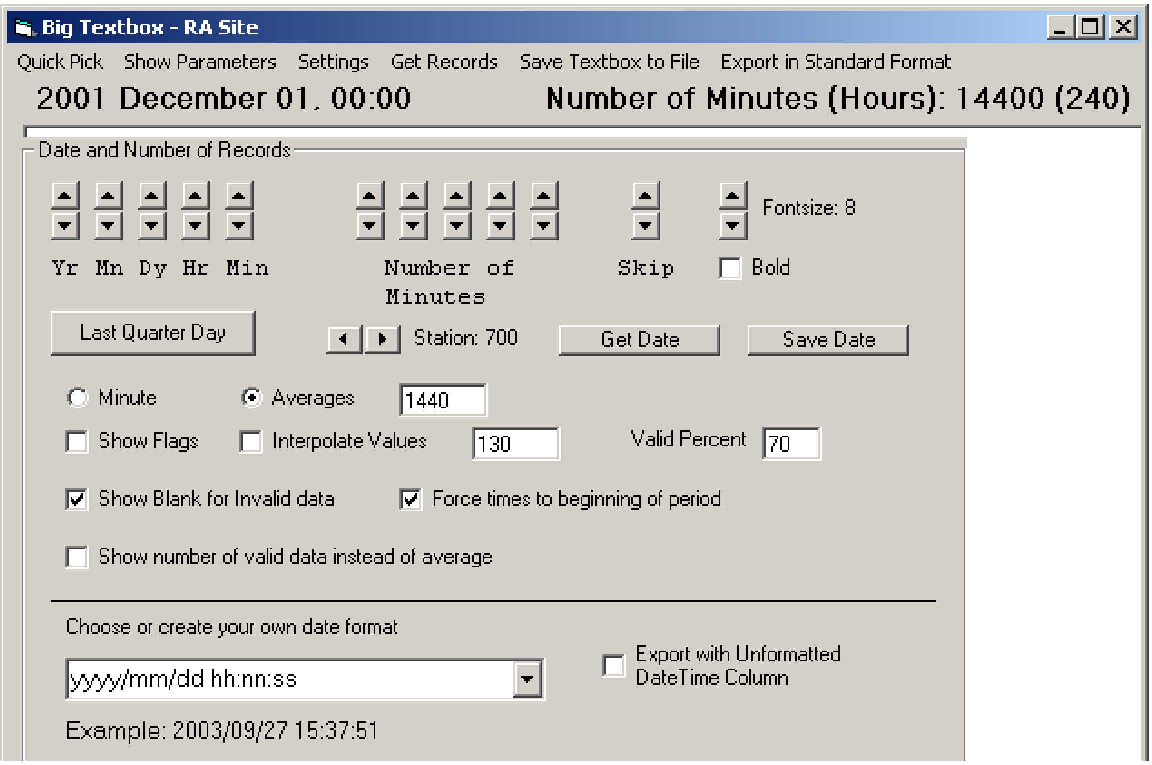
7.3. Record other information including date, analyst name, site name, and narrative.



2001 December 01, 00:00   Number of Minutes (Hours): 14400 (240)

```
July 05, 2006 14:52:38
          Date/Time,     T SF17, NH3_1 L7 I
                   ,           ,         nt
                   ,        [C],        [C]
                   ,          C,
2001/12/01 00:00:00,     17.151,     50.616
2001/12/02 00:00:00,     17.802,     54.375
2001/12/03 00:00:00,     19.122,     51.472
2001/12/04 00:00:00,     20.489,     37.667
2001/12/05 00:00:00,     21.302,     28.816
2001/12/06 00:00:00,     17.837,      36.31
2001/12/07 00:00:00,     16.988,     37.969
2001/12/08 00:00:00,     15.989,     36.192
2001/12/09 00:00:00,     15.264,     42.644
2001/12/10 00:00:00,     15.765,     47.536
```

Figure 9. An example of Display-ShowText window, displaying daily mean ammonia concentrations and exhaust temperatures for 240 h (10 d).



2001 December 01, 00:00   Number of Minutes (Hours): 14400 (240)

Fontsize: 8

☐ Bold

Station: 700

○ Minute   ● Averages 1440

☐ Show Flags   ☐ Interpolate Values 130   Valid Percent 70

☑ Show Blank for Invalid data   ☑ Force times to beginning of period

☐ Show number of valid data instead of average

yyyy/mm/dd hh:nn:ss   ☐ Export with Unformatted DateTime Column

Example: 2003/09/27 15:37:51

Figure 10. An example of Display-ShowText setting window, displaying the selections for displaying data shown in Fig. 8.

8. Quality Control and Quality Assurance

8.1. Compare data converted into the CAPECAB database to the original tabular data, for any inconsistencies. Check at least several days of data to make sure the one-minute values agree, and data columns are consistent.

8.2. If the format of tabular data is changed (e.g., removed, added, or switched columns), make sure the changes and time are recorded in the data processing notebook and update the Convert files accordingly.

8.3. Check the flagging program and processed data to make sure only equilibrium data is extracted as intended.

8.4. Closely monitor the measurement data and calculations, especially the diurnal and seasonal variations. When processing weeks or months of data, spot check results to insure accuracy and correctness. A spot check of one day per three months of data should be conducted. The important variables, such as airflow and emission values should be calculated by another person, and compared with the results obtained using CAPECAB.

8.5. If a variable(s) is observed to be irregular or doubtful, select other variables to inspect and verify by using the CAPECAB program. Inspecting the closely correlated variables (such as concentration, temperature and ventilation rate) or measurements at adjacent sampling location(s) is essential for data quality.

8.6. Users can easily modify the time period (1 h, 2 d, several weeks) of averages and unlimited number of columns and rows of data for inspection.

8.7. Inform the measurement site personnel when an error is found and/or corrective action is needed.

9. References

9.1. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

9.2. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.

9.3. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.

9.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

9.5. SOP G9. 2006. Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.

10. Contact Information

10.1. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com

OPERATION OF THE THERMO ELECTRON MODEL 146C MULTI-GAS DILUTER
Standard Operating Procedure (SOP) C3

OPERATION OF THE THERMO ELECTRON MODEL 146C MULTI-GAS DILUTER

Standard Operating Procedure (SOP) C3

Prepared by
Congna Li

Reviewed by
Bill W. Bogan and Richard H. Grant

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Precise dilution of manufacturer-supplied gases is required during the calibration of the open-path monitoring instruments that are used to monitor emissions from confined animal feeding operations (such as corrals) and open sources (such as lagoons) at livestock facilities.

  1.1.1. Typical dilution ratios needed to calibrate open-source monitoring instruments, such as UV-DOAS (SOP C1) and TDLAS (SOP C2) systems are approximately 100:1 to 1000:1.

1.2. This procedure describes the setup and operation of the Thermo Electron Corporation Model 146C Dynamic Gas Calibrator.

  1.2.1. The Model 146C can handle zero air flows of 0.2-10 L/min, and span gas flows of 1.0-50 sccm.

  1.2.2. The accuracy of each mass flow measurement is 2% of reading or 1% of full scale, whichever is less.

  1.2.3. Linearity of mass flow measurement is 0.5% of full scale.

  1.2.4. Repeatability of mass flow measurement is 2% of reading or 1% of full scale, whichever is less.

  1.2.5. Permeation oven temperature stability is 0.1°C.

2. Summary of Method

The Thermo Environmental Model 146C Multigas Calibrator precisely dilutes calibration gases, which can then be used for precision and Level I span checks, audits, and multipoint calibration of various instrumentation. The Model 146C integrates mass flow controllers, an ozone generator, a permeation tube oven, power supplies, and solenoid valves into a single microprocessor-controlled unit, which can also be controlled remotely using a datalogger or computer. The calibrator uses either permeation tubes (optional add-on) or standard gases as calibration gas sources. The standard Model 146C hardware/plumbing configuration mixes gas and zero air flows. The basic unit can handle three gas standards, which are controlled by individual solenoids and regulated by mass flow controllers; the zero air controller is high-flow, while the gas flow controller is low-flow. The desired concentration is produced in a Teflon mixing chamber. When a permeation gas source is used in conjunction with the gas dilution system, permeation dilution concentration is calculated based on the permeation rate and the flow rate of zero air controlled by the gas dilution system. The permeation oven heats a permeation tube that supplies an internal source of calibration gas. A small amount of zero-air flows through the permeation tube oven and is mixed with the remainder of the zero-air flow in the mixing chamber. Accuracy is achieved through precise control of the release rate of the permeation tube gas and the flow of zero air through the zero-air mass flow controller, as well as maintenance of a stable permeation tube temperature. When only the permeation oven is activated, up to five gas concentration levels (ppm) can be set.

3. Definitions

3.1.	LED	Light-emitting diode
3.2.	MFC	Mass flow controller
3.3.	NIST	National Institute of Standards and Technology
3.4.	QAPP	Quality Assurance Project Plan
3.5.	sccm	Standard cubic centimeters per minute
3.6.	TDLAS	Tunable diode laser acoustic spectroscopy
3.7.	UV-DOAS	Ultraviolet differential optical absorption spectroscopy

4. Health and Safety

4.1. Be careful when connecting the precision standard and dilution gas cylinders to the diluter, especially in the case of toxic, reactive, or otherwise hazardous gases. See SOP G2 for more information on handling gas cylinders.
4.2. Avoid mixing gases that may produce an explosion or other hazardous reaction.
4.3. Be careful when making electrical connections, disconnecting and connecting connectors and making voltage measurements in the instrument as high voltage or current can injure or kill.
4.4. Disconnect power before servicing the unit.

5. Cautions

5.1. Verify that the scheduled calibration date is prior to the expiration date specified on the EPA protocol calibration gas cylinder. Do not use expired cylinders.
5.2. Leave the power on at all times when a permeation tube has been installed. The zero air-air supply should also be connected and active to allow a small flush flow across the permeation tube.
5.3. When determining the actual flow through the mass flow controller, use the LED reading, and not the value set on the potentiometer.

6. Interferences

6.1. Reactive compounds can be lost in this instrument. Follow the procedure to verify that reactive compounds are not lost in the gas dilution system, especially in Methods 15[*], 16, and, 25A and 25B (40 CFR part 60, appendix A) when using a gas other than propane.

7. Personnel Qualifications

7.1. Each operator must read and understand this SOP and SOP G2 before working with the instrument. Any operator using this instrument to calibrate the UV-DOAS and/or TDLAS instruments must also read and understand SOP C1 and/or C2, respectively.

7.2. Each operator must be trained in the use of the handheld multimeter, the barometer, water bath, and mass balance before initiating the procedure.

8. Equipment and Supplies

8.1. Model 146C Dynamic Gas Calibrator (Thermo Electron Corporation, Waltham, MA)
8.2. Permeation tube oven and permeation tube(s) containing appropriate gas(es) (optional)
8.3. Internal ozone generator (optional)
8.4. Teflon tubing
8.5. Zero air and span gas cylinders (EPA protocol standard, 1% certification)
8.6. Stainless steel dual-stage gas cylinder regulators as appropriate for the particular gas(es) (SOP G2)
8.7. Wrench to manipulate gas cylinder connections
8.8. NIST-traceable flow calibrator
8.9. NIST-traceable thermometer with a range of 0-45°C
8.10. Water bath (heatable to 45°C)
8.11. Barometric pressure sensor
8.12. Balance with 0.01 mg accuracy
8.13. Ambient air temperature sensor
8.14. 4.369-KΩ Resistor or resistance box capable of providing 4.369 KΩ
8.15. Wire leads with clips to connect to resistance box
8.16. Multimeter

9. Procedure

9.1. Instrument Setup
  9.1.1. Connect a source of zero air to the inlet port labeled “ZERO AIR” (Fig. 1).
  9.1.2. The zero air source must be capable of supplying the full-scale flow required by the zero air controller (up to 10 L/min) at a pressure between 10 and 40 psi.
  9.1.3. Connect the standard gas cylinders to the ports labeled A, B and C (Fig. 1).

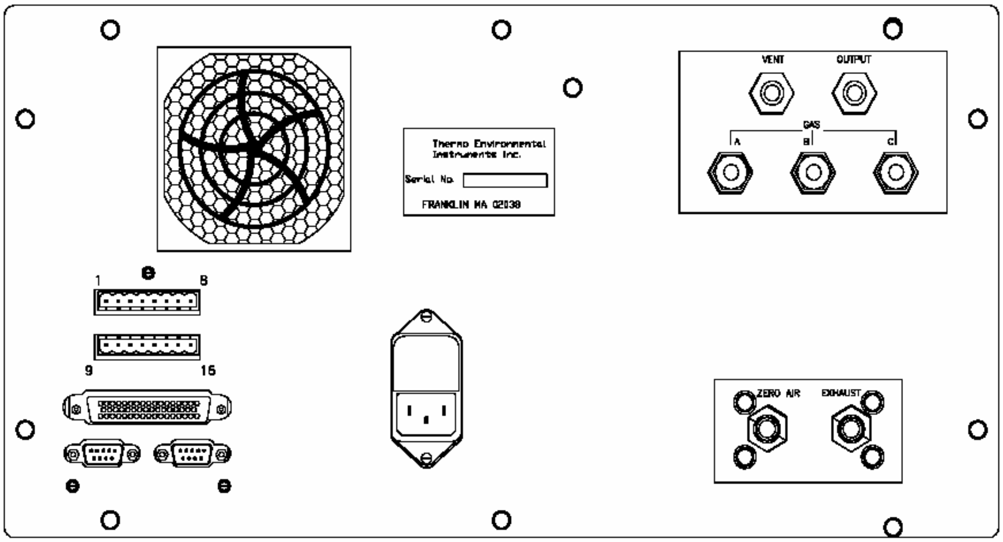


Figure 1. Model 146C Rear Panel.

9.1.4. Install the permeation tube using the following procedure (applicable only if the permeation option is installed):

9.1.4.1. Remove the instrument cover and locate the permeation oven (Fig. 2).

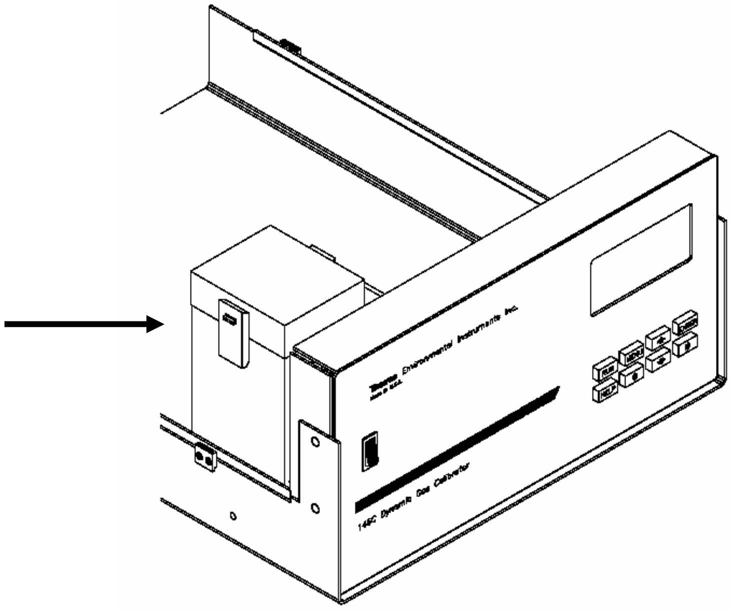

Permeation oven

Figure 2. Removing cover of the TEI 146C to access the permeation oven.

9.1.4.2. Release the latches on the sides of the oven cover, and remove the cover.
9.1.4.3. Remove glass chamber assembly by loosening (not removing) knurled screw, located at the top of the chamber, and gently pulling assembly upward. Completely remove assembly from oven (Fig. 3).
9.1.4.4. Separate the glass chamber from the top assembly by twisting and gently pulling glass away from top. Keep glass clean by using Kimwipes or similar material to handle glass.
9.1.4.5. Place permeation tube in chamber.
9.1.4.6. Attach glass chamber to top assembly by gently pushing together with a slight twisting motion.
9.1.4.7. Replace glass chamber assembly into oven until top of assembly is flush or slightly below oven top (Fig. 4).
9.1.4.8. Tighten knurled screw with finger. Do not use tools to tighten.
9.1.4.9. Replace oven cover, being careful to place tubing and wire in slot of cover.

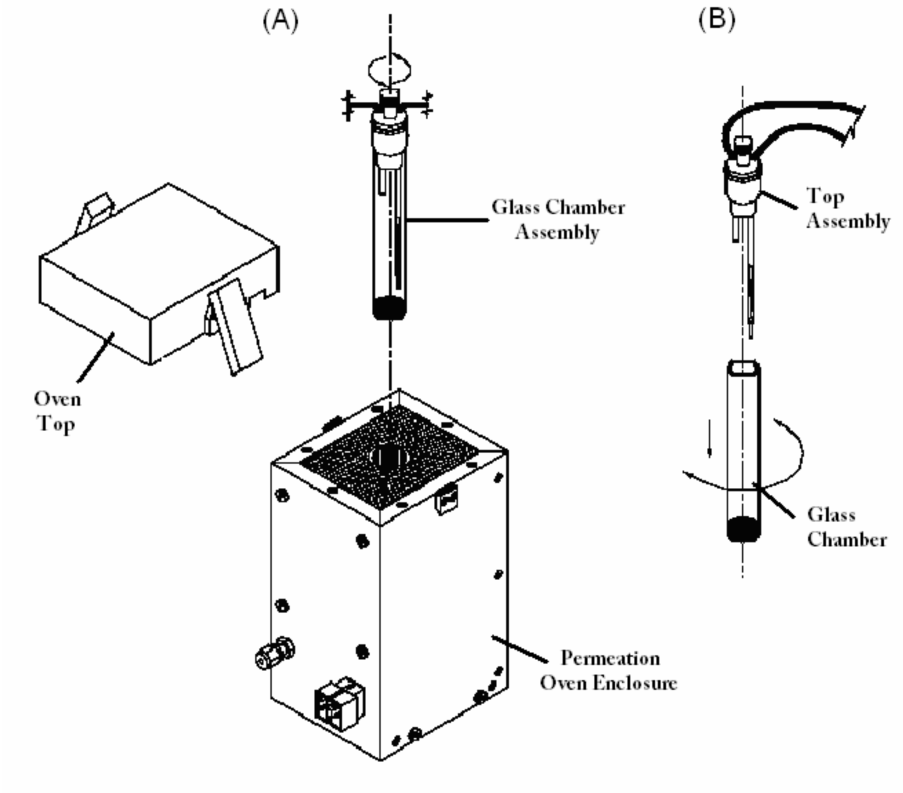


Figure 3. Removing glass chamber from permeation oven (A) and removing top assembly (B).

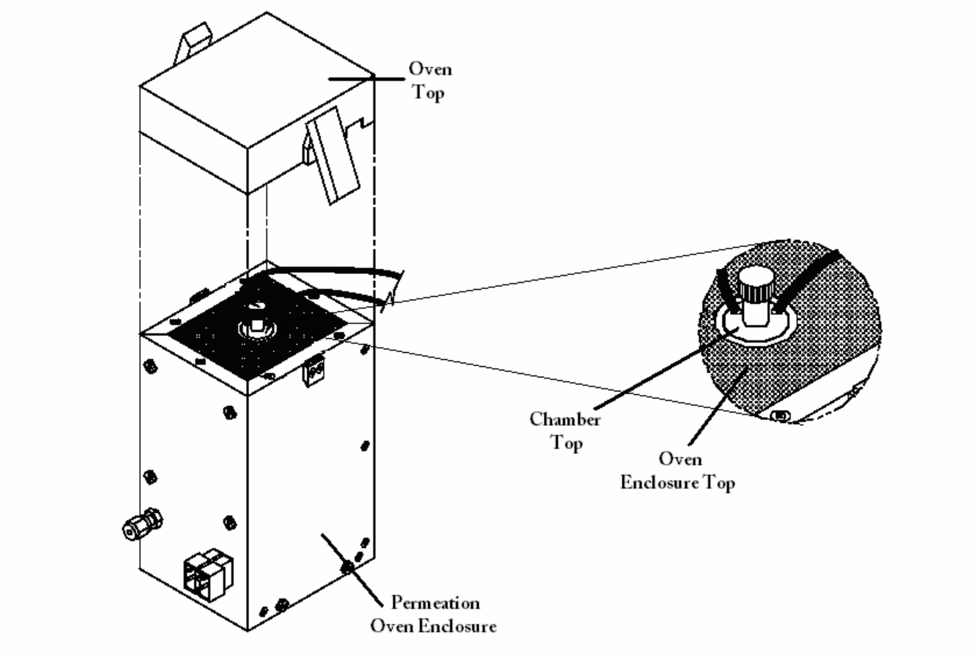


Figure 4. Replacing glass chamber. Inset shows chamber top flush with oven enclosure top.

9.2. Operation

9.2.1. Gas dilution using a gas cylinder

9.2.1.1. Press the "RUN" pushbutton, choose "Run Screen 1", press the "MENU" pushbutton, select the "Local" mode using the ↑ and ↓ pushbuttons, and press "ENTER". Press "MENU" to return to the Main menu.

9.2.1.2. From the "Main Menu", move to Gas A, B, or C by using the ↑ and ↓ pushbuttons. Press "ENTER" to select.

9.2.1.3. Select "Name", move the underscore to select a character, using the ← and → pushbuttons. Select a new character using the ↑ and ↓ pushbuttons. Press the "ENTER" pushbutton to save the selection.

9.2.1.4. Select "Tank Conc", enter the gas concentration using the ← and → and the ↑ and ↓ pushbuttons. Press "ENTER" to save the selection.

9.2.1.5. Select "Span 0 Flow", enter the value of the zero-air flow using the ← and → and the ↑ and ↓ pushbuttons. Press "ENTER" to save the selection.

9.2.1.6. Use the ← and → pushbuttons to select the desired span level (Span 1 to 5, or manual).

9.2.1.7. Select "Span", select the span gas concentration and total flow rate (sum of zero-air and span gas flow) using the ↑ and ↓ pushbuttons. Press "ENTER" to switch to the corresponding screen.

9.2.1.8. Under the "Span" menu, select "Conc PPM", enter the value of the diluted gas concentration using the ← and → and the ↑ and ↓ pushbuttons. Press "ENTER" to save your selection.

9.2.1.9. Under the "Span" menu, select "Span Flow", enter the value of the span gas flow rate using the ← and → and the ↑ and ↓ pushbuttons. Press "ENTER" to save your selection.

9.2.1.10. To manually set the zero-air and gas flows, select "Manual" after selecting Gas A, B, or C, use the ↑ and ↓ pushbuttons to select zero-air and gas flow. Press "ENTER". Then select "ZERO AIR SCCM" to display and modify the zero air flow setting manually, or select "Gas SCCM" to display and modify the span gas flow setting manually using the ← and → and the ↑ and ↓ pushbuttons. Press "MENU" to return to the upper menu or press "ALT" to return to the "Run" screen.

9.2.1.11. Computation of diluted gas concentrations

9.2.1.11.1.

$$\text{Model 146C output (ppm)} = \frac{F_{gas}}{F_{gas} + F_{zero\ air}} \times C_{cyl}$$

Where:
F_{gas} = Flow measured for cylinder gas, sccm.
$F_{zero\ air}$ = Flow measured for zero air, sccm.
C_{cyl} = Concentration of gas in cylinder, ppm

9.2.2. Gas dilution using the permeation tube oven

9.2.2.1. Allow 24 h for permeation tube temperature to stabilize after turning the unit on. If a permeation tube is purchased with a certified rate, R2, at a given temperature, T2, it is possible to calculate the approximate temperature T1 that is needed to achieve permeation rate R1, by using the following equation:

9.2.2.1.1.

9.2.2.1.2. Log R1=logR2-2950(1/T1-1/T2)

Where:
R_1 = Permeation rate in ng/min at T_1,
R_2 = Permeation rate in ng/min at T_2.

9.2.2.2. From Run Screen 1, use the ↑ and ↓ pushbuttons to scroll to the ozone/perm line.

9.2.2.3. Use the ← and → pushbuttons to select the desired permeation level (Perm Levels 1 through 5). Press "ENTER".

9.2.2.4. Set the flow of zero air in the manual settings screen of the flow controls menu.

9.2.2.5. Allow 24 h for the permeation tube temperature to stabilize.

9.2.2.6. Calculate the permeation rate, R, following Section 9.3.2.3.

9.2.2.7. Computation of diluted permeation gas concentrations

9.2.2.7.1. Model 146C output (ppm) = RK/Q_0

Where:

R = Permeation rate, ng/min
Q_o = Zero air flow rate, sccm
K = Constant for specific permeant = 24.45/MW
MW = Molecular weight of specific permeant

9.3. Calibration

9.3.1. Calibration of mass flow controllers

9.3.1.1. Connect a source of clean, dry air to the inlet of the mass flow controller.

9.3.1.2. Measure barometric pressure and room temperature.

9.3.1.3. Connect a suitable flow meter (NIST-traceable calibrator) to the mass flow controller outlet.

9.3.1.4. Set the Model 146C to “Gas Drive” or “Zero Air Flow Calibration”.

9.3.1.5. Enter the flow meter reading using the flow input screen.

9.3.1.6. Repeat the above two steps for the remaining flow settings.

9.3.1.7. If difficulty is encountered due to a malfunction of the flow controller, contact Thermo Environmental Instruments.

9.3.2. Calibration of permeation tube oven

9.3.2.1. Setting water bath to the desired temperature

9.3.2.1.1. Unplug the connector at J3, from the Oven Controller Board (Fig. 5). Place a 4.369-KΩ resistor across pins 3 and 4 of J3 on the Oven Controller Board.

9.3.2.1.2. From the Permeation Oven Menu, select Cal Oven Thermistor. Adjust R2 on the Oven Controller Board until the oven drive voltage is 5.000 volts. Press MENU to return to the Permeation Oven Menu.

9.3.2.1.3. Remove the thermistor from the permeation tube oven. Leave the thermistor connected to the Oven Controller Board. Insert the thermistor into a water bath next to the NIST-traceable thermometer.

9.3.2.1.4. Turn on the power to the water bath. Using a NIST-traceable thermometer with a resolution of ±0.01°C, adjust water bath to 45.00±0.02°C.

9.3.2.1.5. From the Permeation Oven Menu, select Cal Gas Thermistor. Adjust R4 on the Oven Controller Board until the permeation gas temperature reading is 45.00°C.

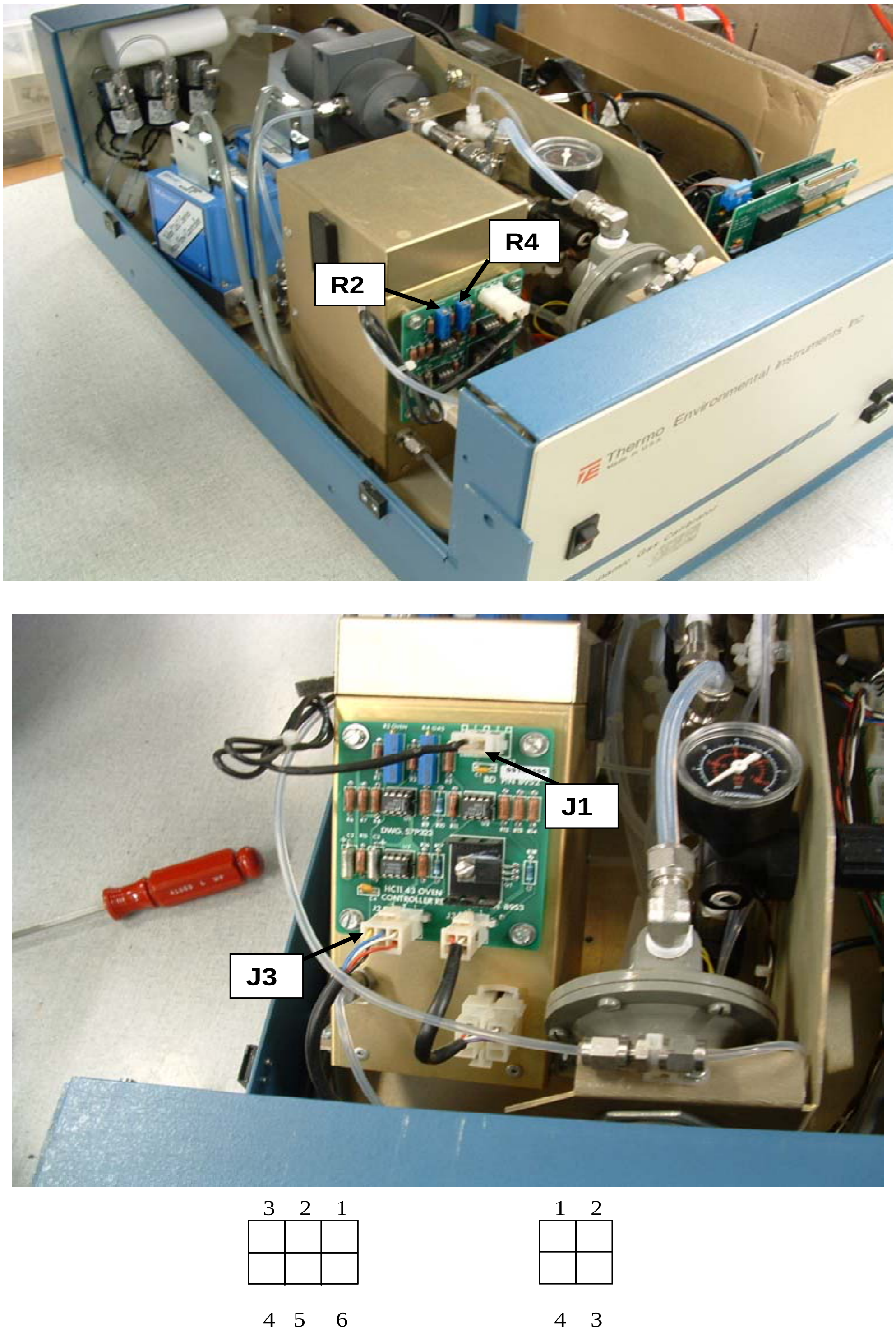
9.3.2.1.6. Remove thermistor from the water bath, dry, and replace into the permeation tube oven.

9.3.2.1.7. Wait for the permeation gas temperature reading to stabilize.

9.3.2.1.8. From the Permeation Oven Menu, select Set Gas Temperature. Adjust R2 until the Perm Gas reading displayed on the first line is 45.00°C. Wait at least 10 min between adjustments.

9.3.2.2. Setting measure temperature with accurately known oven temperature (as an alternative approach to that described in Section 9.3.2.1)

9.3.2.2.1. Unplug the connector at J3, from the Oven Controller Board. Place a 4.369 KΩ resistor across pins 3 and 4 of J3 on the Oven Controller Board.



J3 Pin Layout J1 Pin Layout

Figure 5. The permeation oven controller board, showing the board's location, the locations of R2, R4, J1 and J3 on the board, and the pin layouts of J1 and J3.

9.3.2.2.2. From the Permeation Oven menu, select Cal Oven Thermistor. Adjust R2 on the Oven Controller Board until the oven drive voltage is 5.000 volts. Press MENU to return to the Permeation Oven menu.

9.3.2.2.3. Unplug the thermistor from J1 on the Oven Controller Board.

9.3.2.2.4. Connect a resistance of 4.369 KΩ across pins 1 and 2 of J1.

9.3.2.2.5. From the Permeation Oven menu, select Cal Gas Thermistor. Adjust R4 on the Oven Controller Board until the permeation gas temperature reading is 45°C.

9.3.2.2.6. Reconnect the thermistor to J1.

9.3.2.2.7. Wait for the permeation gas temperature reading to stabilize.

9.3.2.2.8. From the permeation oven menu, select Set Gas Temperature. Adjust R2 until the Perm Gas reading displayed on the first line is 45.00°C. Since it takes several minutes for the permeation oven temperature to stabilize, wait 10 min between adjustments.

9.3.2.3. Determination of permeation rate by weight loss

9.3.2.3.1. Make sure the oven has been calibrated as described above.

9.3.2.3.2. Gently insert the permeation tube using clean tweezers or similar tool. Never touch the tube with your fingers.

9.3.2.3.3. Turn on the Model 146C.

9.3.2.3.4. Wait 48 to 72 hours for the permeation tube temperature to stabilize.

9.3.2.3.5. Carefully remove the permeation tube from the oven and weigh permeation tube to nearest 1 mg. Perform this measurement as quickly as possible.

9.3.2.3.6. Return permeation tube to the oven.

9.3.2.3.7. Allow permeation tube to permeate at constant temperature with gas flow over tube for a period sufficient to generate a measurable weight loss (usually a minimum of 72 h).

9.3.2.3.8. Reweigh permeation tube to nearest 1 mg.

9.3.2.3.9. Compute the permeation rate, R, in terms of ng/min as:

$$R = (\text{Initial weight}-\text{Final weight})/\text{Time}.$$

9.3.2.3.10. Use the permeation tube in the same oven that was used to determine the permeation tube's weight loss.

9.3.2.4. Determination of release rate by use of transfer standard

9.3.2.4.1. To perform this procedure, one Model 43C and two Model 146Cs are needed.

9.3.2.4.2. Ensure that the ovens in both of the Model 146Cs have been calibrated.

9.3.2.4.3. Determine permeation rate for permeation tube in Model 146C being used as calibration standard, or install a certified permeation tube.

9.3.2.4.4. Allow the permeation tubes in both Model 146Cs to stabilize at least 48 h.

9.3.2.4.5. Carefully calibrate an analyzer, such as a Thermo Environmental Model 43C, using the Model 146C with the calibrated permeation tube. Follow the instruction for calibration in the 43C instrument manual.

9.3.2.4.6. Connect calibrated analyzer to Model 146C with permeation tube whose permeation rate is to be determined.

9.3.2.4.7. Adjust flow of the Model 146C so that the analyzer reads close to full scale. Note flow and measured concentration.

9.3.2.4.8. Compute permeant concentration from the following equation:

$$\text{Model 146C output (ppm)} = \frac{R \times K}{Q_o}$$

Where:

R = Permeation rate, ng/min

Q_o = Flow rate, sccm

K = Constant for specific permeant $= \dfrac{24.45}{MW}$

MW = Molecular weight of specific permeant

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this instrument. Supplement this electronic record by a record book designated for this instrument, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all such corrections.

10.4. A copy of the manufacturer' instructions for the operation of the instrument, as well as the most recent calibration documentation shall be made available for the project auditor's inspection upon request.

10.5. A label (Fig. 6) shall be affixed at all times to the gas dilution system listing the date of the most recent calibration, the due date for the next calibration, and the person or manufacturer who carried out the calibration.

Calibration date:__________________
Next calibration due date:__________
Calibrated by:____________________

Figure 6. Sample calibration label.

11. Quality Control and Quality Assurance

11.1. Check and recalibrate the mass flow controller, using a NIST-traceable flow calibrator, whenever the target and actual flow (within the range of 20 to 100% of full scale) deviates greater than ±2% of reading or 1% of full scale, whichever is less. The QAPP for the particular project may have additional requirements.

11.2. Calibrate the permeation tube oven whenever the temperature indicator deviates by 0.2°C (an error of about 0.1°C corresponds to an error of 1% in release rate).

11.3. Calibrate the flow calibrator, thermometer, water bath, barometric pressure sensor, balance and ambient air temperature sensor at the initiation of the study and annually thereafter, unless the QAPP specifies otherwise.

12. References

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TEMPERATURE MEASUREMENT USING THERMOCOUPLES
Standard Operating Procedure (SOP) E1

TEMPERATURE MEASUREMENT USING THERMOCOUPLES

Standard Operating Procedure (SOP) E1

Prepared by
Matthew J. Darr (Ohio State Univ.) and Bill W. Bogan

Reviewed by
Sam Hanni, Teng Lim, Albert J. Heber and Kenneth D. Casey (Texas A&M Univ.)

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Temperature measurements at barns during emissions tests are needed for several reasons.
  1.1.1. Temperature information is needed to make density corrections in the course of determining pollutant concentrations in air.
  1.1.2. Temperature readings are used by the barn’s environmental control system to control fans, heaters, and cooling systems.
  1.1.3. Temperature is important to assess environmental conditions for instruments, people, and animals.
  1.1.4. Temperature is needed to assess and diagnose the environmental processes within the building.
  1.1.5. Temperature affects biological activity, which in turn affects gas emissions.
1.2. This method is specific for Type T thermocouples, which are used with the National Instruments (NI) Model FP-TC-120 signal input module.
1.3. Type T thermocouples are suitable for use within the range of -200 to +350 °C, in mildly oxidizing or reducing environments, and in moist air.
1.4. Because copper/constantan wires can be manufactured to a greater level of homogeneity than most other thermocouple alloys, the measurement error due to wire heterogeneity is smaller, and Type T thermocouples are more accurate than other types. The overall degree of error associated with this method is < ±2 °C within the expected temperature range of -30°C to 40°C.
  1.4.1. The stated standard error for Type T thermocouples is ±1°C or ±0.75% of reading (whichever is greater).
  1.4.2. Cold-junction accuracy for the NI FP-TC-120 input module is 0.15 – 0.30°C.
  1.4.3. Linearization algorithms used by the signal input module are accurate to within ±0.05°C, and are therefore a negligible source of error.
1.5. The locations for positioning thermocouples at a particular site will be specified in the project QAPP, specifically, in the Site Monitoring Plan.

2. Summary of Method

The method described in this SOP measures temperatures through the use of copper/ constantan thermocouples (Type T). The thermocouple is the joint formed by the ends of two copper/constantan wires, which have been twisted together. Each thermocouple is individually connected to a signal input module (NI FP-TC-120). This connection is accomplished through the FP-TB-3 isothermal terminal base, such that all terminals are kept at the same temperature. The TC-120 collects data as described in PAAQL SOPs B1 and B2.

3. Definitions

3.1. Cold junction	The junction formed by joining the thermocouple wires (or their extensions) to the instrument wires. The temperature-dependent voltage created by this junction must be taken into account when determining the temperature at the

		thermocouple tip. This "Cold-junction compensation" function is built into the FP-TC-120 Input Module.
3.2.	Constantan	Any one of a group of copper/nickel alloys that are particularly well-suited for use in thermocouples. Typical constantan compositions used in thermocouples are 40% nickel and 60% copper, with very low thermal expansion coefficients.
3.3.	DAC	Data acquisition and control
3.4.	Electromotive force (emf)	The energy per unit charge that is converted reversibly from (in this case) thermal energy into electrical energy in a metal wire. This quantity will vary depending upon the precise metal composition of the wire or thermocouple.
3.5.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.6.	SOP	Standard Operating Procedure

4. Health and Safety

4.1. Make sure that all wiring meets applicable electrical codes.
4.2. Extreme care should be taken when installing the wiring near animal cages.

5. Cautions

5.1. Thermocouple output signals are prone to picking up electrical "noise". However, unless thermocouples are run in the direct vicinity of power lines, the electrical fields encountered in barns should not be strong enough to cause enough noise to affect this type of thermocouples. The FP-TC-120 rejects "common mode noise" (noise that is common to both wires in the extension cable); thus, if thermocouples must be run through areas with stronger electrical fields, twist the two wires together to ensure that noise signals will be picked up by both wires. Pre-twisted wire can also be purchased commercially.

5.2. Heat dissipated from adjacent equipment (including other thermocouple input modules) can generate thermal gradients by heating up the terminals to different temperatures relative to each other and to the sensor used to measure the cold-junction temperature. The FP-TC-120 is capable of correcting for the errors produced by a gradient of up to 0.2 °C; this is equivalent to a heat dissipation of approximately 4 W. Take steps to ensure that no other equipment in the vicinity of the TC-120 is dissipating more heat than this. Special care should be taken to locate voltage conversion devices (power supplies, computers, AC powered sensors) at least 0.5 meters away from the FP-TC-120 due to their high heat output rates.

5.3. Thermocouple wire itself can be a source of thermal gradients, by conducting heat to or from the terminal connection (depending upon the temperature encountered elsewhere by the wire). Minimize this phenomenon taking the following precautions:

5.3.1. Run extension wires to different thermocouples together as much as possible to keep all wires at the same temperature.

5.3.2. Avoid running thermocouple extension wires near objects that are (or may be) hotter or colder than the rest of the environment.
5.4. Store thermocouple wire in a dry, clean location.
5.5. Do not use any oils or solvents on any part of a thermocouple assembly.

6. Interferences

6.1. Use of other than Type T extension wire will introduce larger error limits, as dissimilar metals or alloys will not display the same emf at a given temperature. Use only Type T thermocouple wire when repairing damaged thermocouples.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the equipment (including thermocouples and their corresponding data acquisition modules) before initiating the procedure.
7.2. Personnel should be trained in proper fabrication and maintenance of thermocouples and thermocouple junctions before installation.
7.3. Each analyst must read this SOP before initiating the procedure.

8. Equipment and Supplies

8.1. Type T (copper/constantan) thermocouple wire, Type T twisted pair, 20 ga (ThermoElectric Wire & Cable, Saddle Brook, NJ), or equivalent
8.2. Heat-shrinkable tubing
8.3. Heat gun or hand-held torch
8.4. Pliers with wire cutters and wire strippers
8.5. Temperature probe for field calibration checks. Required specifications are ±0.2°C accuracy @ 20°C and NIST traceability.
8.6. Hg thermometer with a -10 ºC to 110ºC range (0.5 ºC scale), checked to agree with the temperature probe to within 1.0 ºC
8.7. Insulated Thermos or similar vessel
8.8. Ice
8.9. Microwave
8.10. FP-TC-120 8-Channel Thermocouple Input Module (National Instruments Corporation, Austin, TX)
8.11. FP-TB-3 Isothermal Terminal Base (National Instruments Corporation, Austin, TX)
8.12. Soldering iron
8.13. Electrical tape

9. Procedures

9.1. Fabrication
9.1.1. Remove no more than one inch of insulation from both the copper and constantan wires at the end of the wire that is to serve as the thermocouple.

9.1.2. Wrap the copper and constantan wires around each other a minimum of six turns (roughly ½″). Cut the wires such that a straight cut is made across both (Fig. 1).

9.1.3. Protect the junction and exposed wires by using a commercially available heat-shrinkable tubing. Sheathe the entire exposed wire, and ¼″-½″ of the insulated wire, with the wrap, and cut the wrap approximately ¼″ beyond the welded thermocouple junction. Heat with a heat gun or hand-held torch. When the wrap is firmly in place, crimp the end (the ¼″ beyond the junction) with pliers, taking care not to crimp over or crush the junction itself (Fig. 1).

9.2. Installation

9.2.1. Mount the thermocouple(s) at the specified locations. If airflow is in a prevailing direction, junctions should face into the flow, with the thermocouples themselves trailing in the direction of the flow. Mount thermocouples in locations that are not susceptible to disturbance by animals and/or workers.

9.2.1.1. Mount thermocouples using a flexible coupler or connector. The coupler must allow the thermocouple to bend freely if contacted by animals or facility personnel.

9.2.1.2. In order to ensure thermal insulation from the support structure, ensure that the distance (length of wire) between the attachment point nearest the junction and the junction itself is at least 20 wire diameters.

9.2.2. Prevent excessive sharp bending of the thermocouple wire during installation.

9.2.3. When laying thermocouple wires from the measurement location to the input module, follow all guidelines in Section 5.3, so as to minimize the introduction of thermal gradients to the terminals through the wires, and do not run thermocouple wire near barn power cables, to avoid electrical noise.

9.3. Connection to data acquisition module

9.3.1. Configure each channel of the FP-TC-120 for the type of thermocouple to which it will be connected. This process is described in SOP B1.

9.3.2. Connect Type T extension wires from the different thermocouples to the Input Module “IN(+)” and “IN(-)” terminals, as described in SOP B1 (Fig. 2).

9.3.3. On Type T thermocouples, the blue wire (copper) is “+”, while the red wire (constantan) is “-”.

9.3.4. If shielded thermocouple wires are used, connect one end of the shield to the corresponding “COM” terminal of the module.

9.3.5. Select a temperature range on the FP-TC-120; this is necessary to enable automatic cold-junction compensation. If an input voltage (as opposed to temperature) range is selected, cold-junction compensation will not be performed.

9.4. After installation, conduct a two-point check on each thermocouple (Section 11.2.1) to ensure that the thermocouples’ performance is within acceptable limits across the entire temperature range that might be encountered in the barn.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Initial checks

11.1.1. Upon receipt, thoroughly inspect all thermocouple wire and its packing/shipping containers for any sign of damage.

11.2. Calibration

11.2.1. Initial calibration

11.2.1.1. After placing them in the barn, check each thermocouple for calibration at temperatures above and below the temperature range encountered in barns.

11.2.1.1.1. Insert the thermocouple and a pre-calibrated thermometer into an ice bath in an insulated Thermos or equivalent. Allow temperatures and readings to stabilize for a minimum of 5 min (with stirring or gentle agitation throughout), and record both the thermocouple output and thermometer reading.

11.2.1.1.2. In the microwave oven in the instrument trailer (SOP U1), heat enough water to fill the insulated Thermos or similar vessel about ¾ full. Check the temperature with the pre-calibrated thermometer to ensure that it is at least 60ºC. Immerse the thermocouple and pre-calibrated thermometer in the Thermos, with stirring or agitation, for a minimum of 5 min, and record the thermocouple output and thermometer reading.

11.2.1.1.2.1. Re-heat the water when its temperature drops below 50 ºC.

11.2.1.2. Evaluate the performance of each thermocouple at each temperature according to Section 11.2.3.

11.2.2. Calibration checks during use

11.2.2.1. Check each installed thermocouple every six months by comparing it (in place) with the portable NIST-traceable temperature probe (Section 8.5). Assess performance, and take any necessary corrective action, according to Section 11.2.3.

11.2.3. Performance criteria and data corrections for out-of-calibration thermocouples

11.2.3.1. If the thermocouple reads > ±2°C different from the reference thermometer, record the magnitude of the difference, replace the thermocouple and re-test.

11.2.3.1.1. If the new thermocouple agrees to within 2°C, leave it in place and refer to the following to determine what to do with the old thermocouple and how to treat the data.

11.2.3.1.1.1. If the thermocouple, when checked in Step 11.2.2.1, was found to be ≥ ±6°C different from the reference thermometer or portable sensor, flag the measurements during the period since the thermocouple was last known to be in calibration (i.e. the previous six months) as questionable.

11.2.3.1.1.2. If the thermocouple, when checked in Step 11.2.2.1, was found to be ≥ ±4°C different from the reference thermometer or portable sensor, repeat the two-point temperature check (Section 11.2.1) on the thermocouple before discarding it. Use the regression lines derived from the initial two-point check, and the new one, to correct all temperature data collected since the last calibration, assuming that the drift to the new regression line was linear over time. The amount of correction is therefore time-dependent.

11.2.3.1.2. If the reading with the new thermocouple is still > 2°C different from the reference thermometer, and this problem is not observed with other thermocouples in the barn, carefully evaluate the path of the wire for any possible sources of interference, and consider relocating the thermocouple.

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Figure 1. Steps in thermocouple fabrication. Shown are the twisted wire pair after cutting (Step 9.1.2) and the fully-attached shrink wrap (Step 9.1.3).

Figure 2. Attachment of thermocouples to the NI FP-TC-120 Thermocouple Signal Input Module. Note connection of blue (copper, +) wires to odd-numbered terminals, and red (constantan, -) wires to even-numbered terminals. Exact wiring scheme is given in SOP B1.

MANAGEMENT OF OPEN-SOURCE, WEATHER, AND LAGOON-CHARACTERIZATION DATA

Standard Operating Procedure (SOP) D1

Prepared by

Richard H. Grant

Reviewed by

Bill W. Bogan, Ji-Qin Ni, and Albert J. Heber

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PURDUE APPLIED METEOROLOGY LABORATORY (PAML)
Agronomy, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Careful management of open-source, weather, and lagoon-characterization data is required to ensure that these data are all accurately documented and preserved.

1.1.1. Data generated with the Tunable Diode Laser Absorption Spectrometer (TDLAS) is needed to properly apply the radial plume mapping method, and thus to document the changing ammonia concentrations of the air surrounding the open-air source.

1.1.2. Data generated by Ultraviolet Differential Optical Absorption Spectroscopy (UV-DOAS) is needed to properly apply the backward Lagrangian Stochastic emissions model, and thus to document the changing ammonia and hydrogen sulfide concentrations of the air surrounding the open-air source

1.1.3. Data generated by INNOVA Model 1412 Photoacoustic Multi-gas Monitor (SOP G7) to quantitate total and individual volatile organic compounds (VOCs) from the air surrounding the open-air source needs to be properly documented.

1.1.4. Data on meteorological and lagoon conditions are needed for valid modeling of the effect of weather and microclimate on emissions.

1.2. The data management regime must be capable of managing data collected during multiple measurement periods, and at multiple study locations.

2. Summary of Method

The objective of data management is to ensure data security, easy data identification and retrieval, and efficient publication. All project-related files and data must be classified and organized in the computerized research data storage system. The tools to deliver, backup, inspect, analyze and present data must be available and kept current with the latest updates.

3. Definitions

3.1.	bLS	Backward Lagrangian Stochastic
3.2.	CD	Compact disk
3.3.	DM	Data Manager
3.4.	DVD	Digital video disk
3.5.	Flash memory	Non-volatile rewritable memory
3.6.	FOS	Field operations staff
3.7.	HD	Computer hard drive
3.8.	ODBC	Open data base connectivity
3.9.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.10.	PAML	Purdue Applied Meteorology Laboratory
3.11.	PIC	Path-integrated concentration
3.12.	PM	Project Manager
3.13.	ppb	Parts per billion (by volume)
3.14.	QAM	Quality Assurance Manager
3.15.	QAPP	Quality Assurance Project Plan

3.16. RPM	Radial Plume Mapping method of emissions measurement
3.17. Site PI	Site Principal Investigator
3.18. SMP	Site monitoring plan
3.19. LAN Server	Local Area Network Sever computer
3.20. TDLAS	Tunable Diode Laser Absorption Spectrometer/Spectroscopy
3.21. UV-DOAS	Ultraviolet Differential Optical Absorption Spectrometer/ Spectroscopy
3.22. VOC	Volatile organic compounds
3.23. WXL	Weather and lagoon

4. Personnel Qualifications and Responsibilities

4.1. Most of these procedures assume a familiarity with the use of personal computers and general computer application software (e.g. MS Office), as well as the following:
  4.1.1. UV-DOAS procedures (SOP C1) and the WINDTRAX bLS software (SOP O1)
  4.1.2. The RPM software (SOP O2) and the TDLAS procedures (SOP C2)
  4.1.3. INNOVA 1412 Photoacoustic Multi-gas Monitor procedure (SOP G7)
  4.1.4. The data analysis software programs which are used to perform the transformations described in SOPs W1-W5
  4.1.5. The data acquisition and control software described in SOP W6
4.2. The site PI will follow an orderly system of data recording, organization, and safeguards, and will ensure that all members of the research team (including appropriate administrative personnel) understand and follow the system.
4.3. Data access management will be controlled according to Purdue University (Information Technology at Purdue) procedures defined for sensitive data (Appendix A). Those authorized to access research data will use strong passwords that are difficult to crack, according to Appendix B. Passwords will not be written down or shared with others. Passwords will be changed on a regular basis (every two months at a minimum).
4.4. Only those people explicitly authorized to access the research data will be allowed to write to the files (Appendix A).

5. Equipment and supplies

5.1. Data transfer pouch
5.2. UV-DOAS 4-Gb flash memory drives (2 per measurement period)
5.3. 64Mb CompactFlash® memory card (1 per measurement period)
5.4. 256Mb flash memory sticks (3 per measurement period)
5.5. Blank CDs
5.6. Fire-proof data vault
5.7. Innova Gas Monitor Software (Version 7304)

6. Procedures

6.1. Classification of electronic files
  6.1.1. Classify all electronic files according to the following four categories:

6.1.1.1. Research information and data. These files, if lost, cannot be rebuilt or recovered.
  6.1.1.1.1. Measurement data
  6.1.1.1.2. Data acquisition configuration data
  6.1.1.1.3. Calibration data forms
  6.1.1.1.4. Data logged by instruments (TDLAS and UV-DOAS) with internal data storage
  6.1.1.1.5. Calibration data recorded by TDLAS and UV-DOAS systems, and electronic calibration forms
  6.1.1.1.6. Data recorded by INNOVA 1412 Photoacoustic multi-gas monitor
  6.1.1.1.7. Field notes
  6.1.1.1.8. Email messages
  6.1.1.1.9. Image files (digital photos or graphs)
6.1.1.2. Project-specific configurations that could be rebuilt or recovered, if lost
  6.1.1.2.1. Hardware configuration files
  6.1.1.2.2. Configurations of firewalls, virus protection, etc
  6.1.1.2.3. Email accounts, address books, message rules
  6.1.1.2.4. Favorite lists
6.1.1.3. Project-specific software and documents
  6.1.1.3.1. Thunder Scientific WINDTRAX
  6.1.1.3.2. Boreal Laser GasView2
  6.1.1.3.3. Arcadis RPM
  6.1.1.3.4. INNOVA Gas Monitor Software 7304
  6.1.1.3.5. Campbell Scientific LoggerNet data logger programming and collection software
  6.1.1.3.6. National Instruments LabVIEW
  6.1.1.3.7. Files provided by vendors, such as instrument manuals and application notes
  6.1.1.3.8. Instrument communication software
6.1.1.4. General PC Software
  6.1.1.4.1. Microsoft Windows XP
  6.1.1.4.2. Microsoft Office
  6.1.1.4.3. WS_FTP server and ftp encryption software
  6.1.1.4.4. PC Anywhere
  6.1.1.4.5. Network Associates Enterprise
  6.1.1.4.6. Spybot S&D
  6.1.1.4.7. Genie Backup Manager

6.2. Data acquisition of UV-DOAS PIC spectra (SOP O1) for NH_3 and H_2S concentration calculation is conducted by the on-site ‘bLS’ computer (Fig. 1).

6.2.1. Data is stored in a 4Gb flash memory drive on each UV-DOAS receiver. After 20 days, memory used is approximately 500Mb.

6.3. Data acquisition of TDLAS PIC spectra (SOP O2) for NH_3 concentration calculations is conducted by each of the on-site ‘TDLAS/scanner’ computers (Fig. 2).

6.3.1. Data is stored in the HD of each TDLAS/scanner computer. After 20 days, memory used is approximately 3.3Mb.

6.4. Data acquisition using INNOVA 1412 Photoacoustic multi-gas monitor (SOP G7) for total and individual VOC concentrations stored directly in the HD of the LAN computer (Fig. 3).

6.5. Data acquisition of lagoon temperature, pH, and redox state (SOPs L1, L2 and L3), barometric pressure, air temperature, relative humidity, solar radiation, surface wetness, and data logger power supply voltage (SOPs E3, W1, W3, and W5) is conducted by a datalogger (SOP W6) (Fig. 4).

6.5.1. Data is stored in a first in first out (FIFO) memory, and on a 64Mb CompactFlash® memory card. After 20 days, memory used is approximately 64Kb.

6.6. Data acquisition of wind components at three heights (SOP W2) is conducted by the on-site LAN Server computer (Fig. 4).

6.7. Data processing for the parameters listed in Section 6.2 is conducted by the on-site 'bLS' computer, which is connected to the UV-DOAS system by radio communications (Fig. 1).

6.8. Data processing for the parameters listed in Section 6.3 is conducted by the on-site LAN server computer, which is connected to the two 'TDLAS/scanner' computers by Ethernet (Fig. 2).

6.9. Data processing for the parameters listed in Section 6.4, and control of the INNOVA Multi-gas Monitor, are conducted by the Gas Monitoring Software 7304 running in the on-site LAN Server computer, which is connected by RS 232 cable to the INNVOA 1412 (Fig. 3).

6.10. Data processing for the parameters listed in Section 6.5 is conducted by the on-site Network Server computer, which is connected to the datalogger by radio communications.

6.11. File organization

6.11.1. All project-specific files on computers will be in folders called *YY*farm*n*, where *YY* is a two-letter abbreviation for the state and *n* is the farm identifier within the state. For example, two farms in Missouri would be identified as MOfarm1 and MOfarm2.

6.11.2. The <u>flash memory drive of each UV-DOAS instrument</u> (Fig. 1) contains:

6.11.2.1. Raw 5-min average PIC spectra [MinMinHrHr, PIC NH_3, PIC H_2S]

6.11.2.2. Spreadsheet of 5-min PIC averages (filename 'C'MMDDYY [MinMinHrHr] containing: background PIC, SignalStrength, IntegrationTime, PIC NH_3, NH_3 measurement error, PIC H_2S, H_2S measurement error, RMSnoise)

6.11.3. The <u>datalogger flash memory</u> (Fig. 4) contains:

6.11.3.1. Raw data files (named by MMDDYY, containing farm number, MMDDYY, HrHrMinMin, 5-min averages of lagoon temperature, pH, and redox state, barometric pressure, air temperature, relative humidity, solar radiation, surface wetness, and power supply voltage) (SOP W6)

6.11.4. In the <u>on-site computer associated with both UV-DOAS systems</u> (Fig. 1), termed the 'bLS computer', store all project date-specific measurement files in folders called MMDDYY where MM is numerical month, DD is numerical day in month, and YY is a two-letter abbreviation for the year in which the WINDTRAX bLS program was started. Organize the subfolders as:

6.11.4.1. Program. WINDTRAX bLS software

6.11.4.2. Config. Contains configuration files for bLS at location *YY*farm*n*.

6.11.4.3. Touchdown tables (See SOP O1) for *YY*farm*n*

6.11.4.4. 5-min 2-m height wind turbulence statistics (SOP W2) for *YY*farm*n* so that statistics coincide with periods of PIC measurements according to SOP O1.

  6.11.4.4.1. Wind data is transferred from the LAN server computer to the UV-DOAS systems through the Ethernet connection.

6.11.4.5. UV-DOAS Instrument 1 data for location *YY*farm*n*

  6.11.4.5.1. Raw 5-min average PIC spectra [MinMinHrHr, PIC NH_3, PIC H_2S

  6.11.4.5.2. Spreadsheet of 5-min PIC averages (filename 'C'MMDDYY [MinMinHrHr] containing: background PIC, SignalStrength, IntegrationTime, PIC NH_3, NH_3 measurement error, PIC H_2S, H_2S measurement error, RMS noise)

6.11.4.6. UV-DOAS Instrument 2 data for location *YY*farm*n*

  6.11.4.6.1. Raw 5-min average PIC spectra [MinMinHrHr, PIC NH_3, PIC H_2S

  6.11.4.6.2. Spreadsheet of 5-min PIC averages (filename 'C'MMDDYY [MinMinHrHr] containing: background PIC, SignalStrength, IntegrationTime, PIC NH_3, NH_3 measurement error, PIC H_2S, H_2S measurement error, RMSnoise)

6.11.4.7. WINDTRAX input spreadsheet for location *YY*farm*n*

  6.11.4.7.1. 5-min <u>average difference</u> in PICs and wind data (filename MMDDYY [MinMinHrHr]; containing: turbulence statistics, PIC NH_3, PIC H_2S)

6.11.4.8. WINDTRAX output file for location *YY*farm*n* (filename MMDDYY [MinMinHrHr]

6.11.5. In the <u>on-site data acquisition computer associated with each TDLAS/scanner system</u> (each of 2 computers and associated systems, located according to Fig. 2), The two TDLAS/scanner systems are designated TDLAS1 and TDLAS2. All date-specific measurement files are in folders called MMDDYY where MM is numerical month, DD is numerical day in month, and YY is a two-letter abbreviation for the year in which the RPM program was started. Organize the subfolders as:

6.11.5.1. Config1. Contains all files associated with first plane of measurement for RPM analysis of TDLAS

  6.11.5.1.1. Config. Contains geometry configuration file

  6.11.5.1.2. Input file. Includes PIC values for each time period of averaging

    6.11.5.1.2.1. Format according to SOP O2.

  6.11.5.1.3. Plume map graphs. Contains each averaging period plume map from the RPM program (See SOP O2) as a jpeg file (70Kb/image)

  6.11.5.1.4. Flux output file. Contains flux measurements with QA/QC checks on the RPM measurement according to SOP O2

  6.11.5.1.5. Valid raw wind data

    6.11.5.1.5.1. Format according to SOP W2.

    6.11.5.1.5.2. Data is transferred from the LAN server computer through the Ethernet connection.

  6.11.5.1.6. Parsed wind data so that the measurement period of wind data coincides with the measurement period of each complete cycle of PIC measurements.

  6.11.5.1.7. Raw PIC measurements from TDLAS

    6.11.5.1.7.1. Beam1. PIC values along beamline 1 with QA/QC flags (SOP C2).

    6.11.5.1.7.2. Beam2. PIC values along beamline 2 with QA/QC flags (SOP C2).

6.11.5.1.7.3. Beam3. PIC values along beamline 3 with QA/QC flags (SOP C2).

6.11.5.1.7.4. Beam4. PIC values along beamline 4 with QA/QC flags (SOP C2).

6.11.5.1.7.5. Beam5. PIC values along beamline 5 with QA/QC flags (SOP C2).

6.11.5.2. Config2. Contains all files associated with second plane of measurement for RPM analysis of TDLAS

6.11.5.2.1. Config. Contains geometry configuration file

6.11.5.2.2. Input file. Includes PIC values for each time period of averaging

6.11.5.2.2.1. Format according to SOP O2.

6.11.5.2.3. Plume map graphs. Contains each averaging period plume map from the RPM program (SOP O2) as a jpeg file (70Kb/image)

6.11.5.2.4. Flux output file. Contains flux measurements with QA/QC checks on the RPM measurement according to SOP O2

6.11.5.2.5. Valid raw wind data

6.11.5.2.5.1. Format according to SOP W2.

6.11.5.2.5.2. Data is transferred from the LAN server computer

6.11.5.2.6. Parsed wind data so that the measurement period of wind data coincides with the measurement period of each complete cycle of PIC measurements

6.11.5.2.7. Raw PIC measurements from TDLAS

6.11.5.2.7.1. Beam6. PIC values along beamline 6 with QA/QC flags (SOP C2).

6.11.5.2.7.2. Beam7. PIC values along beamline 7 with QA/QC flags (SOP C2).

6.11.5.2.7.3. Beam8. PIC values along beamline 8 with QA/QC flags (SOP C2).

6.11.5.2.7.4. Beam9. PIC values along beamline 9 with QA/QC flags (SOP C2).

6.11.5.2.7.5. Beam10. PIC values along beamline10 with QA/QC flags (SOP C2).

6.11.6. In the on-site INNOVA data acquisition computer (which is also the on-site LAN server) organize the subfolders in the C drives as :

6.11.6.1. C:\INNOVA (for all single point data acquisition and control)

6.11.6.2. \Data acquisition program (Gas Monitoring Software7304)

6.11.6.3. \Configuration file (common for all measurement locations)

6.11.6.4. Data collected from the Gas Monitor Software 7304 (SOP G7) by the LAN server will be saved in the directory [C:\INNOVA\Farm number\MMDDYY\ODBC] (SOP G7).

6.11.6.5. 5-min raw sample values will be stored on the LAN server in MS-access format (ODBC).

6.11.6.6. Data includes: Measurement times, measurement sequence numbers, Error and user flags, atmospheric pressure, water vapor, NH_3 concentration, acetic acid concentration, methanol concentration, ethanol concentration.

6.11.7. In the on-site weather data acquisition computer (which is also the on-site LAN Server) organize the subfolders in the C drive as:

6.11.7.1. LabVIEW files (for wind sensor data acquisition and control)

6.11.7.1.1. Data acquisition program

6.11.7.1.2. Configuration file (common for all measurement locations)

6.11.7.1.3. Wind data files for *YY*farm*n* (See SOP W2)

6.11.7.1.3.1. File with 30 min of raw 16-Hz data for spectral analysis (including U, V, W, T_v)

6.11.7.1.3.2. 5-min average statistics

6.11.7.1.3.3. 30-min average statistics

6.11.7.2. LoggerNet® datalogger software directories and subdirectories according to LoggerNet manual (page 2-3) for data collection and datalogger control of weather and lagoon characterization sensors (Section 5.2 of manual).

6.11.7.2.1. Communication logs

6.11.7.2.2. System. Includes binary files, configuration files and raw data downloads collected by the data acquisition program named as [MMDDYY-*YY*farm*n*]

6.11.7.2.3. PakBusGraph. Contains daily plots of raw data.

6.11.7.2.3.1. Data files for *YY*farm*n* (named by date MMDDYY, containing HrHrMinMin, 5-min averages of lagoon temperature, pH, and redox state, barometric pressure, air temperature, relative humidity, solar radiation, surface wetness, and power supply voltage)

6.11.7.3. Datalogger configuration and program editors

6.11.7.4. Library directory containing compilers and definition files

6.11.7.5. Calibration. Contains calibration sheets, gas cylinder logs, control charts, and other records

6.11.7.6. QAPP. The latest copy of the Quality Assurance Project Plan

6.11.7.7. SOP. Latest copies of all relevant Standard Operating Procedures

6.11.7.8. SMP. Site monitoring plan

6.11.7.9. Certifications

6.11.7.10. Measurement period records. Indicates dates and locations

6.11.7.11. Field Notes

6.11.7.11.1. Typed logs of activities and observations (All notes must include name and date of the person making the note)

6.11.7.11.2. Producer Event forms and updated farm specific information (layout drawings etc) other farm lagoon management data (information on animals, weight, feed, etc) collected from the farm manager (SOP S7)

6.11.7.12. Photos. Digital pictures of field setup and observations

6.11.7.13. Email. Contains email messages and attachments. Name the email account yyfarmn@zzz.zzz where zzz.zzz is the internet service provider’s domain. Outlook Express is the preferred email program.

6.11.7.14. Miscellaneous

6.11.7.14.1. Site equipment inventory including gas cylinders, etc

6.11.7.14.2. Transported equipment inventory

6.11.8. The administrative server at PAML contains the following folders and information, and operates various personal computers:

6.11.8.1. Weather data from outside sources for each day and every location that measurements are taken. Example of an outside source might be; http://www.wunderground.com/us/nc/elizabethtown.html.

6.11.8.2. Data ftped from *YY*farm*n*

6.11.8.3. UV-DOAS and bLS data and configuration files

6.11.8.4. TDLAS and RPM data and configuration files

6.11.8.5. Excel files of text data exported from bLS and RPM directories during processing

6.11.8.6. LoggerNet configuration files

6.11.8.7. INNOVA Gas Monitor Software 7304 configuration files
6.11.8.8. LabVIEW configuration files
6.11.8.9. Excel files of data exported from LoggerNet during processing
6.11.8.10. Excel files of data exported from LabVIEW during processing.
6.11.8.11. AutoCad drawings of lagoon and equipment
6.11.8.12. Data tables for reports and manuscripts
6.11.8.13. Farm production data
6.11.8.14. Reports
6.11.8.15. ftp transfer logs

6.12. Data security

6.12.1. The on-site computer associated with the UV-DOAS (Fig. 1) is linked through an Ethernet local area network to the Network Server computer.

6.12.2. Each on-site data acquisition computer linked with each TDLAS instrument is linked to the Network server computer in the trailer through an Ethernet local area network (SOP U4).

6.12.3. Datalogger

6.12.3.1. Three 5-digit security passwords are needed to change the data acquisition program, download data, or change the clock.

6.12.3.1.1. FOS will each have all security codes.

6.12.3.2. Replace 1Mb flash memory at the end of each measurement period (identified here as WXL).

6.12.3.2.1. Put flash memory into the zippered Data pouch.

6.12.4. LoggerNet will be operated as a service on the on-site computer, so that the program will restart after power failures.

6.12.5. Innova Gas Monitoring Software 7304 shortcut will be placed in the start up folder so the program will restart after power failure or restart.

6.12.6. Program Windows “Scheduled Tasks” to ftp the 24-h data files from the on-site weather data acquisition computer, Innova Gas Monitoring software, and the data acquisition computers linked to the TDLAS instruments and UV-DOAS instruments to the PAML computer at midnight.

6.12.6.1. All ftp file transfers are encrypted.

6.12.7. Collect archived raw data from flash drives in each UV-DOAS instrument (approximately 500MB of data on each of the 4GB flash drives) at the conclusion of the measurement period.

6.12.7.1. Replace the flash drive in each instrument.

6.12.7.2. Copy content of each UV-DOAS flash drive onto two CDs.

6.12.7.2.1. Identify CD with location (*YY*farm*n*), measurement period (MM-DD-YY to MM-DD-YY), “UVDOAS1” for “UVDFlash1” and “UVDOAS2” for “UVDFlash2” and label “vault” or “carry”.

6.12.7.2.2. Copy using LAN Server computer

6.12.7.2.3. Put one copy of each of the two CDs into the fire-proof data vault in the trailer.

6.12.7.2.4. Put the other copy of each CD in Data pouch.

6.12.7.3. Store all data-containing UV-DOAS Flash drives in Data pouch.

6.12.8. Field notes
  6.12.8.1. Notes are stored on the HD of the LAN server computer, and are (automatically) backed up daily on an external HD.
  6.12.8.2. Email field notes to PM and DM at the end of each work day in the field, before leaving the site.
  6.12.8.3. Download field notes onto flash memory stick.
  6.12.8.4. Store memory stick in the zippered Data pouch.
6.12.9. FOS copies of calibration data and control charts
  6.12.9.1. Email to PM, DM, and QAM after each 20-day measurement period.
  6.12.9.2. Retain one paper copy in trailer.
  6.12.9.3. Download onto flash memory stick with field notes.
  6.12.9.4. Store memory stick in the zippered Data pouch.
6.12.10. Send (by ftp) configuration files to DM whenever they are updated.
6.12.11. File backups by field staff
  6.12.11.1. Back up project folders and subfolders *YY*farm*n* of each onsite computer onto an external hard drive at 1:00 a.m. each night during the measurement period.
  6.12.11.2. Back up data files onto DVD at the conclusion of every measurement period.
    6.12.11.2.1. Two copies each of UVDOAS1, UVDOAS2 from LAN server.
    6.12.11.2.2. Two copies each of TDLAS 1 and TDLAS 2 from respective Data Acquisition computers.
    6.12.11.2.3. Two copies of INNOVA data files from LAN server
    6.12.11.2.4. Two copies of WXL data from LAN server
    6.12.11.2.5. Identify each CD with data type (above), location (*YY*farm*n*) and measurement period (MM-DD-YY to MM-DD-YY). Label one copy of each DVD as “vault”, one copy as “carry”.
    6.12.11.2.6. Put “vault” copy of DVD into the fire-proof data vault.
    6.12.11.2.7. Put “carry” copy of DVD in the data pouch.
  6.12.11.3. Manually back up the operating system of any computer onto an external HD whenever significant changes are made to the system.
6.12.12. Automatically back up filesystem of the LAN server onto an external HD every day at 2:00 a.m.
6.12.13. Carry Data pouch in hand luggage upon returning to PAML.
  6.12.13.1. Data pouch includes:
    6.12.13.1.1. For latest measurement period:
      6.12.13.1.1.1. One pair of 4-Gb UV-DOAS flash memory drives (UVDFlash1 and UVDFlash2)
      6.12.13.1.1.2. One pair of CDs with copies of UV-DOAS flash memory drives (UVDOAS1 and UVDOAS2)
      6.12.13.1.1.3. Two CDs with TDLAS data (TDLAS1 and TDLAS2)
      6.12.13.1.1.4. One CD with weather,and lagoon (WXL) and INNOVA data from recently-completed measurement period
      6.12.13.1.1.5. One 64-Mb flash memory chip of weather and lagoon (WXL) data from recently-completed measurement period
      6.12.13.1.1.6. One 256-Mb memory stick with Field notes, calibration data and control charts from recently-completed measurement period

- 6.12.13.1.1.7. One DVD with *YY*farm*n* backup of all *YY*farm*n* directories
- 6.12.13.1.2. For previous measurement period (material previously stored in data vault):
  - 6.12.13.1.2.1. One pair of CDs with copies of UV-DOAS flash memory drives (UVDOAS1 and UVDOAS2)
  - 6.12.13.1.2.2. Two CDs with TDLAS data from the previous measurement period (TDLAS1 and TDLAS2)
  - 6.12.13.1.2.3. One CD with weather, lagoon (WXL) and INNOVA data from previous measurement period
  - 6.12.13.1.2.4. One DVD with *YY*farm*n* backup of all *YY*farm*n* directories
- 6.12.13.1.3. Electronic data transfer forms for both recently-completed and previous measurement period (Appendix C) with upper section filled out.
- 6.12.13.2. Deliver Data pouch to DM on arrival.
  - 6.12.13.2.1. Document delivery of data to DM with Electronic Data Transfer Forms (Appendix C).
    - 6.12.13.2.1.1. Forms to be stored in the folder marked ‘Electronic data Transmittal records’ under the control of the DM.
- 6.12.14. DM archives files on the PAML computer onto an external HD drive every day at 5:00 a.m.
- 6.12.15. DM downloads all flash memory to a separate directory on PAML computer for backup.
- 6.12.16. DM stores all received CDs in an off-campus location.
- 6.12.17. DM archives files on the PAAQL server., which is backed up daily on the Purdue University backup system.

6.13. Retention of data
- 6.13.1. Keep all data files for at least six (6) years.

7. Quality Control and Quality Assurance

- 7.1. Verify that the following software are included in their respective computers’ startup menus, for automatic recovery after power failure.
  - 7.1.1. LoggerNet, Gas Monitor Software 7304, and LabVIEW (in the on-site, LAN server, computer)
  - 7.1.2. WINDTRAX program (in the bLS computer)
  - 7.1.3. RPM program (in each TDLAS/scanner data acquisition computer)
- 7.2. Verify that all data acquisition computers log power failures, and that emails are sent to the QAM and DM upon restart.
- 7.3. Check field computer and relevant software, and take immediate measures to solve related problems, if the daily data file ftp, and/or emails with other files are not received.
- 7.4. Multiple means of irreplaceable data transfer to PAML
  - 7.4.1. Daily ftp of files
  - 7.4.2. Hand delivery of data from each measurement period at end of measurement period and at the end of the next sequential measurement period (stored in the data vault)
- 7.5. Raw data stored in multiple places prior to transfer to PAML
  - 7.5.1. UV-DOAS raw (Fig. 1)
    - 7.5.1.1. Flash memory drive of each UV-DOAS instrument

7.5.1.2. bLS computer HD

7.5.2. TDLAS raw and RPM processed data (Fig. 2)

7.5.2.1. TDLAS data acquisition computer HD

7.5.2.2. External HD

7.5.3. bLS computer filesystems (including wind measurements and bLS input files and results) (Fig. 1)

7.5.3.1. bLS computer HD

7.5.3.2. External HD

7.5.4. INNOVA raw data (Fig. 3)

7.5.4.1. LAN server HD

7.5.4.2. External HD

7.5.5. Datalogger raw data (excluding wind measurements) (Fig. 4)

7.5.5.1. CompactFlash memory card

7.5.5.2. On-site datalogger

7.5.5.3. LAN server HD

7.5.5.4. External HD

7.5.6. LAN Server computer filesystems (including wind measurements) (Figs. 1-4)

7.5.6.1. HD of on-site computer

7.5.6.2. External HD

7.6. DM tracks all modifications to electronic files. This includes tracking the original data entered, tracking who and when an individual or system viewed or changed any data, and recording why data was changed.

7.6.1. Save and archive all raw data in their original form.

7.6.2. Use a “notes” worksheet in Excel files to describe modifications.

7.6.3. Include date at the end of file name in the following format: MM-DD-YY, ex: 01-09-06. Leading zeros in day and month can be omitted, ex. 1-9-06.

7.6.4. Utilize electronic audit trails as much as possible.

8. References

8.1. Campbell Scientific Inc. 2005. LoggerNet Instruction Manual, v. 3.2, Campbell Scientific Inc., Logan UT.

8.2. Campbell Scientific Inc. 2006. CR1000 Measurement and Control System Operators Manual. v. 3/06, Campbell Scientific Inc., Logan, UT

8.3. Information Technology at Purdue. 2006. Electronically Stored (Computer-based) Information. Available at: http://www.itap.purdue.edu/security/procedures/dataHandling/electrStored.cfm. Accessed 2-28-2006.

8.4. Information Technology at Purdue. 2006. Password Guidelines. Available at: http://www.itap.purdue.edu/security/procedures/passGuidelines.cfm. Accessed 2-28-2006.

8.5. SOP C1. 2006. Open Path Measurement of Ammonia and Hydrogen Sulfide with the Cerex UV Sentry Ultraviolet Differential Optical Absorption Spectrometer. Standard Operating Procedure C1. Purdue Applied Meteorology Lab.

8.6. SOP C2. 2006. Measurement of Ammonia with the Boreal Laser GasFinder Tunable Diode Laser Absorption Spectrometer (TDLAS) Standard Operating Procedure C2. Purdue Applied Meteorology Lab.
8.7. SOP E3. 2006. The Measurement of Solar Radiation with the Licor Model 200SL or 200SZ Silicon Pyranometer. Standard Operating Procedure E3. Purdue Ag Air Quality Lab.
8.8. SOP G7. 2006. Use of the INNOVA 1412 Photoacoustic Multi-gas Monitor. Standard Operating Procedure G7. Purdue Ag Air Quality Lab.
8.9. SOP L1. 2006. Measurement of Lagoon pH with Innovative Sensors Model CSIM11 Sensor. Standard Operating Procedure L1. Purdue Applied Meteorology Lab.
8.10. SOP L2. 2006. Measurement of Lagoon Temperature with Campbell Scientific Model 107-L Thermistor. Standard Operating Procedure L2. Purdue Applied Meteorology Lab.
8.11. SOP L3. 2006. Measurement of Lagoon Redox State with Campbell Scientific CSIM11_ORP Sensor. Standard Operating Procedure L3. Purdue Applied Meteorology Lab.
8.12. SOP O1. 2006. Emissions Estimation Using the Thunder Beach Scientific Windtrax Backward Lagrangian Stochastic Model. Standard Operating Procedure O1. Purdue Applied Meteorology Lab.
8.13. SOP O2. 2006. Emissions Estimation Using the ARCADIS Radial Plume Mapping Model. Standard Operating Procedure O2. Purdue Applied Meteorology Lab.
8.14. SOP S7. 2006. Producer Collaborations at Area Source Monitoring Sites. Standard Operating Procedure S7. Purdue Applied Meteorology Lab.
8.15. SOP U4. 2006. Open-source Instrument Trailer. Standard Operating Procedure U4. Purdue Applied Meteorology Lab.
8.16. SOP W1. 2006. Measurement of Atmospheric Temperature and Humidity with the Vaisala Model HMP45C Sensor and Solar Shield. Standard Operating Procedure W1. Purdue Applied Meteorology Lab.
8.17. SOP W2. 2006. Measurement of Wind with the RM Young Model 81000 3-Dimensional Sonic Anemometer. Standard Operating Procedure W2. Purdue Applied Meteorology Lab.
8.18. SOP W3. 2006. Measurement of Wetness with the Campbell Scientific Model Resistance Grid. Standard Operating Procedure W3. Purdue Applied Meteorology Lab.
8.19. SOP W5. 2006. The Measurement of Barometric Pressure with the Setra Model 278 (Campbell Scientific CS100) Barometer. Standard Operating Procedure W5. Purdue Applied Meteorology Lab.
8.20. SOP W6. 2006. Establishment, Data Acquisition and Control of Weather and Lagoon Characterization Hardware.. Standard Operating Procedure W6. Purdue Applied Meteorology Lab.

Figure 1. Data Processing and Management: UV-DOAS and bLS Data.

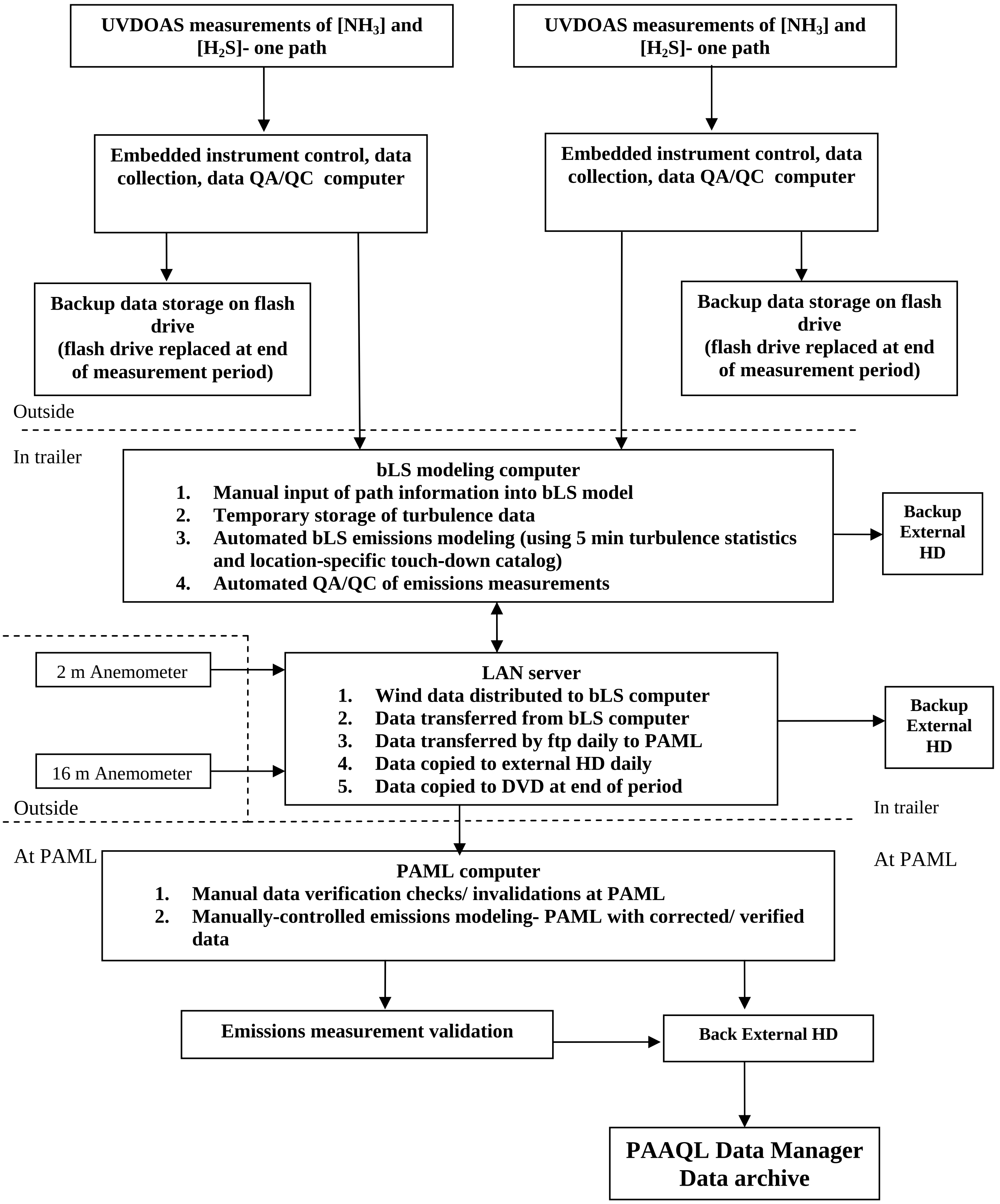


Figure 2. Data Processing and Management: TDLAS and RPM Data.

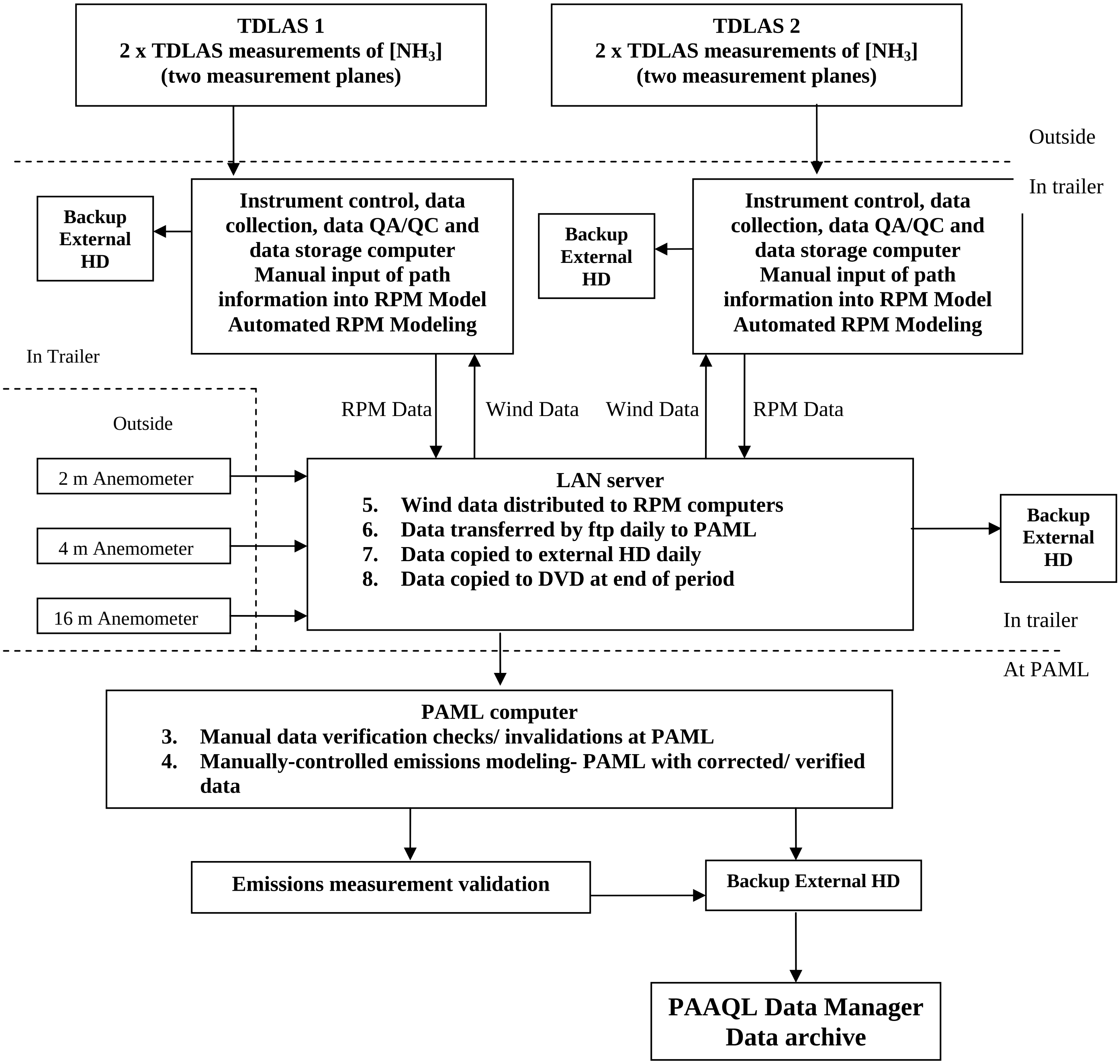
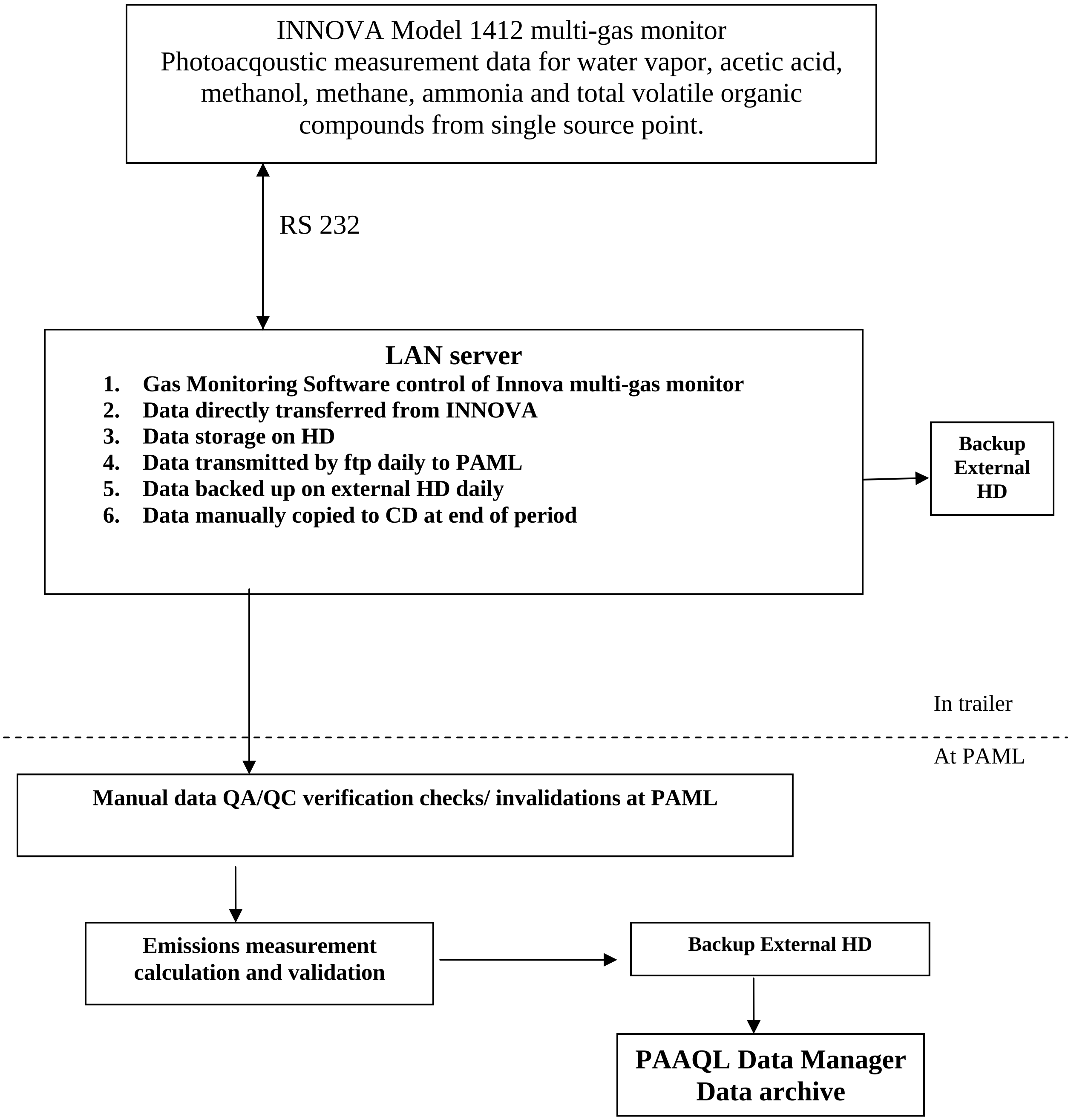
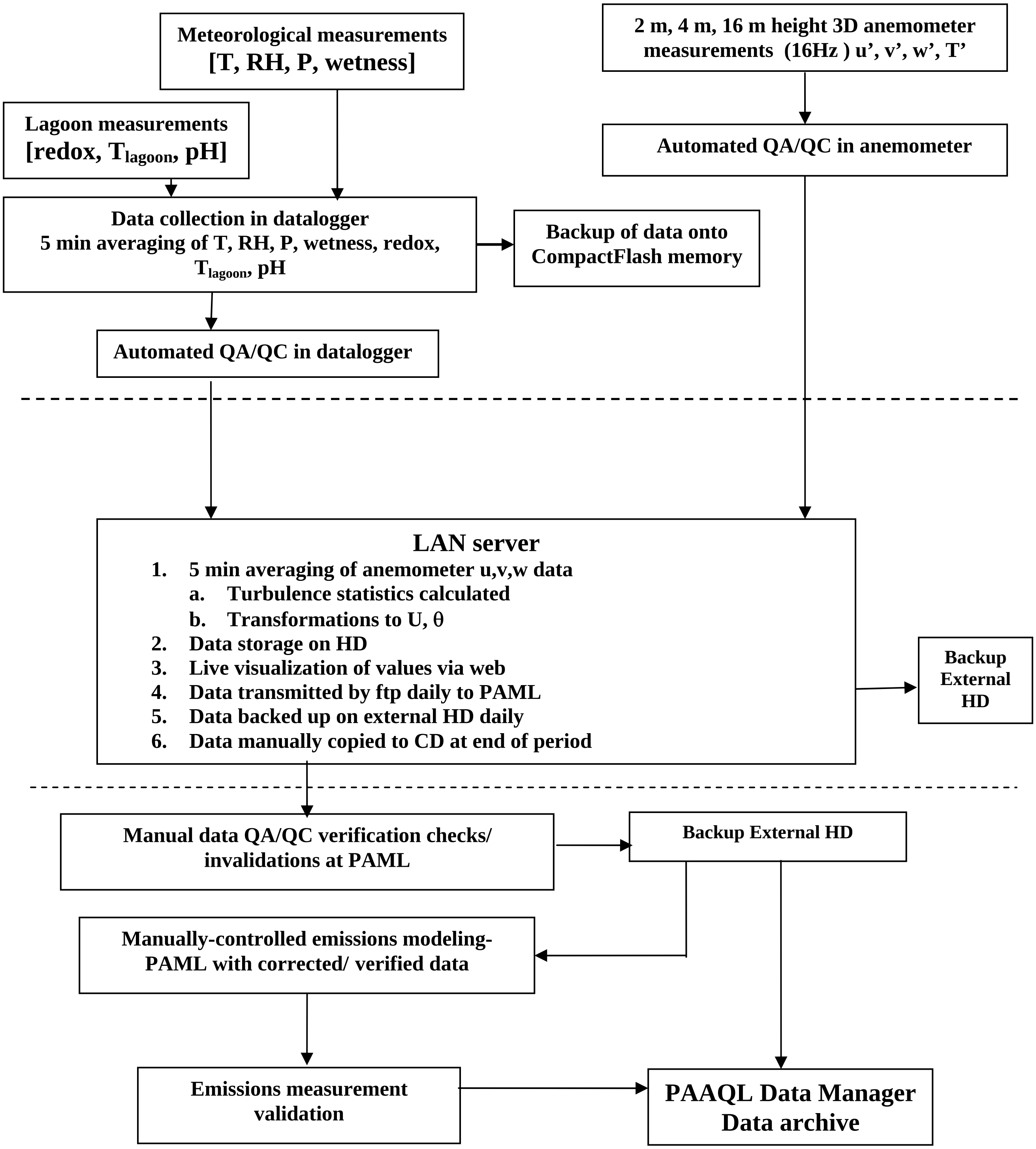


Figure 3. Data Processing and Management for INNOVA 1412.



1. Gas Monitoring Software control of Innova multi-gas monitor
2. Data directly transferred from INNOVA
3. Data storage on HD
4. Data transmitted by ftp daily to PAML
5. Data backed up on external HD daily
6. Data manually copied to CD at end of period

Figure 4. Data Processing and Management: Meteorological and Lagoon Data.



Appendix A
Guidelines for Managing Electronically-stored Sensitive Information[1]

Action	Sensitive Information
Storage on fixed media with access controls	No encryption required
Storage on fixed media without access controls, but accessible via the web	Not advised. If you must store data via this media, it must be encrypted.
Storage on fixed media without access controls, but not accessible via the web	No encryption required
Storage on removable media	No encryption required
Read access to information (includes duplication)	Access is based on roles defined by QAPP
Create / Update access to information	Access is based on roles defined by QAPP
Delete access to information	Access is based on roles defined by QAPP
Print hard copy report of information	Unattended printing permitted only if physical access controls are used to prevent unauthorized viewing.
Internal labeling of information at the application or screen/display level	No special requirement
Disposal of the physical electronic media device (diskettes, tapes, hard disks, etc.)	Physical destruction beyond ability to recover.
Disposal of information	Delete files through normal platform delete command, option or facility.
Data Manager & Information Owner review Data Confidentiality for continued applicability	Review annually

1: modified from Information Technology at Purdue:

http://www.itap.purdue.edu/security/procedures/dataHandling/electrStored.cfm,

Appendix B
Purdue University Password Requirements

- Passwords must contain at least 1 letter.
- Passwords must contain at least 1 number or punctuation mark.
- Passwords must be at least 8 characters long.
- Passwords must contain more than 4 unique characters.
- Passwords may not contain easily guessed words (e.g. Purdue, itap, boiler).
- Passwords may not contain a name or parts of the name (e.g., Bill, Julie, Bob, or Susan).
- New passwords must be different than the previous password (re-use of the same password will not be allowed for 180 days).
- Passwords never should be stored on your computer or written down and stored in plain sight (e.g., taped to the bottom of your computer keyboard). If a password must be written down, it should be locked up and stored in a place that is difficult for others to access.
- Passwords may be used only by the authorized user. Do not share your password with anyone.
- All users must change their password at least once every 30 days.
- If you suspect your password has been compromised, it should be changed immediately.

Appendix C
Electronic Data Transfer Form

Location of measurements: _________________________

Period represented: From Date (MM/DD /YYYY) _________ time (GMT: 24h clock) _____: _____

To Date (MM/DD/YYYY) _________ time (GMT: 24h clock) _____: _____

Data preparation/ copying done by: _____________________________________

Calibration conducted during period

UVDOAS1: s/n _______ Date (MM/DD/YYYY) _________ time (GMT: 24h clock) _____: _____

UVDOAS2: s/n _______ Date (MM/DD/YYYY) _________ time (GMT: 24h clock) _____: _____

TDLAS1: s/n ________ Date (MM/DD/YYYY) _________ time (GMT: 24h clock) _____: _____

TDLAS2: s/n ________ Date (MM/DD/YYYY) _________ time (GMT: 24h clock) _____: _____

Notes:

Data Receipt

Received: Date (MM/DD/YYYY) _____________________ time (GMT: 24h clock) _____: _____

Physical condition of TDLAS1 data CD	(Excellent / Good / Fair / Poor)
Physical condition of TDLAS2 data CD	(Excellent / Good / Fair / Poor)
Physical condition of UVDOAS1 data CD	(Excellent / Good / Fair / Poor)
Physical condition of UVDOAS2 data CD	(Excellent / Good / Fair / Poor)
Physical condition of WXL and INNOVA data CD	(Excellent / Good / Fair / Poor)
Physical condition of WXL and INNOVA flash memory chip	(Excellent / Good / Fair / Poor)
Physical condition of UVDFlash1 memory drive	(Excellent / Good / Fair / Poor)
Physical condition of UVDFlash2 memory drive	(Excellent / Good / Fair / Poor)
Physical condition of Backup DVD	(Excellent / Good / Fair / Poor)
Physical condition of memory stick	(Excellent / Good / Fair / Poor)

Received by: _____________________________________

MEASUREMENT OF RELATIVE HUMIDITY (RH) AND TEMPERATURE WITH THE NOVUS RHT-WM TRANSMITTER Standard Operating Procedure (SOP) E2

MEASUREMENT OF RELATIVE HUMIDITY (RH) AND TEMPERATURE WITH THE NOVUS RHT-WM TRANSMITTER

Standard Operating Procedure (SOP) E2

Prepared by
Erin L. Cortus, Congna Li, and Bill W. Bogan

Reviewed by
Teng-Teeh Lim and Albert J. Heber

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. The NOVUS RHT humidity and temperature transmitter is used in indoor and outdoor environments to measure relative humidity (RH) and temperature (T).
1.2. The temperature measurement range of the instrument is -40ºC to +120ºC. Accuracy is ±0.5ºC at 25ºC, with a maximum error of ±2.0ºC between -40ºC and 80ºC. Barn temperatures may range between -10ºC and 40ºC, but are usually maintained at approximately 20ºC, depending on the species and age of animals.
1.3. The RH measurement range is 0 to 100%, as compared with typical average barn RH of 65%. Accuracy is ±1.5% RH for 20 to 80%RH and ±3.0% for RH values below 20% and above 80% (at 25ºC).
1.4. The NOVUS RHT transmitter can be calibrated with a series of salt solutions.
1.5. The NOVUS RHT transmitter can be calibrated or spot-checked with a fundamental measurement instrument or a NIST-transfer device.
1.6. The NOVUS RHT transmitter is available in wall mount (WM) or duct mount (DM) housing options. The sensor and electronics are identical between the two models; mounting instructions were provided in this SOP for the WM version only.

2. Summary of Method

The purpose of the method is to continuously monitor the RH and T of indoor and exhaust air. The NOVUS RHT humidity and temperature transmitter uses a microprocessor-based sensor. The thin polymer film either absorbs or releases water vapor as the relative humidity of the ambient air rises or drops. The dielectric properties of the film depend on the amount of water contained in it; as the RH changes, the capacitance of the sensor also changes. The electronic circuit of the instrument measures the capacitance of the sensor and converts it into a humidity reading. The sensor is protected from physical contact with solid, foreign objects greater than 1 mm in diameter by an IP40 capsule. The capsule should be covered with a filter material to further reduce the build-up of dust on the sensor element, although the sensor itself can be cleaned. The electronics in the transmitter are protected by IP65 housing. This makes the transmitter suitable for humid and wet environments, such as those found on livestock farms.

3. Definitions of Terms and Acronyms

3.1.	DAC	Data acquisition and control
3.2.	K_2SO_4	Potassium sulfate
3.3.	LiCl	Lithium chloride
3.4.	$MgCl_2$	Magnesium chloride
3.5.	NaCl	Sodium chloride
3.6.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.7.	RH	Relative humidity
3.8.	SOP	Standard Operating Procedure
3.9.	T	Temperature

4. Health and Safety

4.1. Be careful when working with the electrical power connections.

4.2. The lithium chloride (LiCl) solution used in the instrument calibration (Section 9.3) is corrosive so avoid contact with exposed skin. LiCl salt and solution are harmful if swallowed. Never add water directly to dry LiCl salt.

5. Interferences

5.1. Barn environments will deposit dust particles onto the RH/Temp sensor, which will likely decrease the accuracy of the RH sensors if they are not cleaned frequently enough.

5.2. High concentrations of chloride acid, nitride acid, sulfuric acid, ammonia, acetone, ethanol or propylene glycol may cause irreversible measurement errors. The concentration of ammonia gas that causes the sensor to shift has not been quantified, but the impact is assumed to be similar to the effects of ammonia on other electronics.

5.3. Extended exposure to contaminating vapors or high humidity may cause the RHT sensor calibration to change.

6. Cautions

6.1. Avoid installing a transmitter at a measurement location where the air is not well-mixed, or which is not representative of the barn area.

6.2. The NOVUS RHT transmitter comes factory-set with a temperature range of 0 to 100 ºC. The temperature range can be adjusted to -40 to 120 ºC using the TXConfig software. Ensure that the temperature range of the instrument set in AirDAC is the same as the current sensor settings.

6.3. When using the HMI41 humidity calibrator or equivalent for spot-checks and/or calibration, allow a sufficient amount of time (at least 10-30 min) for both the transmitter and calibration indicator to stabilize. Take several minutes' worth of data to compare, especially for RH measurement.

6.4. When using salt chambers to calibrate the RH transmitter, allow enough time (at least 10-30 min) for the transmitter to stabilize after the sensor probe is inserted into the salt calibration chamber. Other salt calibration procedures are as follows:

  6.4.1. Discard LiCl solutions that have been exposed to temperatures below +18°C. Exposure of the LiCl solution to temperatures below +18°C will cause a permanent change in its equilibrium humidity.

  6.4.2. Hold the probe as little as possible. Do not hold the salt chamber or other parts of the calibrator in your hand during calibration, as they may warm up and cause errors in the readings.

  6.4.3. Place the thermometers in holders when the thermometers are not in use, or when the calibrator is being moved from one place to another.

  6.4.4. Usually, errors during humidity calibration are due to temperature differences. Use the salt solutions in the part of the room where the temperature is most stable and keep it out of direct sunlight and away from localized heat sources.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument before initiating the procedure.
7.2. Each analyst must read the entire instrument manual and this SOP before operating the instrument.

8. Equipment and Supplies

8.1. NOVUS RHT-WM Humidity Transmitter (Novus Electronics, Brazil)
8.2. Air conditioner filter material and cable ties, or equivalent.
8.3. Computer (if sensor configuration is required)
8.4. TXConfig software and Interfacing Cable (if sensor configuration is required)
8.5. Vaisala HMK15 Humidity Calibrator (Vaisala Inc., Woburn, MA) or equivalent set of salt solutions and calibration chamber.
  8.5.1. Certified salts to make standard salt solutions for HMK15 humidity calibrator or equivalent (LiCl salt for 11% RH, $MgCl_2$ salt for 33% RH, NaCl salt for 75% RH, and K_2SO_4 for 97% RH)
  8.5.2. Distilled deionized water
8.6. Vaisala HMI41 Portable RH/T transmitter with NIST-calibration certificate (Vaisala Inc., Woburn, MA) or equivalent NIST-calibrated device for RH and temperature comparisons
8.7. Spare NOVUS RHT-WM transmitter and/or sensor.

9. Procedures

9.1. Installation of NOVUS RHT-WM
  9.1.1. The NOVUS RHT-WM humidity and temperature transmitters are intended to be mounted directly on the wall with the probe pointing downwards to assure the specified accuracy and protect the sensor. Choose a location which is representative of the larger environment, or of the specific exhaust air stream to be measured.
  9.1.2. For wall-mounting, open the transmitter cover to access two mounting holes.
  9.1.3. For measuring RH/T of barn exhaust air stream, locate a representative location to position the transmitter. A convenient installation approach is to attach the transmitter to the TEOM PM_{10} sampling inlet supporting rod atop the enclosure unit (SOP P1).
  9.1.4. Wrap the sensor capsule with some filtering material and secure the material with a cable tie. An example filter material is an air-conditioner filter.
9.2. Electrical connections
  9.2.1. Thread the power and signal cable through the cable gland.
  9.2.2. In the center of the transmitter are two jumper switches (labeled 4 and 5) that can be set to Position A or Position B, independently, depending on the desired output variables. For humidity and temperature outputs, set both jumper switches to Position A. The Output 1 signal will be temperature, and the Output 2 signal will be RH. For other output configurations, refer to the transmitter operating manual.

9.2.3. The circuit board has six terminals for wiring (Fig. 1). The terminals are clearly identified on the circuit board inside the transmitter. The output signal range is 0-10 VDC for an excitation of 18 to 30 VDC

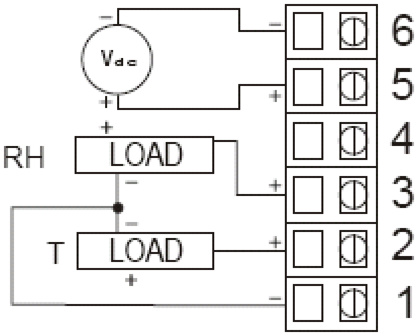


Figure 1. Wiring diagram of the RH/T transmitter. (Source: NOVUS RHT-WM and RHT-DM Datasheet).

9.2.1. Connect the power and ground conductors to terminals 5 and 6, respectively. Connect the digital signal conductor for humidity to terminal 3, the digital signal conductor for temperature to terminal 2, and a signal ground wire to terminal 1.

9.2.2. Connect the opposite end of the digital signal, power and ground wires to the appropriate terminals of the data acquisition and control (DAC) system (SOP B1).

9.2.3. Enter the sensor’s signal and measurement ranges into the AirDAC software so that the RH/T readings can be converted, displayed, and recorded (SOP B2).

9.3. Calibration using the HWK15 Humidity Calibrator. Calibration is based on the fact that certain saturated salt solutions generate a specific, reproducible RH in the air above them. The salt solutions suitable for the HMK15 are lithium chloride LiCl (11% RH), magnesium chloride $MgCl_2$ (33% RH), sodium chloride NaCl (75% RH) and potassium sulphate K_2SO_4 (97% RH). Calibration using the HMK15 Humidity Calibrator is usually performed at a minimum of two different humidities to ensure the sensor accuracy over the entire humidity range (0-100 % RH). When calibrated with salt solutions, the accuracy of the sensor is ±2% RH (0-90% RH) and ±3% RH (90-100% RH).

9.3.1. Open the transit cover of the chamber. Remove the measurement cover from the chamber holder and press the transit cover on the holder.

9.3.2. Pour the required amount of deionized water (Table 1) into the chamber.

9.3.3. Sprinkle the contents of a salt package slowly into the chamber, stirring constantly. If using the measurement cup to transfer the salt, make sure that the cup is clean and dry. Rinse and dry the cup after every use. Amounts of salt added and final volumes of the standard solutions are listed in Table 1.

Table 1. Salt solutions used in HMK15 Humidity Calibrator.

Salt	Initial water added (mL)	Mass of salt (g)	Solution final volume (mL)
LiCl	14	15	18
$MgCl_2$	3	30	30
NaCl	10	20	15
K_2SO_4	10	30	20

9.3.4. Close the chamber with the chamber cover. Fasten the salt chamber on the base plate and close the measurement holes with rubber plugs. Make sure that chamber covers and plugs are carefully closed.

9.3.5. Write the preparation date of the solution on a sticker and affix to the chamber.

9.3.6. Allow approximately 24 h for stabilization and equilibration of humidity before use. Ensure that the HMK15 calibrator and the probe are at the calibration site for at least 1 h before starting the calibration in order to let the probe temperature stabilize.

9.3.7. Remove the capsule from the probe, exposing the sensor. Insert the sensor into a suitable hole of the LiCl salt chamber. Press it downwards till it passes through the O-rings. Wait until the humidity reading stabilizes; this will take about 10-30 min. The shorter the time the hole stays open before inserting the probe; the shorter the stabilization time required.

9.3.8. In the temperature range of 25-30°C, LiCl humidity changes only very slightly; thus, it is not necessary to use the thermometer. However, it may still be used to ensure that the sleeve is in the correct place. Read the salt chamber temperature from the thermometer; then read the closest humidity value from Greenspan’s calibration table (Table 2).

Table 2. Greenspan’s calibration table (% RH ± uncertainty).

°C	LiCl	$MgCl_2$	NaCl	K_2SO_4
0	*	33.7 ± 0.3	75.5 ± 0.3	98.8 ± 1.1
5	*	33.6 ± 0.3	75.7 ± 0.3	98.5 ± 0.9
10	*	33.5 ± 0.2	75.7 ± 0.2	98.2 ± 0.8
15	*	33.3 ± 0.2	75.6 ± 0.2	97.9 ± 0.6
20	11.3 ± 0.3	33.1 ± 0.2	75.5 ± 0.1	97.6 ± 0.5
25	11.3 ± 0.3	32.8 ± 0.2	75.3 ± 0.1	97.3 ± 0.5
30	11.3 ± 0.2	32.4 ± 0.1	75.1 ± 0.1	97.0 ± 0.4
35	11.3 ± 0.2	32.1 ± 0.1	74.9 ± 0.1	96.7 ± 0.4
40	11.2 ± 0.2	31.6 ± 0.1	74.7 ± 0.1	96.4 ± 0.4
45	11.2 ± 0.2	31.1 ± 0.1	74.5 ± 0.2	96.1 ± 0.4
50	11.1 ± 0.2	30.5 ± 0.1	74.4 ± 0.2	95.8 ± 0.5

9.3.9. Repeat Step 9.3.8 for the wet reference standard.

9.3.9.1. Use NaCl as the wet reference standard (75% RH) if measured RH values are expected to be ≤ 80%.

9.3.9.2. Use K_2SO_4 as the wet reference standard (97% RH) if measured RH values are expected to be very high (90-100%). The risk for errors increases in high humidity, and the stabilization time should be longer (about 20-40 min).

9.3.10. Replace the capsule.

9.3.11. Make necessary adjustments to the sensor output using the TXConfig program (Step 9.6)

9.4. Spot-checking of RH/T using the HMI41 hand-held meter or equivalent. In addition to using the salt chambers, the transmitter can be spot-checked easily by using a transfer standard. The transfer standard may be either a NIST-traceable hand-held instrument (i.e. HMI41 hand-held meter with HMP46 probe) or a fundamental measurement device such as a psychrometer. A method using the HMI41 hand-held meter is as follows:

9.4.1. Ensure that the probe is correctly installed, and make sure batteries are good.

9.4.2. Turn on the power. The RH/T readings should appear automatically.

9.4.3. Press “MODE” to display the dewpoint temperature (Td).

9.4.4. Press “HOLD” to freeze the display of the current reading. Then press “MODE” or “ENTER” to return to the normal mode.

9.4.5. Press “HOLD” under the HOLD-mode, then the minimum reading after power on will show.

9.4.6. Press “HOLD” under the MIN-mode to show the maximum reading. Then press any button except ON/OFF to return to the normal mode.

9.5. When diagnosing transmitter malfunctions, replace the sensor to check if there is a problem with the sensor, the transmitter, or both. The sensor probes are interchangeable.

9.5.1. If there is dust build-up around the sensor, try using a fine brush (i.e. a paint brush) to remove the dust particles. If the dust sticks to the sensor, try dampening the paint brush slightly. Ensure the sensor has dried before taking measurements again.

9.6. Transmitter configuration using TXConfig

9.6.1. The transmitters come pre-configured to give a 0-10 VDC analog output for 0-100% RH and 0 to 100ºC. These measuring ranges can be altered, or a zero-correction factor can be added using the TXConfig software and interfacing cable set.

9.6.1.1. Download the TXConfig software to the hard drive of the site computer.

9.6.1.2. Connect the female DB9 connector of the TXConfig Interfacing cable to the serial port of the computer.

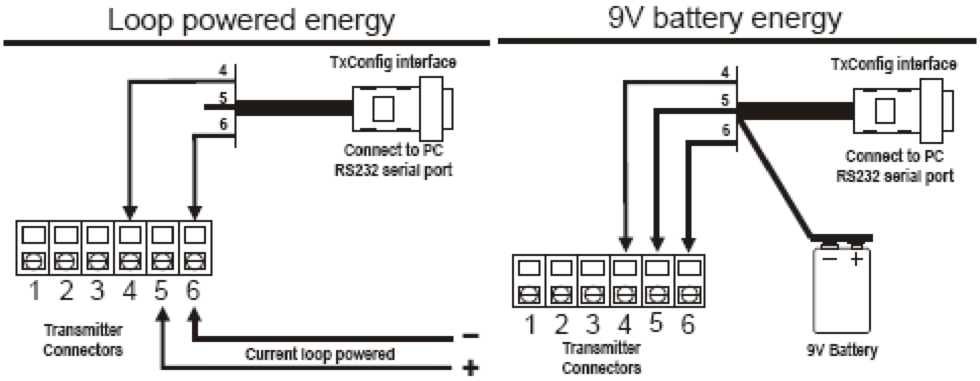
9.6.1.3. Connect the other end of the TXConfig Interfacing cable to the transmitter using the connections shown in Fig. 3a when a power supply is used, or Fig. 3b when a 9VDC battery is used.

9.6.1.4. Run TXConfig.exe.

9.6.1.4.1. The TXConfig main software prompt (Fig. 4) will appear. Select the tab for RHT or RHT-WM/DM (depending on the version of software).

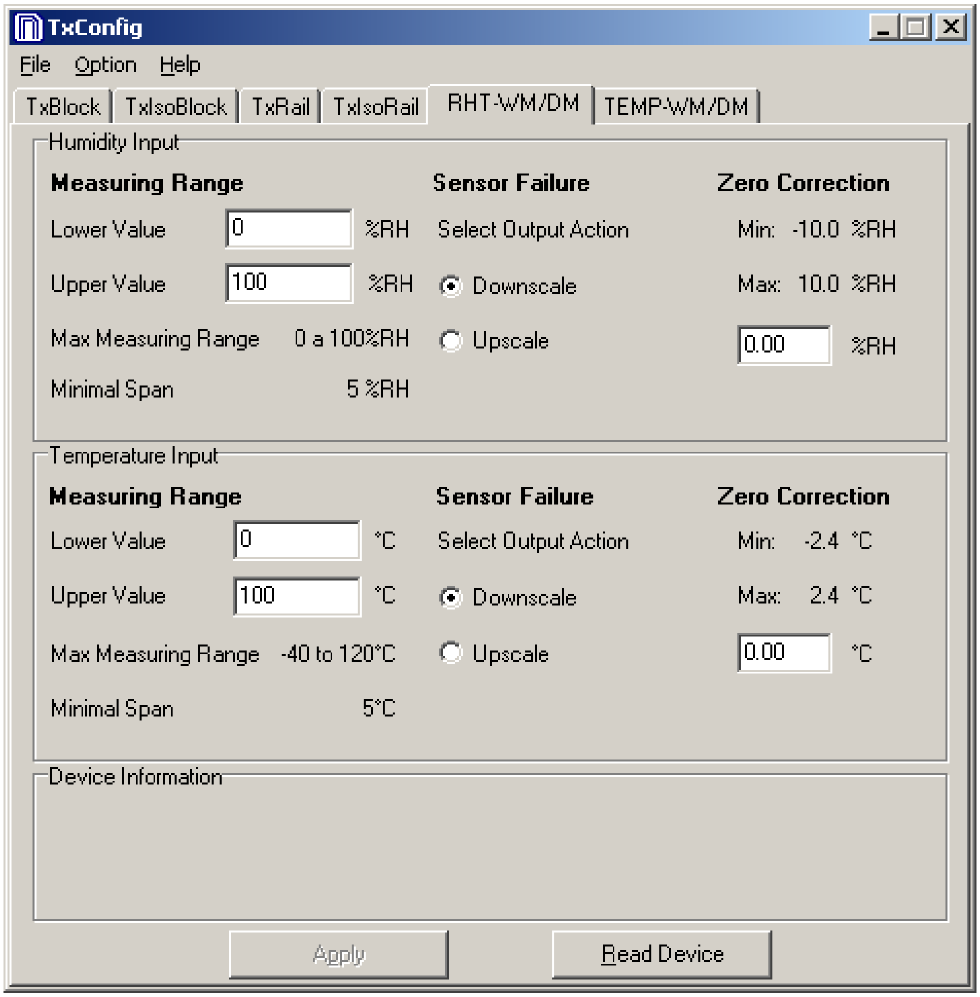
9.6.1.4.2. Click “Read Device”. The program will communicate with the sensor and display the current settings.

9.6.1.4.3. The measuring ranges for RH and temperature can be adjusted, within the limits shown on the software prompt.



(a) (b)

Figure 3. TXConfig Interface connections with a power supply (a) or 9VDC battery (b) power supply for sensor (Novus RHT Operating Manual)



Humidity Input

Measuring Range
Lower Value 0 %RH
Upper Value 100 %RH
Max Measuring Range 0 a 100%RH
Minimal Span 5 %RH

Sensor Failure
Select Output Action
● Downscale
○ Upscale

Zero Correction
Min: -10.0 %RH
Max: 10.0 %RH
0.00 %RH

Temperature Input

Measuring Range
Lower Value 0 °C
Upper Value 100 °C
Max Measuring Range -40 to 120°C
Minimal Span 5°C

Sensor Failure
Select Output Action
● Downscale
○ Upscale

Zero Correction
Min: -2.4 °C
Max: 2.4 °C
0.00 °C

Device Information

Figure 4. TXConfig software prompt form.

9.6.1.4.4. Click “Apply” and allow time for the computer to communicate these new settings to the sensor.

9.6.1.4.5. Click File – Exit to quit the TXConfig program. The cable set can be removed and the sensor can be re-installed for monitoring purposes.

9.7. Data Acquisition, calculations & data reduction requirements

9.7.1. A 0-10 VDC analog output (0-100% RH, 0 to 100°C by default) is monitored by AirDAC.

9.7.2. Report this data with 3 significant digits.

9.7.3. Follow SOP B4 to correct gas concentrations for calibration and air density.

9.8. Computer hardware & software

9.8.1. AirDAC (SOP B2)

9.8.2. ADPP (SOP B3)

9.8.3. CAPECAB (SOP B6)

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets located in the logbook with permanent ink, and in the electronic field notes.

10.4. Strike out all errors with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Calibration

11.1.1. Calibration of each instrument and calibration check will performed within intervals specified in the Quality Assurance Project Plan (QAPP).

11.1.2. Replace (prepare new) standard salt solutions every 6-12 mos.

11.1.3. Visually check each salt solution every 2-3 mos. Discard the solution and prepare a new one if there is not at least 10% of undissolved salt at the bottom of the chamber, or the salt is not clean. LiCl may crystallize on the surface, but may still have solution under the surface. In such case, stir solution and check the next day. (If the salt solution is not going to be reused within 1 mo of its initial use, it is recommended that it should be disposed of after its use.)

11.1.4. Check the O-rings on the salt chambers at each salt replacement. If they are damaged, replace with new ones. For correct calibration, it is essential that salt chambers are tightly closed.

11.1.5. The uncertainties achieved using the standard salt solutions at 20ºC are shown in Table 3.

11.2. Refer to Lemay et al. (2001) for more precautions and procedures for using RH sensors in livestock buildings.

Table 3. Uncertainties achieved using standard salt solutions at 20°C.

Salt	RH (%)	Total uncertainties (%RH)
Lithium chloride (LiCl)	11	±1.3
Magnesium chloride ($MgCl_2$)	33	±1.2
Sodium chloride (NaCl)	75	±1.5
Potassium sulphate (K_2SO_4)	97	±2.0

12. References

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12.4. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.
12.5. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.6. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.
12.7. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.
12.8. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.9. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
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THE MEASUREMENT OF SOLAR RADIATION WITH
THE LICOR MODEL 200SL OR 200SZ SILICON PYRANOMETER
Standard Operating Procedure (SOP) E3

THE MEASUREMENT OF SOLAR RADIATION WITH THE LICOR MODEL 200SL OR 200SZ SILICON PYRANOMETER

Standard Operating Procedure (SOP) E3

Prepared by

Juan Carlos Ramirez, Bill W. Bogan, and Richard H. Grant

Reviewed by

Albert J. Heber, Ji-Qin Ni, and Kenneth D. Casey (Texas A&M Univ.)

Effective Date: November 6, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The method described in this SOP is to use the silicon photodiode to measure solar incident radiation in the 300 to 1200 nm wavelength band.

1.2. This procedure applies only to the LiCOR Model LI-200SL Pyranometer for monitoring solar radiation during barn air emissions measurements, or for atmospheric stability class determination. By default, these instructions apply to both measurement scenarios. If there are any differences between the two applications, this will be specified.

1.3. Detection limit is 10 W/m^2. Ambient range is 10 to 1300 W/m^2.

2. Summary of Method

A pyranometer is an instrument for measuring solar radiation. The Model LI-200SL Pyranometer (LiCOR, Lincoln, NE) includes a Model LI-200SA pyranometer sensor and a millivolt converter. The sensor is installed on a mounting and leveling fixture to receive solar radiation (Figure 1). It uses a silicon-based photodiode semiconductor that converts the solar energy into a microamp current proportional to the solar radiation. The current signal is provided to a converter through a BNC connector. The converter contains a variable resistor that is unique to the LI-200SA sensor, and that converts the current signal to a standardized output voltage, 10 mV per 1000 W/m^2. The ultimate termination of the converter consists of bare leads to be connected to the data acquisition system, which converts the voltage signal to solar radiation in W/m^2, displays it on a computer monitor, and saves it into data files.

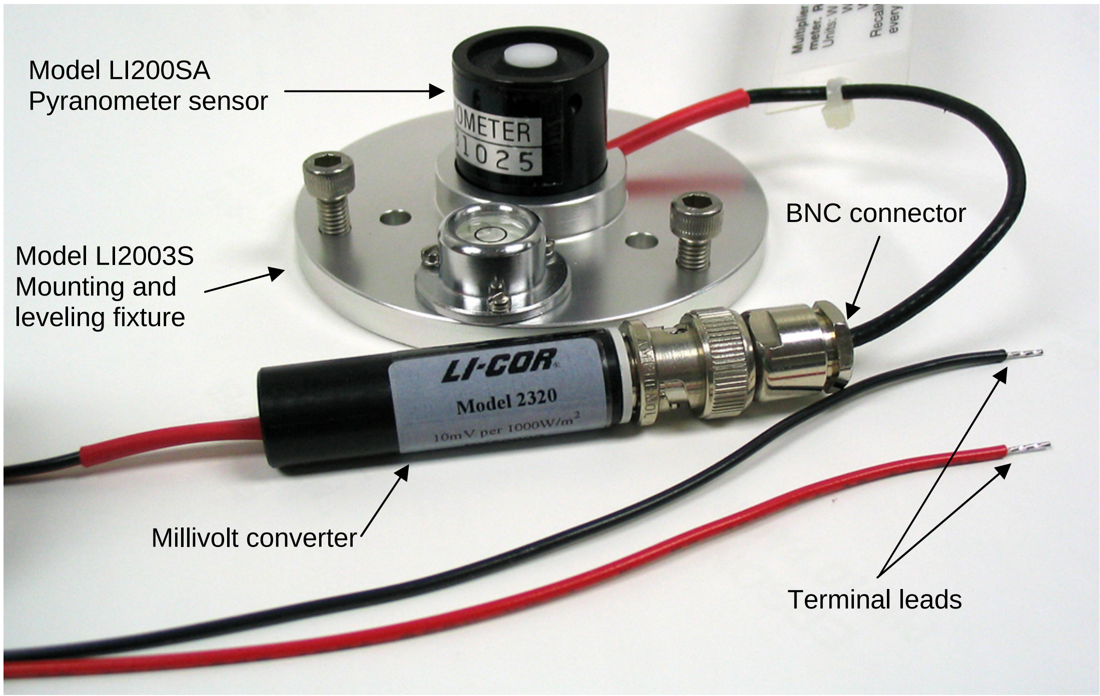

Figure 1. Model LI-200SL Pyranometer (including a LI-200SA Pyranometer sensor and a LI-2302 standardized millivolt adapter) and Model LI2003S Mounting and Leveling Fixture (adapted from LI-COR, 2006a).

3. Definitions

3.1.	BNC	Bayonet Neill Concelman connector (used with coaxial cables)
3.2.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.3.	QAPP	Quality Assurance Project Plan

4. Health and Safety

4.1. The pyranometer only produces weak electric signal that does not pose a health concern.

4.2. The pyranometer is installed outdoors, usually several meters above the ground. Follow all relevant safety precautions during installation and maintenance. Locate the sensor where it can be reached safely by the operator during the periodic clean up procedures.

5. Cautions

5.1. The acrylic material used in LI-COR light sensors can be crazed by exposure to alcohol or organic solvents, which adversely affects the response of the sensor. Clean the diffuser element of the sensor only with water and mild soap such as dishwashing soap. Do not use alcohol, organic solvents, abrasives, or strong detergents. LI-COR has found that vinegar can also be used to remove hard water deposits from the diffuser element, if necessary.

5.2. The spectral response of the LI-200 does not include the entire solar spectrum. Therefore, use the pyranometer in the same lighting conditions as those under which it was calibrated. Use it only to measure unobstructed daylight, not reflected sunlight.

5.3. Remove and save the red protective cap from the sensor. This is used to protect the sensor when it needs to be calibrated or stored.

5.4. Be careful when connecting the sensor cable to the data acquisition system. Make sure the connections are tight, and are made according to SOP B1.

5.5. Each pyranometer sensor is used only with the millivolt converter that is supplied with it and the serial numbers must match in the Model LI200SL. Be sure to change both the sensor and the converter if the LI200SL needs to be replaced.

5.6. The millivolt converter is not weatherproof. Install it inside the instrument shelter or protect it in a weatherproof enclosure.

6. Interferences

6.1. Incorrect siting of the solar radiation sensors can lead to inaccuracies over the period of data collection. One example is installing the sensor where it receives the shadow of a building or other object. Another example is installing the sensor where it receives the reflection of a clear painted wall or other object. It should not be used under vegetation.

6.2. Particulate matter and bird droppings on the optical head will cause low readings. The risk of this interference is greater near livestock buildings.

6.3. The signal provided by the converter to the data acquisition is a weak voltage. To prevent excess signal noise pickup, avoid using long cable between the converter and the data acquisition system or running the cable close to power cords.

7. Personnel Qualifications

7.1. Personnel must be trained in the use of the handheld millivolt multimeter before initiating the procedure. Training requires 10 minutes.
7.2. Each member of the field staff must read the pertinent sections of the sensor instruction manual (pp 1-5, 10-13) and this SOP before operating this instrument.

8. Equipment and Supplies

8.1. For barn measurement locations:
  8.1.1. Model LI-200SL Pyranometer (LiCOR, Inc., Lincoln, NE), which includes a LI-200 SA pyranometer, a BNC connector and a millivolt adapter. The LI-200SL comes with a 15-ft cable.
8.2. For open source measurement locations:
  8.2.1. Model LI-200SZ Pyranometer (no BNC connector) with Model 2220 millivolt adaptor (LiCOR, Inc., Lincoln, NE)
  8.2.2. Weatherproofed NEMA 4X box
  8.2.3. Data logger (SOP W6)
8.3. Model LI2003S Mounting and Leveling Fixture (LiCOR, Inc.)
8.4. Sensor stand and mounting arm (Fig. 2) if they are not available in the weather tower.
8.5. Machine screws with nuts to mount the Mounting and Leveling Fixture to the sensor stand.
8.6. 3/64″ hex wrench to mount the pyranometer sensor to the Mounting and Leveling Fixture, and 1/8″ screwdriver to fasten the screws
8.7. Plastic cable ties to fix the sensor cable
8.8. Multimeter to check the pyranometer signal output, with a resolution of ≤ 0.01 mV
  8.8.1. Multimeter must be pre-calibrated for open-source applications. This is not necessary for barn applications.
8.9. Soft cloth, soap, water and soft toothbrush if the sensor needs cleaning
8.10. Electronic parts cleaner
8.11. Heat shrink tubing
8.12. Heat blower
8.13. Unused LiCOR LI-200 (to calibrate the sensor)

9. Procedures

9.1. Acceptance
  9.1.1. Verify that the serial number on the calibration certificate matches the serial number on the instrument.
  9.1.2. Verify that the serial numbers of the pyranometer sensor and the converter match.
  9.1.3. Response check:

9.1.3.1. Place pyranometer outside facing towards the sky on a sunny day.
9.1.3.2. Remove and save the red protective cap from the sensor.
9.1.3.3. Connect the sensor and the converter with the BNC connector.
9.1.3.4. Measure sensor response across the positive and negative wires with a multimeter.
9.1.3.4.1. The multimeter resolution should be better than 0.01 VDC. For atmospheric stability classification uses, the multimeter should be a calibrated model.
9.1.3.5. If sensor voltage is less than 1 mV, return sensor to supplier for replacement.
9.1.4. Zero check:
9.1.4.1. Obstruct all light from entering the optical window using a non-reflective cup or other means and measure the voltage with a millivolt multimeter across the sensor wires.
9.1.4.2. Value should be less than 0.01 mV. If value is greater than 0.01 mV, return the instrument to supplier for replacement.
9.1.5. Installation
9.1.6. Mount the Mounting and Leveling Fixture to the horizontal platform, 2 ft away from the S side of the Weather Station Tower (or the S side of a 10-ft mast, in open-path measurements) using a mounting arm or a cross arm stand (Fig. 2), such that no obstruction can cast a shadow over the sensor, according to SOP E5 (barn installation), SOP U5 (lagoon/basin installation), or U7 (corral installation).

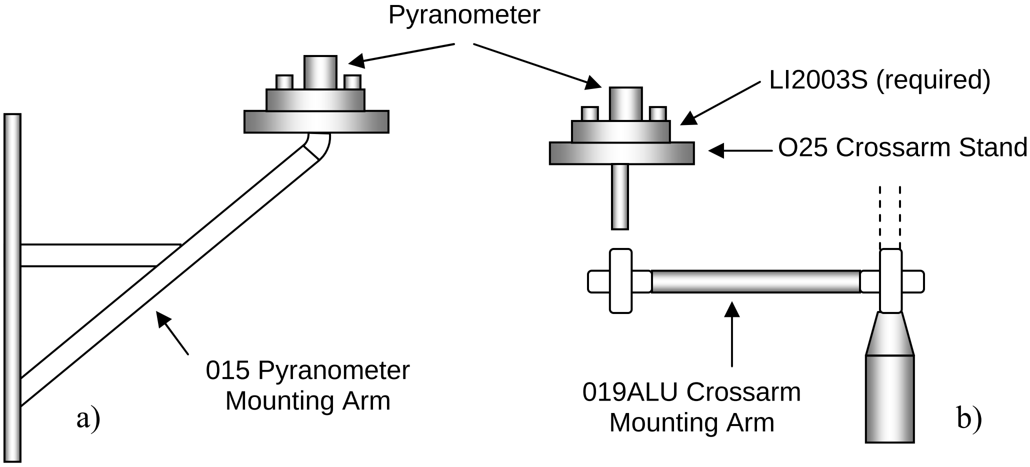

Figure 2. Pyranometer mounting arm (a) and cross arm stand (b) (LiCor Inc., 2006b).

9.1.7. Securely mount the pyranometer sensor onto the Mounting and Leveling Fixture using the 3/64″ hex wrench.
9.1.8. Adjust the level of the Mounting and Leveling Fixture.
9.1.9. If installing the sensor for open-source use, pass the coaxial cable through the appropriate knockout of the weatherproofed NEMA 4X box.

- 9.1.10. If installing the sensor for barn use, no NEMA 4X box is needed. Wrap the BNC connector, and its junction with the millivolt adapter, with electrical tape.
- 9.1.11. Run the cable from the pyranometer to the instrument shelter or trailer.
  - 9.1.11.1. If a field datalogger is being used (i.e. during open-source applications), use the 1/8″slotted screwdriver to connect the positive signal wire to the single-ended measurement channel, and the black wire to ground according to SOP W6.
- 9.1.12. Connect the cable to the Millivolt Converter inside the instrument shelter.
- 9.1.13. Measure voltage across the two wires using a multimeter. On a sunny day, the voltage should be at least 1 mV.
- 9.1.14. Attach wires to data acquisition system according to SOP B1.

9.2. Calibration checks

- 9.2.1. Check the calibration of a pyranometer which is in use by comparing its readings with an unused pyranometer of the same model which is known to be accurate.
  - 9.2.1.1. This can be done in the field or at Purdue. The QAPP for a particular project will state which option is to be used.
    - 9.2.1.1.1. If these checks are to be done in the field, it is necessary to include an additional support and additional wiring for the collocated sensor, as well as the corresponding wiring, when installing the sensor. There must also be an available input channel in the data acquisition system for this collocated sensor.
    - 9.2.1.1.2. This is not necessary if the instruments are to be sent to Purdue for calibration.
  - 9.2.1.2. Measurements are made every 5 min for 2 d, using the same data acquisition system used in the study to collect data from both sensors.
  - 9.2.1.3. The calibration check frequency will be specified in the QAPP.
    - 9.2.1.3.1. The manufacturer recommends recalibrating this instrument every two years. A shorter interval can be chosen based on the QAPP's Quality Objectives.
- 9.2.2. Calculate the difference in each 5-min paired measurement, and compute the mean difference between the two sensors for the daylight hours over the two days.
- 9.2.3. If the mean difference between the sensor under calibration and the unused sensor is < ±5% of the unused sensor's reading, then the sensor being calibrated is assumed good. In this case, calculate a correction factor to apply to the in-field sensor.
- 9.2.4. If the mean difference between the sensor under calibration and the unused sensor is greater than ±5% of the unused sensor's reading, then check the cleanliness and the connections of the sensor that is being checked, and repeat the calibration check. If the difference persists, the sensor being checked is assumed to be defective, and must returned to the supplier for repair or replacement.

9.3. Troubleshooting

- 9.3.1. Low readings are often due to a dirty optical window. Clean surface of sensor with soap and water.
- 9.3.2. Erratic values are often due to poor connections. Check connections for tightness.

9.4. Data acquisition, calculations & data reduction requirements

- 9.4.1. The LI-200SL output is acquired by a data acquisition (DAQ) system (SOP B1 and SOP B2) at a frequency of 1 Hz.

9.4.2. The DAQ system converts the voltage signals to W/m^2, averages them every 15 s and 60 s, and saves the averaged data in data files.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method, as well as in a bound record book designated for the method.
10.2. Manage all data according to SOP B5 (for barn measurements) SOP D1 (for open-source meteorological measurements).
10.3. Document all data and information on field data sheets and in site logbooks with permanent ink, or in electronic notes.
10.4. Strike out errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Do the following at the beginning and end of each measurement period, or as specified in the QAPP:
  11.1.1. Check physical cleanliness of the pyranometer's optical window. If dirty, clean with soap and a wet cloth. Always use lens cloth to avoid scratching the glass surface.
  11.1.2. Perform recalibration if the optical window shows any scratches, or discoloration that cannot be washed off.
  11.1.3. Check physical cleanliness of connectors. If corroded, clean with electronic cleaner and toothbrush.
  11.1.4. Check integrity of the plastic casing of the signal cable.
    11.1.4.1. If damaged slightly, repair with heat-shrink tubing.
    11.1.4.2. If damaged significantly, replace sensor and return sensor to manufacturer for repair.
  11.1.5. Perform zero checks (Section 9.1.4).
  11.1.6. Record results of each check in the calibration file (Appendix A) for open-source applications, or a similar table entry in the electronic field notes for barn applications.
  11.1.7. Calibration checks against a collocated sensor (Section 9.2).
11.2. Do the following daily:
  11.2.1. Compare the measurement with potential irradiance based on time of day, latitude and longitude of the location, and a solar constant of 1367 W/m^2 (Appendix B).
  11.2.2. Ratio of sensor measurement to potential irradiance must be less than 0.9.
  11.2.3. If ratio is greater than 0.9:
    11.2.3.1. Flag data value as invalid.
    11.2.3.2. Perform a calibration check against an unused pyranometer (Section 9.2). If the sensor fails this check (Section 9.3.4), replace sensor and return sensor to factory for repair.
  11.2.4. Check measurements between 10 AM and 2 PM.
    11.2.4.1. If measurements are less than 100 W/m^2:
      11.2.4.1.1. Flag data values for day as invalid
      11.2.4.1.2. Check wiring and optical window. Repair, clean, or replace as necessary.

12.

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12.10. SOP D1. 2006. Management of Open-source, Weather, and Lagoon-characterization Data. Standard Operating Procedure D1. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.
12.11. SOP E5. 2006. Roof-mounted Weather Station Tower. Standard Operating Procedure E5. Purdue Ag Air Quality Lab.
12.12. SOP U5. 2006. The Installation of Open-source Measurement Equipment. Standard Operating Procedure U5. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.
12.13. SOP U7. 2006. The Instrument Trailer and Installation of Open-Source Measurement Equipment (Corrals). Standard Operating Procedure U7. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.
12.14. SOP W6. 2006. Establishment, Data Acquisition and Control of Weather and Lagoon Characterization Hardware. Standard Operating Procedure W6. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.
12.15. National Oceanic and Atmospheric Administration (NOAA). Solar Position Calculator. Available on http://www.srrb.noaa.gov/highlights/sunrise/azel.html. Accessed on 7/10/2006.
12.16. Free Zip Code Lookup. Available at http://zipinfo.com/search/zipcode.htm. Accessed on 7/10/2006

13. Contact Information

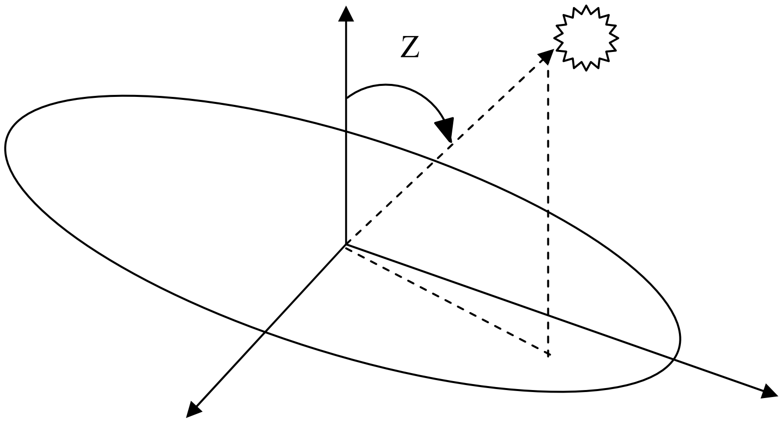
13.1. Distributor: Campbell Scientific, Inc., 815 West 1800 North, Logan, Utah, 84321. Technical support (435)-753-2342.

Appendix A. Calibration form: LI-200SL Solar Radiation Sensor

Instrument Serial Number: ___________________________________ **Location:** _______________________________________

Date (D-M-Y)	Time Begin	Time End	Mean irradiance (W/m^2)		Difference, (unused-measured)		Action Taken (Adjust, Replace)	Analyst
	AM/PM	AM/PM	Unused sensor	Sensor in use	W/m^2	%		

Appendix B. Procedure to Calculate the Potential Solar Radiation on a Horizontal Surface.



Calculate the vertical component of the potential solar radiation on a horizontal surface using the following equation:

Ho = Io * CosZ

Where:

Ho = Potential extraterrestrial insolation on a horizontal surface (W/m^2)

Io = Extraterrestrial solar radiative flux (1367 W/m^2)

Z = zenith angle (from the vertical position to the position of the sun).

Obtain the site-specific Cosine of the Zenith angle (CosZ) from the National Oceanic and Atmospheric administration (NOAA) website (http://www.srrb.noaa.gov/highlights/sunrise/azel.html), by entering the geographic location of the monitoring site (latitude and longitude) and the time of day. The online calculator will determine the cosine of the zenith.

If unsure of the latitude and longitude of the specific monitoring site, this can be obtained through the website http://zipinfo.com/search/zipcode.htm, by checking the “latitude and longitude” box and the entering the ZIP code of the location.

WIND SPEED AND DIRECTION MEASUREMENTS
USING THE R. M. YOUNG MODEL 03002VM WIND SENTRY
Standard Operating Procedure (SOP) E4

WIND SPEED AND DIRECTION MEASUREMENTS USING THE R. M. YOUNG MODEL 03002VM WIND SENTRY

Standard Operating Procedure (SOP) E4

Prepared by
Juan Carlos Ramirez

Reviewed by
Ji-Qin Ni, Albert Heber, Bill W. Bogan,
and Kenneth D. Casey (Texas A&M Univ.)

Effective Date: November 7, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Wind speed and direction data is needed to provide local weather conditions, which can help explain some abnormalities registered by other instruments.

1.1.1. One important example of this is the effect of wind on the performance of the barn's low-pressure exhaust fans.

1.2. This SOP describes the installation, operation and maintenance of the R.M. Young Model 03002VM Wind Sentry. The range of this instrument is 0-50 m/s (0-112 mph).

1.2.1. This method has a wind speed threshold of 1.1 m/s (2.5 mph).

1.3. This instrument is typically installed on top of a tower at barn emission sites, on or near the barn where wind speed and direction are secondary variables.

2. Summary of Method

The R.M. Young Model 03002VM Wind Sentry (Fig. 1) measures horizontal wind speed and direction. Cup rotation produces an AC sine wave voltage signal with a frequency proportional to wind speed. The vane orientation is sensed by a 10 kΩ precision conductive plastic potentiometer. Internal circuitry converts both of these signals to a linear 0-5 V voltage signal. Signal conditioning electronics are integrated into the instrument junction box. The mounting ring is secured to the mounting pipe after the proper vane orientation is verified.

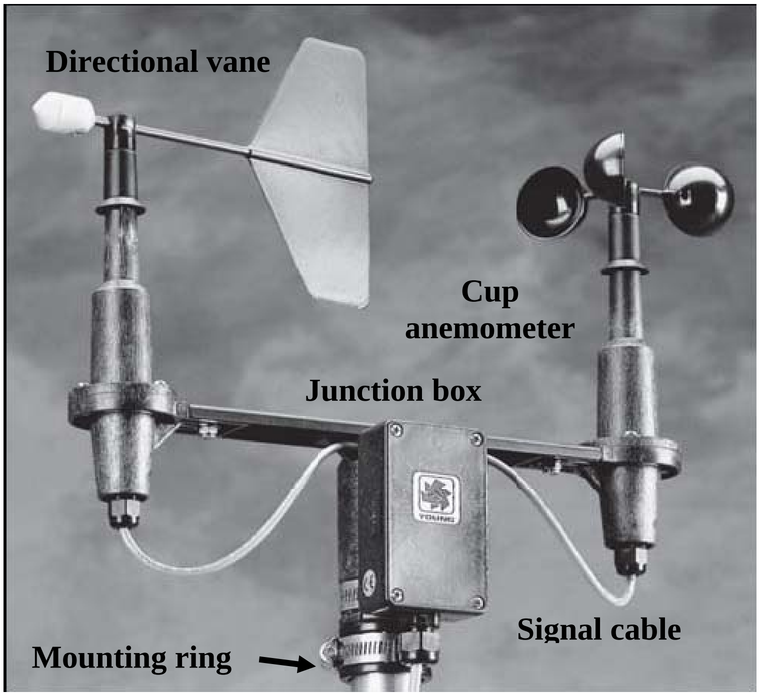


Figure 1. R.M. Young Model 03002VM Wind Sentry (R.M. Young Company).

3. Definitions

3.1.	DAS	Data acquisition system
3.2.	AirDAC	Data acquisition and control software (See SOP B2)
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	QAPP	Quality Assurance Project Plan

4. Health and Safety

4.1. Any work performed on the roof when installing weather monitoring equipment, including the wind monitor, should follow the OSHA (U.S. Occupational Safety and Health Administration) requirements for roof work and ladder safety, as covered in Section 4 of SOP E5.

4.2. Use a safety harness when climbing or working on a tower.

4.3. Towers should preferably be lowered to the ground to install the wind monitor.

5. Cautions

5.1. Grounding the Wind Sentry is vitally important. Without proper grounding, static electrical charge can build up during certain atmospheric conditions and discharge through the transducers, inducing erroneous signals or transducer failure.

  5.1.1. Do not paint the contact surface between the instrument and the tower. The instrument is grounded using the metal pipe or tower structure. The tower must be connected to a grounding rod.

  5.1.2. The instrument “Earth Ground” (Fig. 3) on the circuit board assembly inside of the junction box must be connected to an earth ground using the shield of one of the signal cables that takes the wind speed signal or the wind direction signal to the data acquisition computer. Connect this shield to the same ground as the computer.

5.2. Bearing damage can cause the wind speed threshold value to increase. Check the bearings whenever noise is detected or the speed threshold increases.

5.3. The potentiometer used to measure the wind direction requires a DC excitation voltage of 8-24 V. Do not exceed 24 VDC.

6. Interferences

6.1. Proper grounding prevents electrostatic noise from affecting the signal.

6.2. Nearby obstacles (trees, tall buildings, etc) can affect wind patterns, and result in inaccurate data.

6.3. The building upon which a roof tower is mounted can interfere with the measurement. This interference is acceptable for secondary measurements.

6.4. The directional sensor has an 8° deadband region from 352º to 360º, although the mechanical range of the instrument is 360°. The signal conditioning of the 03002VM has an active "pull up circuit". This means that when the wiper of the potentiometer is in the 8° deadband area, instead of the output signal floating electrically giving random values, the output is pulled up to full scale. The instrument cannot be used to distinguish wind directions between 352º and 360º.

7. Personnel Qualifications

7.1. Installer and operator must read this SOP before attempting to install or do any maintenance activity on the instrument.
7.2. Installer or operator must read the "Health and Safety" Section (Section 4) of SOP E5, which covers precautions for working on roofs and using ladders.
7.3. Installer must understand how to wire signal cables.
7.4. Personnel responsible for installing the wind monitor tower should be comfortable with heights.

8. Equipment and Supplies

8.1. Equipment
  8.1.1. Wind Sentry (Model 03002VM, R. M. Young Co., Traverse City, MI), with 0-5 VDC outputs for both wind speed and direction
  8.1.2. Shielded signal cable, 2-pair, 22 AWG
  8.1.3. Vane angle bench stand (Model 18112, R. M. Young Co.) to calibrate direction (optional)
  8.1.4. Anemometer Drive (200 to 15,000 rpm) to calibrate wind speed (Model 18802, R.M. Young Co.)
  8.1.5. Propeller torque disc (Model 18314, R. M. Young Co.)
  8.1.6. Compass
  8.1.7. Ladder that extends at least 3 ft above the roof or landing surface
  8.1.8. Safety harness system (to work on roof or tower)
  8.1.9. Slip-resistant shoes (to work on roof or tower)
  8.1.10. Plastic cable ties (to fasten signal and electric cables).
8.2. Critical spare parts
  8.2.1. The instrument parts likely to need replacement (due to normal wear) are the precision bearings and the potentiometer:

8.2.1.1.	Flange bearing (2 each on the cup and vane shafts)	03126S
8.2.1.2.	Potentiometer mounting & coil assembly	03330A

9. Procedure

9.1. Receiving inspection check
  9.1.1. Upon receipt, check the instrument for any visual shipping damage.
9.2. Initial performance checkout

Before installing the instrument on the roof tower, bench test the instrument mechanically and electrically.

  9.2.1. Initial mechanical checkout
    9.2.1.1. Using the mounting ring, install the instrument on a suitable support in its working position.

9.2.1.2. Place the cup wheel on the anemometer shaft, and tighten the set screw on the side of the hub.

9.2.1.3. Check that the vane and the cup wheel rotate freely without any friction.

9.2.1.4. Blow gently on the cups. Watch for obvious high torque or irregular rotation.

9.2.1.5. Check vane balance by holding the instrument base so the vane surface is horizontal. It should have near-neutral torque without any tendency to rotate. A slight imbalance will not degrade performance.

9.2.1.6. The anemometer bearing conditions can be checked using a propeller torque disc. This disc allows verification of the anemometer bearing torque with 0.1 g-cm resolution. The disc temporarily replaces the cup wheel for torque measurement. The disc also can be used for simple and accurate pass/fail checks. Charts included with the disc relate torque to propeller threshold with limits for acceptable bearing performance.

9.2.2. Initial check of outputs of wind speed and direction circuits

9.2.2.1. Connect excitation voltage and signal cables to terminal strip, located in the junction box (Figure) according to the wiring diagram in the instrument manual. If the instrument cannot be connected to the DAC system that will be used during data collection, a multimeter can be used.

9.2.2.2. Connect the “Earth Ground” terminal from the junction box (Fig. 2) to the shield of one of the two paired cables that are used to transmit the wind speed signal or the wind direction signal. Then connect this ground to the computer ground.

9.2.2.3. The excitation voltage must not exceed 24 VDC.

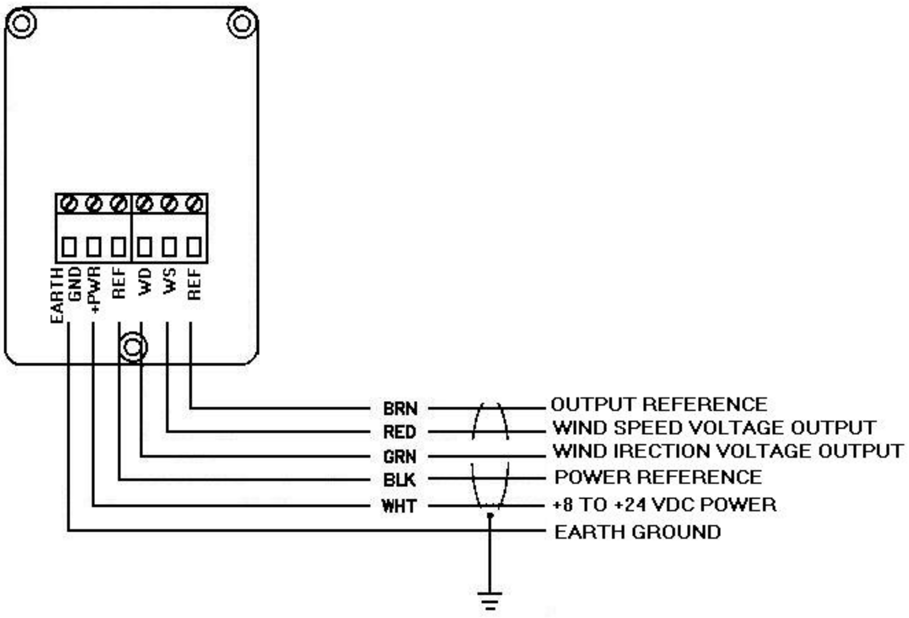


Figure 2. Wind anemometer PC board in junction box (Model 03002V Manual).

9.2.2.4. The output of the propeller rotation can be calibrated using an Anemometer Drive (R. M. Young Model 18802 or equivalent) attached to the anemometer shaft (after disconnecting the cup wheel). Apply the appropriate calibration formula (Section 9.4.3.2 in this SOP) to the calibrating motor rpm and adjust the electronics to the proper value.

9.3. Installation

9.3.1. Mount Wind Sentry (Fig. 3)

9.3.1.1. Install the mounting post on the tower (SOP E5).

9.3.1.2. Place Wind Sentry on mounting post. Do not tighten the mounting ring band clamp yet.

9.3.2. Connect Instrument Cable

9.3.2.1. Follow the instructions presented in Section 9.2.2.1 of this SOP. Also, refer to the Wind Sentry cable and wiring diagram included in the instrument manual.

9.3.3. Align Vane

9.3.3.1. Connect the anemometer to the DAC system (which will show wind direction in angular degrees), or to a multimeter (which will measure voltage output only).

9.3.3.2. Point the instrument in a known direction

9.3.3.2.1. If a known directional reference point exists, this may be used.

9.3.3.2.2. A compass may be used to orient the instrument in a known direction, if the values are considered secondary or auxiliary data.

9.3.3.3. Sighting down the vane centerline, point the counterweight on the vane at the reference point, or in the direction indicated by the compass.

9.3.3.4. While holding vane in position, slowly turn base until the indicator shows the proper value.

9.3.3.4.1. If the DAC system is used as the indicator, the proper value will be the direction, expressed in angular degrees (0 = due north).

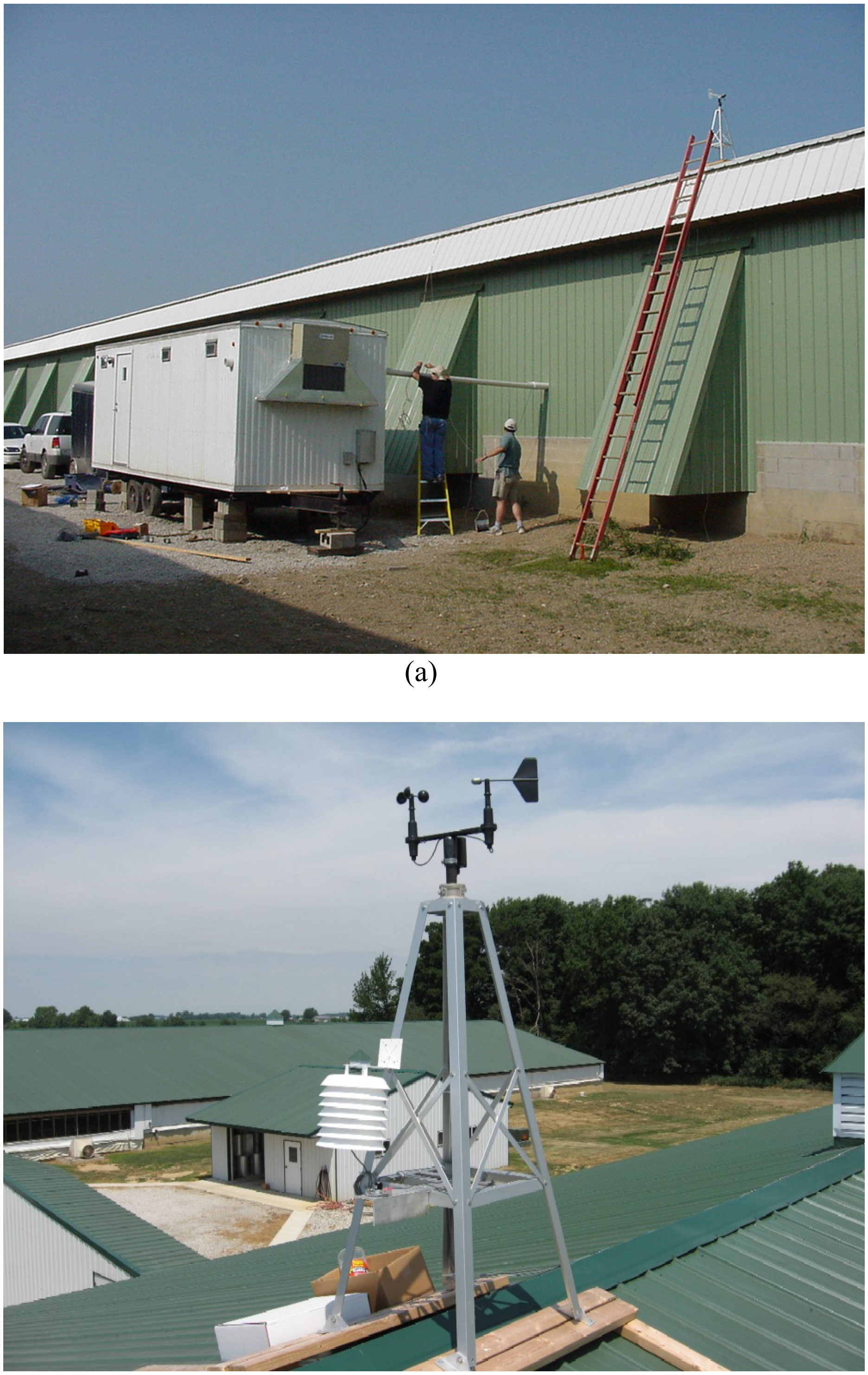
9.3.3.4.2. If a multimeter is used, the 0-5 VDC output of the instrument must be adjusted to 0-4.89 VDC, given the 8-degree deadband (Section 6.4). The proper output is thus determined by:

$$\frac{\text{Orientation (angular degrees)}}{352^{\circ}} \times 4.89\ \text{VDC} \qquad (1)$$

9.3.3.5. Tighten mounting post band clamp.

9.3.4. Grounding the instrument

9.3.4.1. Follow the steps described in Section 9.2.2.2.



(a)

(b)

Figure 3. Wind Sentry installation next to the on-farm instrument shelter at a site (a), and a close view of the Wind Sentry and weather station tower on the barn roof at another site (b) (PAAQL files).

9.4. Instrument calibration

9.4.1. The wind monitor is fully calibrated before shipment and should require no adjustments. If recalibration is necessary after maintenance, send it to the manufacturer.

9.4.2. Certain applications of the wind direction data require an accurate wind direction calibration, which can be performed using the vane angle bench stand. Other applications of the data require a less accurate calibration, such as secondary data situations. In this case, the calibration of the instrument can be checked using a compass. Consult the QAPP for the particular project to determine which directional calibration is needed.

9.4.3. Wind speed calibration is determined by the cup wheel turning factor and the output of the transducer. Standard accuracy is ± 0.3 m/s (0.6 mph) for air speed and ± 3° for wind direction. For greater accuracy, the instrument must be individually calibrated in comparison with a NIST-traceable wind speed standard.

9.4.3.1. To calibrate Wind Sentry electronics using a signal from the instrument, temporarily remove the cup wheel and connect the anemometer drive to the cup wheel shaft. Apply appropriate calibration formula to the calibrating motor rpm, and adjust the electronics for the proper value. The calibration formula relates wind speed to cup wheel rpm. This calibration formula was obtained by the manufacturer after wind tunnel tests on the specific cup wheel design.

9.4.3.2. Calibration formulas for the wind monitor with propeller:

9.4.3.2.1. Wind speed vs. cup wheel rpm

m/s = (0.01250 x rpm) + 0.2
knots = (0.02427 x rpm) + 0.4
mph = (0.02795 x rpm) + 0.4
km/h = (0.04499 x rpm) + 0.7

9.4.3.2.2. Wind speed vs. output voltage (0-5 V)

m/s = 0.25 x mV
knots = 0.50 x mV
mph = 0.50 x mV
km/h = 1.00 x mV

9.4.3.2.3. For example, to determine indicated wind speed (in m/s) when cup wheel is turning at 1000 rpm, perform the following calculations:

(1000 rpm * 0.01250 (m/s)/rpm) + 0.2 = 12.7 m/s.

12.7 m/s should be the value indicated by the display of the DAC system. If not, adjust the DAC system as required.

9.4.3.3. Torque verification (bearing/transducer condition verification)

9.4.3.3.1. Remove the Wind Sentry from the tower, remove the cup wheel from the anemometer shaft, and replace with the torque disc.

9.4.3.3.2. Use torque disc to measure anemometer torque in both directions (clockwise and counterclockwise). Using a combination of black nylon screws (0.1 g) and pan-head stainless steel screws (1.0 g), place weights at the various radii on the torque disc to create the desired torque. Hold torque disc with the weights in a horizontal line, then release the disc. Disc should rotate freely downwards.

9.4.3.3.3. For a new anemometer, the acceptable threshold is 1.2 g-cm. This corresponds to a stainless steel screw at the 1-cm radius, plus a nylon screw at the 2-cm radius. For a used anemometer, in order to maintain a threshold of 1.1 m/s, this same maximum acceptable torque value applies.

9.4.3.3.4. Failure to freely rotate downwards indicates degraded bearings, which require service.

9.5. Troubleshooting

9.5.1. If noise from the Wind Sentry is detected:

9.5.1.1. Check grounding of the instrument.

9.5.1.2. Check flange bearings on the top and bottom of the cup wheel shaft or vane shaft (as appropriate, depending on which signal(s) is noisy).

9.5.2. If wind speed threshold increases, check flange bearings on the cup wheel shaft.

9.5.3. If signal output is nonlinear, check the potentiometer and/or replace it.

9.6. Data acquisition, calculations & data reduction requirements

9.6.1. The Wind Sentry signals (velocity and direction) are acquired by the data acquisition system according to SOP B2.

9.6.2. The data acquisition system (DAS) converts the wind speed output signal (0-4.89 VDC) to wind speed in m/s.

9.6.3. The DAS converts the wind direction signal (0-4.89 VDC) to wind direction in angular degrees (0-352°).

9.7. Computer hardware & software

9.7.1. The DAS provides a regulated DC excitation voltage (maximum 24 VDC) to the potentiometer.

10. Data and Records Management

10.1. Collect, store, and distribute data according to SOP B5 and the QAPP.

10.2. Store the original calibration documents in the on-site instrument shelter in the instrument folder that contains the manual and certifications.

10.3. Document all instrument checkouts (initial and periodic) in the electronic field notes.

10.4. Screen data using the criteria in Table 1.

10.5. Strikeout all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. The instrument is calibrated by the manufacturer and is shipped with a calibration certificate.

11.2. During the receiving inspection check, verify the wind speed and direction outputs (Section 9.2).

11.3. Conduct a performance check (including bearing status using the propeller torque disc) at intervals specified by the QAPP.

11.4. Routinely inspect data for validity, and flag data automatically according to criteria in Table 1. Investigate flagged data following procedures in SOP B5.

12. References

12.1. R.M. Young Co. (2001). Model 003002V Wind Sentry with Voltage Outputs Manual PN 03002V-90, Revision C060403.
12.2. R.M. Young Co. (2003). Wind System Calibration, Recommended Calibration Interval, Procedure, and Test Equipment. Manual PN 18860-90. PDF format.
12.3. US EPA, Office of Air Quality Planning and Standards. 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications. Available at http://www.epa.gov/scram001/guidance/met/mmgrma.pdf. Accessed on 2/10/2006.
12.4. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.
12.5. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.6. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.7. SOP E5. 2006. Roof-mounted Weather Station Tower. Standard Operating Procedure E5. Purdue Ag Air Quality Lab.

13. Supplier Contact Information

R.M Young Company
2801 Aero Park Drive, Traverse City, Michigan 49686 USA
Tel: (231) 946-3980, Fax: (231) 946-4772
E-mail: met.sales@youngusa.com
www.youngusa.com

Table 1. Wind speed and direction data screening criteria.

Variable	Screening criteria: Flag data if the value
Wind speed	is less than zero or greater than 25 m/s does not vary by more than 0.1 m/s for 3 consecutive hours does not vary by more than 0.5 m/s for 12 consecutive hours is zero for more than two hours consecutively
Wind Direction	is less than zero or greater than 360 degrees does not vary by more than 1 degree for more than 3 consecutive hours does not vary by more than 10 degrees for 18 consecutive hours

Reference: US EPA, 2000, Table 8.4, page 8-24.

ROOF-MOUNTED WEATHER STATION TOWER
Standard Operating Procedure (SOP) E5

ROOF-MOUNTED WEATHER STATION TOWER

Standard Operating Procedure (SOP) E5

Prepared by

Juan Carlos Ramirez

Reviewed by

Albert J. Heber, Bill W. Bogan and Kenneth D. Casey (Texas A&M Univ.)

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. A commercial aluminum tapered tower is needed to support sensors for solar radiation, wind speed and direction, ambient temperature and relative humidity at a barn emission monitoring site.
1.2. The roof-mounted tower will be located at the ridge of the barn near the instrument shelter. The vertical distance from the ground depends on the ridge height of the barn.
1.3. Weather data collected using this tower will be used to help explain abnormalities registered by other instruments, such as the effect of wind direction on the performance of the barn's low-pressure exhaust fans.
1.4. The data will be used to model thermal characteristics of the barn including heat loss and ventilation rate.
1.5. The tower will be installed on barn roofs with a slope not exceeding 4:12 (rise:run).
1.6. This SOP applies to the Model RT-424 tapered tower (Glenn Martin Engineering, Boonville, MO) or equivalent.

2. Summary of Method

A four-legged 1.37-m (4.5-ft) high tower with a maximum width of 0.6 m (24.5 in.) will be installed on the roof of a barn, and weather instruments will be installed on the tower, as shown in Fig. 1. The tower weighs about 30 lb, and is strong enough to support weather instruments. Stainless steel hardware and fasteners are included with the tower. Independent cables will be used for the lightning ground and for grounding the sensors. The farm's employees will install the tower on the roof, and project personnel will install the sensors and the corresponding signal, power, and grounding cables.

3. Definitions

3.1.	NEC	National Electrical Code
3.2.	OSHA	Occupational Safety and Heath Agency
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory

4. Health and Safety

Any work performed on the roof when installing the tower and the weather monitoring equipment should follow OSHA requirements for roof work and ladder safety, which include, as a minimum, the following aspects:

4.1. Inform the farm contact person to obtain authorization to work on or access the roof. Fill out any necessary forms.
4.2. Ask for assistance from the farm licensed electrician to install any electric cable.
4.3. Roof Work Safety
  4.3.1. Do not attempt to climb onto slippery roofs. Inspect for and remove ice and snow before getting onto roof surfaces. If the roof surface is wet, wait until the surface is dry.

  - 4.3.2. Use a safety harness system with a solid anchor point on steep roofs if the ground-to-eave height exceeds 25 ft.
  - 4.3.3. Do not access the roof during storms, high winds or other adverse weather conditions.
  - 4.3.4. Remove or properly guard any impalement hazards.
  - 4.3.5. Wear shoes with slip-resistant soles.
- 4.4. Ladder Safety:
  - 4.4.1. Keep manufactured and job-made ladders in good condition and free of defects.
  - 4.4.2. Inspect ladders before use for broken rungs or other defects so falls don't happen.
  - 4.4.3. Secure ladders near the top or at the bottom to prevent them from slipping.
  - 4.4.4. When you can't tie the ladder off, be sure the ladder is on a stable and level surface so it cannot be knocked over or have its bottom kicked out.
  - 4.4.5. Place ladders at the proper angle (4:1 slope = rise:run).
  - 4.4.6. Extend ladders at least 3 ft above the eave of the roof to provide a handhold, or for balance when getting on and off the ladder from the roof.
  - 4.4.7. Always face the ladder and maintain 3 points of contact when climbing it.
- 4.5. If you drop something while working on a roof, NEVER try to catch or stop it. Let it fall and keep your own balance secure. If you are working on the ground while someone else is on the roof, be mindful of the possibility of falling objects, and try to avoid these areas.
- 4.6. Always have someone helping you nearby.
- 4.7. Avoid installing the tower close to wires or power lines. Stay at least 1½ times the overall height away from any power lines or wires.

5. Cautions

- 5.1. Test the resistance to ground of the lightning rod before cutting the lightning rod cable (Section 8.10.2). If a second rod is necessary, the length of the grounding cable should be longer.

6. Personnel Qualifications

- 6.1. Installer and operators need to read and understand this SOP, and must be able to work in open heights without getting dizzy.

7. Equipment and Supplies

- 7.1. Tapered tower (Model RT-424, Glen Martin Engineering, Boonville, MO)
- 7.2. Mast to support the wind speed and direction sensor
- 7.3. Mast clamps (2) for non-rotating masts (Part #MC-10)
- 7.4. Side arm to install other sensors, such as the solar radiation pyranometer and the temperature and relative humidity sensors
- 7.5. U bolts to mount the side arm
- 7.6. Lightning Rod kit (Part #LR-8400) with Aluminum Tapered Point
- 7.7. Lightning cable
- 7.8. Copper grounding rod

7.9. Ground wire: 4 AWG solid soft bare copper wire, or equivalent
7.10. Battery-powered drill (to attach the bolted grounding cable to the tower)
7.11. Screwdriver to tighten the mast adaptor
7.12. Clipper to tighten the leg bolts, clamps, U bolts, etc
7.13. UV-resistant plastic ties to hold cables
7.14. Safety harness with lifeline
7.15. Ladder that can be extended at least three feet above the roof or landing surface

8. Procedure

8.1. Establish the tower location as close as possible to the instrument shelter. Make sure that trees or buildings will not cast a shadow on the solar radiation sensor that will be installed on a side arm on the tower.
8.2. Check that the roof presents the following conditions:
  8.2.1. Dry: If it is wet, dry the surface or wait until it is dry.
  8.2.2. Clean: Any material on the roof can create a slippery surface.
  8.2.3. Smooth: Warped roofs imply potential damage to the deck under the shingles.
  8.2.4. Secure: Verify that there are no nails or other materials that present a hazard.
8.3. Secure the bracket for the lifeline that will be connected to the safety harness.
  8.3.1. Construct roofing brackets to fit the pitch of the roof. Secure brackets in place by nailing, in addition to the pointed metal projections. Drive the nails full length into the roof (in accordance with 29CFR 1919.28(s)).
  8.3.2. When rope supports are used, they shall consist of first-grade manila of at least three-quarter-inch diameter, or equivalent.
  8.3.3. The safety belt lanyard shall be a minimum of ½-in nylon, or equivalent, with a maximum length to provide for a fall of no greater than 6 ft. The rope shall have a nominal breaking strength of 5,400 lbs.
8.4. Assemble the tower in accordance with the instruction manual.
8.5. Prepare the tower before installing it on the roof.
  8.5.1. Install all the instrumentation on the tower when it is on the ground, to verify that all the components are in place and to minimize the work on the roof (drilling, measurements, etc.).
  8.5.2. Install the U bolts so the side arm can be installed once on the roof.
  8.5.3. Mark which side should face south (the side arm for the solar sensor projects southward), so that the installer will clearly know the correct orientation.
  8.5.4. Attach the bolted fixture to which the lightning rod and cable will be installed.
  8.5.5. After testing sensors on the ground with the data acquisition system (as described in their respective SOPs), uninstall the sensors and have the tower ready to be lifted up by the farm employees.
8.6. Install the tower on the roof.
  8.6.1. Coordinate the installation of the tower on the roof.
  8.6.2. When hoisting lines are used to raise tools, materials, or instruments to a roof greater than 16 ft from ground to eaves without a parapet (or with a parapet less than 30 in. in height), the installer on the roof shall be secured by an approved safety belt attached to a lifeline.

8.7. Install grounding rod and cable.
  8.7.1. Measure the distance from the tower to the location of the grounding rod.
  8.7.2. Check that the layout of the cable on the roof is not going to pose a trip hazard.
  8.7.3. Drive at least 8 ft of the rod into the earth (NEC, Sect. 250.83, 1996).
8.8. Install weather sensors.
  8.8.1. Install the wind speed and direction sensor on a non-rotating post on top of the tower. Follow SOP E4.
  8.8.2. Install the solar radiation sensor according to SOP E3.
  8.8.3. Install the temperature and relative humidity sensors, following SOP E2.
8.9. Install the sensors' signal cables.
  8.9.1. Follow each instrument's SOP for the signal and power connections.
  8.9.2. Tie up all these cables together.
8.10. Troubleshooting
  8.10.1. If tower becomes loose from its foundation, have the farm contact person tighten it.
  8.10.2. If resistance to ground of the lightning rod is higher than 25 ohms, install a second rod at a minimum distance of 6 ft, and connect the two rods (NEC, Section 250.83, 1987).

9. Data and Records Management

9.1. Maintain all records in the electronic field notes. Supplement this electronic record by a bound record book, which should contain copies of the electronic record.
9.2. Manage all data according to SOP B5.
9.3. Document all data and information on field data sheets located in the logbook with permanent ink, and in the electronic field notes.
9.4. Strike out all errors with a single line. Initial and date all such corrections.

10. Quality Control and Quality Assurance Section

10.1. Verify that the resistance to ground of the lightning system is below 25 ohms (in accordance with Reference 11.2, Section 250.84). If it is not, refer to Section 8.10.2.

11. References

11.1. NAHB-OSHA National Association of Home Builders/ U.S. Occupational Safety and Health Administration (1999). Jobsite Safety Handbook, 2nd ed. Available on line at http://www.osha.gov/doc/jobsite/, Accessed on January 4, 2006.
11.2. National Fire Protection Association. 1995. National Electric Code, 1996 Edition. National Fire Protection Association, Quincy, MA.
11.3. SOP E2. 2006. Measurement of Relative Humidity (RH) and Temperature with the Vaisala HMT100 Humidity Transmitter. Standard Operating Procedure E2. Purdue Ag Air Quality Lab.
11.4. SOP E3. 2006. The Measurement of Solar Radiation with the Licor Model 200SL Silicon Pyranometer. Standard Operating Procedure E3. Purdue Ag Air Quality Lab.

11.5. SOP E4. 2006. Wind Speed and Direction Measurements Using the R.M. Young Model 05103L Anemometer. Standard Operating Procedure E4. Purdue Ag Air Quality Lab.
11.6. SOP U2. 2006. Installation of Barn Measurements. Standard Operating Procedure U2. Purdue Ag Air Quality Lab.

12. Contact Information

12.1. Manufacturer: Glen Martin Engineering, Inc., 13620 Old Hwy 40 Boonville, MO 65233. (660) 882-2734. http://www.glenmartin.com/industrial/pg17.htm.
12.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.
  12.2.1.

Figure 1. Weather station tower installation on a barn rooftop.

THE PAAQL GAS SAMPLING SYSTEM

Standard Operating Procedure (SOP) G1

THE PAAQL GAS SAMPLING SYSTEM

Standard Operating Procedure (SOP) G1

Prepared by

Juan Carlos Ramirez, Sam M. Hanni, and Ji-Qin Ni

Reviewed by

Bill W. Bogan and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Comprehensive measurement of gas emissions from livestock barns often requires sequential collection of air samples from multiple locations for delivery to a single gas analyzer or a set of multiple analyzers. Sharing analyzers among sampling locations reduces analytical costs and eliminates bias caused by instrument differences. A multipoint gas sampling system (GSS) facilitates sharing of the analyzers.

1.2. This gas sampling method is designed to sample air from inside and outside barns at confined animal feeding operations (CAFOs).

1.3. The GSS draws air through long sampling lines from gas sampling probes that are up to several hundred feet away and delivers the air to analyzer(s) that are less than 10 ft away in the instrument shelter.

1.4. This method includes auxiliary manual sampling from a selected location using bags, sorbent tubes, impingers, and canisters for off-line analysis.

1.5. Only 0.0005% to 0.025% of the total airflow of a barn fan is sampled by the GSS.

1.6. Leak checking of the GSS is facilitated with this method.

1.7. Delivery of calibration gases to the analyzer is facilitated with this method.

2. Summary of Method

2.1. The GSS in this SOP was developed by the Purdue Agricultural Air Quality Laboratory (PAAQL) in 2006 and supersedes the GSS described by Heber et al. (2006, in press). It has sampling and bypass manifolds that are arranged in a parallel configuration on a sloped mounting board (Fig. 1). Compared to the previous design, it has better gas leakage/blockage prevention, lower gas adsorption/desorption time, and more convenient operation and maintenance. A schematic diagram of the GSS, as it is integrated with the other components at a site (gas analyzers, DAC system) is presented in Fig. 2.

2.2. A sampling pump draws air from selected sampling locations at 4-7 L/min.

2.3. A bypass pump composites all unsampled probes and purges them simultaneously with a total flow of about 10 L/min.

2.4. The sample air is continuously delivered to a slightly positive analyzer manifold from which each gas analyzer draws continuous subsamples.

2.5. The sample air is optionally delivered to a manually operated valve for collecting samples for offline analysis.

2.6. A computer data acquisition and control system (SOP B1 and SOP B2) controls the automatic or manual sequential gas sampling through an array of independently-controlled 3-way solenoid valves in the GSS. Typically, air from only one sampling location is provided to the sampling and analyzer manifolds.

2.7. This GSS has built-in continuous sensors that measure pressure (positive or negative) in the sampling manifold, and the flow rate, relative humidity, and temperature of the sampling air. Sensor data is recorded by the data acquisition system (SOPs B1 and B2).

2.8. This GSS is enclosed and is heated by thermal energy dissipated by the pumps and solenoids. The increased GSS temperature improves adsorption/desorption of gases and helps to prevent condensation.

3. Definitions

3.1.	AI	Analog input
3.2.	CAFO	Confined animal feeding operation
3.3.	DAC	Data acquisition and control
3.4.	DAQ	Data acquisition
3.5.	DO	Digital output
3.6.	GSS	Gas sampling system
3.7.	Ma	Analyzer manifold
3.8.	Mb	Bypass manifold
3.9.	Mc	Calibration manifold
3.10.	Ms	Sampling manifold
3.11.	OFIS	On-farm instrument shelter

4. Health and Safety

4.1. The GSS has two 120-VAC vacuum pumps. Follow electrical safety rules when working on the pumps.

4.2. Air sampled from the barns may contain air pollutants with high concentrations that could cause negative health effects. Properly exhaust excess sample air to the outside of the OFIS and keep the OFIS well ventilated.

5. Cautions

5.1. Handle the GSS with care to avoid dropping it to the floor.

5.2. When transporting the GSS or storing it for a long time, seal all the openings of the solenoid valves and tubes to avoid contamination.

5.3. Only hand-tighten fittings inside the GSS to avoid over tightening them.

5.4. Each compression fitting inside the GSS has a gripper (seal) and a ferrule. Use them correctly to avoid air leakage.

5.5. Use a filter (Section 8.9) with about 1 mm x 1 mm mesh holes at the end of the GSS exhaust to prevent flies from entering the exhaust tubes. Make sure that the filter does not create excessive (>10 Pa) pressure drop in the exhaust.

5.6. Verify all power and signal connections and make sure that they are correct before using the GSS.

5.7. A 47-mm Teflon filter does not always stay flat when taking it out of the box. When inserting filters into the filter holders, carefully check the filter and make sure that it does not leave part of the surface area uncovered before tightening the holder. Always tighten the filter holder with the special filter holder wrenches.

6. Interferences

6.1. Air leaks into the system can dilute the sample gas. Maintain the GSS and perform leak checks when suspicions arise. Correct all problems discovered during leak checks.

6.2. Condensation of sampling air will not only introduce measurement error, but also may damage the analyzers. Stop the GSS if condensation is found in the tubes that provide sampling air to the GSS until the problem is solved.
6.3. Particulate matter in the sample air can cause malfunction of the solenoid valves and the mass flow meter. Verify proper installation of the in-line Teflon filter in all sampling inlets.
6.4. Improper conditioning of the Tedlar bags for the bag test (Section 9.10) can cause inaccurate results. Strictly follow the procedures in Section 9.10.3 to condition each bag,

7. Personnel Qualifications

7.1. Personnel should read and understand this SOP and be trained in the use of the GSS before initiating the procedures.
7.2. The operator should be trained to change air filters, to check sensors (relative humidity, temperature, and pressure), and to perform leak checks.
7.3. Personnel should read the Instruction of the Gas Sampling System prepared by PAAQL and delivered with the GSS and additional information and updates.

8. Equipment and Supplies

8.1. The PAAQL Gas Sampling System
8.2. Approximately 100 ft of Teflon tube (1/4″ OD x 1/8″ ID) for connecting the GSS to the 47-mm Teflon filters (Fig. 3)
8.3. Approximately 5000 ft of Teflon tube (3/8″ OD x 1/4″ ID) that connects the 47-mm Teflon filters at the sampling point to the 47-mm Teflon filters before the GSS (Fig. 3)
8.4. Approximately 15 ft of PVC tube (3/16″ ID) for connecting bypass exhaust air from the GSS to outdoors
8.5. Approximately 15 ft of PVC tube (5/8″ ID) for connecting excess sample air from the GSS to outdoors
8.6. Approximately 25 ft of 16-conductor 22-gage shielded or unshielded cable for connecting the solenoid control receptacle in the GSS to the DO channels in the DAC hardware. If 16-conductor cable is not available, use two pieces of 8-conductor or 10-conductor 22-gage shield or unshielded cables.
8.7. Approximately 25 ft of 14-conductor 22-gage shielded cable for connecting the sensor power/signal receptacle in the GSS to the AI channels in the DAC hardware and the low voltage DC power supplies. If 14-conductor cable is not available, use two pieces of 8-conductor 22-gage shielded cables.
8.8. Teflon filters (1-µm pore size and 47-mm diameter) used with the in-line filter holders
8.9. Standard filter holders (2″ dia), with discs of air conditioner filter foam (“NaturalAire” filters, or equivalent) to keep flies out of sampling lines
8.10. One or two 0-5 or 0-10 L/m rotameters for checking sampling air flow balance
8.11. Polyethylene pipe insulation with 1/2″ wall thickness and different inside diameters (e.g. 1/2″, 3/4″) for sampling tube insulation
8.12. Electrical tape to seal the ends of the tubes to prevent their contamination during maintenance, testing, transportation or storage

8.13. Multimeter to check electrical connections

8.14. A pair of walkie-talkies to communicate between operators

8.15. Tedlar bags for the bag test. The size of the Tedlar bag depends on the sampling flow rate. Generally, a 80 L Tedlar bag will work in most all cases.

9. Procedure

9.1. Setup

9.1.1. Before setting up the GSS in the OFIS, open its front and back panels and carefully check for any possible damage, loose connections, tubing/wire drops, etc. Fix all observed problems.

9.1.2. Set up the GSS on a solid table and make its gas ports face the gas analyzers. Locate the GSS about six inches from the wall.

9.2. Sampling and exhaust tubes connection

9.2.1. Insert a piece of 1/4″ OD Teflon tube through the tube holder on the top of the GSS (Fig. 1) to the common solenoid port that faces upward (Fig. 3). Connect the tube to the Teflon adapter in the solenoid by hand tightening the nut (Fig. 4, left). Hand-tighten the adapter (tube holder) on the top panel so that the tube does not move (Fig. 4).

9.2.2. Cut the 1/4″ tube with a sharp tube cutter by leaving several feet above the GSS depending on the sampling tube setup inside the OFIS.

9.2.3. Install a Teflon filter with 1-µm pore size in the 47-mm in-line filter holder and tighten the holder with the special filter holder wrenches.

9.2.4. Connect the other end of the 1/4″ Teflon tube to the outlet of the Teflon filter holder. Tighten it with a wrench (this is different type of compression fitting that does not have ferrules).

9.2.5. Connect the inlet of the filter holder to the 3/8″ OD air sampling tube (Fig. 3).

9.2.6. Repeat Sections 9.2.1 to 9.2.5 to connect all the sampling tubes to the GSS.

9.2.7. To prevent condensation in the sampling tubes, wrap the tubes between the GSS and the raceway with pipe insulation that is available in local hardware stores.

9.2.8. Connect a piece of 3/16″ ID PVC tube to the bypass exhaust (Fig. 3), and lead the other end of the tube to outside the OFIS.

9.2.9. Insert a piece of 5/8″ ID PVC tube through the sample exhaust hole (Fig. 3) and connect it to the barbed fitting on the top of the analyzer manifold (Fig. 5) and run the other end of the tube to outside the OFIS.

9.2.10. Connect the inlet tubes of the gas analyzers to the gas ports (Fig. 1), and hand-tighten the fittings.

9.3. Cable connection

9.3.1. There are two cable connection receptacles in the GSS. One has 16 pins and is for solenoid control. Another has 14 pins and is for sensor power and sensor signals.

9.3.1.1. Connect the solenoid control cable. Refer to the GSS internal wire connection tables and drawings specified in the GSS Instructions. Refer to the DAC design and configuration described in the DAC measurement and control signal table in SOP B1. Make a table of connections (Table 1) and record it to the field note.

9.3.1.2. Connect a 16-conductor cable or two 8-conductor cables to the 16-pin receptacle plug based on the connection table.

9.3.1.3. Connect the other end of the cable(s) to the FieldPoint DO channels of the DAC hardware according to the connection table.

Table 1. Example of the record table for GSS solenoid control connection.

Solenoid #	Pin #	Cable wire color	DO channel #	Terminal #	Sampling location
S1	1	Brown	0	1	Barn 1, fan 1
S2	2	Red	1	2	Barn 1, fan 5
S3	3	Orange	2	3	Barn 1, fan 10
S4	4	Yellow	3	4	Barn 1, fan 15
S5	5	Green	4	5	Barn 1, fan 20
S6	6	Blue	5	6	Barn 1, fan 25
S7	7	Purple	6	7	Barn 2, fan 1
S8	8	Grey	7	8	Barn 2, fan 5
S9	9	White	8	9	Barn 2, fan 10
S10	10	Black	9	10	Barn 2, fan 15
S11	11	Brown/black	10	11	Barn 2, fan 20
S12	12	Red/black	11	12	Barn 2, fan 25
S13	13	Orange/black	12	13	Barn 1, inlet
S14	14	Yellow/black	13	14	Barn 2, inlet
Ground	15	Green/black			

9.3.2. Connect the sensor cable

9.3.2.1. Refer to the GSS internal wire connection tables and drawings specified in the GSS Instructions. Refer to the DAC design and configuration described in the DAC measurement and control signal table in SOP B1. Make a table of connections for GSS sensors (Table 2) and record it in the field notes.

9.3.2.2. Connect a 14-conductor cable to the 14-pin receptacle plug.

9.3.2.3. Connect the other end of the cable to the relevant channels of the DAC hardware.

Table 2. Example of GSS sensor connection record table.

Sensor	Pin #	Wire color	DAC channel#	Terminal #	Ground
Pressure transducer, signal	1	Brown	FP-AI-2 ch0	2	
Pressure transducer, ground	2	Red			Ground
RH Sensor, signal	3	Orange	FP-AI-2 ch1	4	
T Sensor, signal	4	Yellow	FP-AI-2 ch2	6	
RH/T sensor, ground	5	Green			Ground
Mass flow meter, signal	6	Blue	FP-AI-2 ch3	7	
Mass flow meter, ground	7	Purple			Ground
Thermocouple, blue	8	Grey	FP-TC-3 ch0	1	
Thermocouple, red	9	White	FP-TC-3 ch0	2	
Cooling fan, +24 DVC	10	Black	FP-DO-1 ch14	15	
Cooling fan, ground	11	Brown/black			Ground

9.4. Cooling fan control

9.4.1. The cooling fan (shown in Fig. 1) turns on when the GSS internal temperature exceeds the set point. Set the thermostat of the fan control inside the GSS to 50°C.

9.4.2. Follow SOP E1 to install a thermocouple inside the GSS so that its internal temperature is monitored and recorded in the AirDAC. Install the thermocouple measurement point close to the inlet of the cooling fan.

9.5. Software configuration

9.5.1. The GSS is designed to have 50% of the solenoids normally open to the sampling manifold and other 50% normally open to the bypass manifolds (Fig. 3). This is to avoid choking the pumps in case that all solenoids are off (e.g. computer shut-down or DAC power failure) but the pumps are still running.

9.5.2. The control of the GSS is realized by DAC hardware and software. The control configuration is set up in the DAC software, AirDAC (SOP B2).

9.5.3. Follow procedures specified in SOP B2 and start AirDAC. Go to page DO in AirDAC (Fig. 6) and click Change to enable the configuration table.

9.5.4. Refer to the instructions in the DO page for configuration.

9.5.4.1. Enter the names of the sampling locations or other controls in the column "Name." The Ctrl # and their matching names with the "Air smpl" control type will be automatically saved in each data file. They will also be displayed in the AirDAC for automatic or manual control as shown in the upper right corner of Fig. 6.

9.5.4.2. Select control type (Ctrl type), automatic sampling sequence (Seq.), and automatic sampling frequency (Freq.). Enter the automatic sampling time (Time, m).

9.5.4.3. Configure the FieldPoint digital output channels by clicking the check box table on the right side of the DO page. For instance, when controlling Ctrl # 1 (sampling location at B1, fan 1) the configuration in Fig. 6 shows that for FP-DO module 1, channels 0, and 7 through 13 will be turned on while channels 1 through 6 will be turned off.

9.5.4.4. Verify that the completed configuration is correct. Click Apply and save button to record the configuration to the AirDAC Config Excel file (Fig. 7). Click Change to disable the configuration table.

9.5.4.5. If the changes need to be cancelled before applying and saving, click the Cancel changes button.

9.6. Power up GSS

9.6.1. Verify and ensure that all the completed connections are correct.

9.6.2. Plug the GSS power cord into a 115 VAC power outlet to power up the GSS.

9.6.3. Turn on the sampling pump and the bypass pump.

9.7. GSS initial test

9.7.1. Verify the GSS sensors

9.7.1.1. Go to the DAC page in the AirDAC that is running and is also correctly configured for acquiring GSS sensor signals (Refer to SOPs B1 and B2).

9.7.1.2. The pressure sensor should have values in the range between -3000 and -8000 Pa at normal sampling. If it is not in this range there may be either a leakage or a blockage in the sampling tube anywhere from the sampling location to the sampling pump.

9.7.1.3. The sampling flow rate should be between 4 and 7 L/m. If it is not in this range, check the sampling tubes, the sampling pump, and the mass flow meter.

9.7.1.4. The RH/temp sensor in the GSS should be within a reasonable range that reflects the sampling air, e.g. the RH between 20% and 70% and the T between 20°C and 45°C. Check the sensor, the sensor connection to the DAQ, and the DAQ configuration if no reasonable readings are shown.

9.7.1.5. The GSS temperature should show the air temperature inside the GSS.

9.7.2. Test solenoid control

9.7.2.1. Switch to manual sampling control by clicking the Auto Smpl button at the upper right corner of the AirDAC. The Select... ▾ button appears.

9.7.2.2. Click the Select... ▾ button and select one sampling location. When the button is released, a small clicking sound can be heard from inside the GSS, indicating that the solenoids are switching.

9.7.2.3. Verify that the air sample is being taken from the selected location.

9.7.2.3.1. This can be done by simply covering the inlet tube with a finger and seeing if there is suction occurring.

9.7.2.4. Go through all the sampling locations and make sure that all the solenoids are configured correctly and working properly.

9.7.3. Verify sampling air flow balance to check for leaks in the GSS itself and in its immediate connections.

9.7.3.1. This method can be used prior to leak testing of the entire sampling system (Section 9.9), since most leaks will occur in the GSS itself, or in its immediate connections. It requires two persons to work together.

9.7.3.2. Check the airflow balance using two airflow (mass flow) meters, one at the inlet and another at the outlet of the sampling system.

9.7.3.3. The mass flow meter inside the GSS can serve as the outlet airflow meter. Use another airflow meter or a rotameter as the inlet measurement device. Make sure that the two meters are calibrated together before the test.

9.7.3.4. Connect the outlet of the airflow meter or rotameter to the inlet of the Teflon filter holder inside the barn or in the ambient air using a short piece of flexible tube.

9.7.3.5. Select to sample this location in the AirDAC (Section 9.7.2) and compare the airflow readings from the air flow meter with that from the mass flow meter in the GSS. The positive difference in readings (difference = inlet - outlet) indicates a possible air leakage.

9.7.3.6. If there is leakage, the leak should be identified and removed.

9.7.3.7. This procedure can be combined with that of solenoid testing (Section 9.7.2) to save testing time.

9.7.4. Verify bypass air flow

9.7.4.1. Make sure that the bypass pump has about 10 L/m flow rate and is running.

9.7.4.2. Measure the airflow rate in the inlet of the filter holder at the sampling location when the line is not being sampled. Airflow rate of > 0.5 L/m should be detected, depending on the total sampling locations in the system.

9.7.4.3. If the airflow rate is too small, check the flow restrictor inside the 1/4″ OD Teflon tube between the bypass manifold and the solenoid connected to this particular sampling line (Fig. 8). If it is necessary, pull out the flow restrictor from the 1/4″ OD Teflon tube and cut it a little shorter (enlarge the orifice) before inserting it back into the 1/4″ OD Teflon tube. Because there is a balance of bypass airflow among all sampling lines, be cautious not to enlarge the orifice of the flow restrictor too much.

9.8. GSS leakage test

- 9.8.1. Connect the GSS to the DAQ hardware and software so that the solenoids can be controlled, and the pressure and airflow rate can be monitored.
- 9.8.2. Check all air passage connections. Hand-tighten fittings inside the GSS if loose.
- 9.8.3. Make sure that the GSS pressure and airflow rate measurement are correct.
  - 9.8.3.1. When the sampling pump inside the GSS is shut off, both pressure and airflow rate should read zero.
  - 9.8.3.2. If they do not read zero, re-set them to zero by adjusting the “9. Intercept (B)” entry in tab “DAQ” in AirDAC. “Apply and save” the settings.
- 9.8.4. Turn the sampling location to “GSS test” that shuts off all solenoids from connecting between sampling lines and the sampling manifold.
- 9.8.5. Watch the readings of the sampling pressure and sampling flow rate. Both of them should drop down quickly.
- 9.8.6. If the sampling airflow drops to nearly 0.0 L/m within about one minute, the GSS is leakage proof starting from the solenoids. Do not leave the vacuum status too long because the GSS is “over loading” during the “GSS test.”

9.9. Entire sampling system leakage test (requires two persons and a pair of walkie-talkies)

- 9.9.1. Turn the sampling location on one by one manually (described in Section 9.7.2) to test the leakage beyond the solenoid inlets.
  - 9.9.1.1. Record the sampling pressure and sampling airflow rate.
  - 9.9.1.2. Close the inlet of the filter holder at the sampling point, which is located inside or outside the barn, by a cap or simply tightly press a finger onto the inlet opening. If the sampling line does not have any leakage, the sampling airflow will drop down to close to zero within a couple of minutes, depending on the length of the tube. If the airflow is below 1% of the total sampling air flow (0.05 L/min for a 5 L/min sampling airflow), the sampling system should be considered normal.
- 9.9.2. Record the test results in the test notes.

9.10. Bag Test

- 9.10.1. Connect 3 m (10 ft) of 1/4″ Teflon tubing to the output of the Environics diluter.
- 9.10.2. Referring to SOP G11, access the concentration mode in the Environics software, and program the diluter to produce an ammonia concentration significantly different from that which is currently being measured at the sampling location. The exact concentration of ammonia that is appropriate for this step will vary from site to site and season to season, as will the actual ammonia concentrations measured at the site. Selecting a different concentration from that which is being measured allows the operator to easily see that a particular location is being tested, and to visualize differences from one sampling location to another during the bag test.

9.10.3. Conditioning of the Tedlar bags

- 9.10.3.1. Check the Tedlar bags for damage that might cause leaks (holes, cuts, a bad or loose valve, etc.)
- 9.10.3.2. Using flexible (i.e. vinyl) tubing, connect the first Tedlar bag to the vacuum pump that is used for the GSS leak test. Evacuate the bag, then disconnect it and evacuate the other 3 bags.
- 9.10.3.3. Fill 1/3 full with ammonia gas of a known concentration for the bag test.
- 9.10.3.4. Repeat Sections 9.10.3.2 - 9.10.3.3 two more times.
- 9.10.3.5. Completely fill the Tedlar bag with ammonia gas of a known concentration.
- 9.10.3.6. Repeat Sections 9.10.3.2 - 9.10.3.5 for the other 3 Tedlar bags

9.10.4. Test each sample location's integrity as follows:

- 9.10.4.1. Enter the AirDAC program (SOP B2).
- 9.10.4.2. Switch to manual sampling control by clicking the Auto Smpl button at the upper right corner of the AirDAC. The Select... button appears.
- 9.10.4.3. Click the Select... button and select one sampling location.
- 9.10.4.4. Sample that location for a minimum of 5 min before attaching the Tedlar bag with the known ammonia concentration.
- 9.10.4.5. Using flexible (i.e. vinyl) tubing, attach Tedlar bag to the sampling location that is being measured. Use a reducing union, and make sure that the connection is a tight connection to avoid any leaks.
- 9.10.4.6. Open valve on Tedlar bag with 3 turns. (Do not open any further than this, because the valve will come apart)
- 9.10.4.7. Sample the Tedlar bag for 10 min.
- 9.10.4.8. Monitor the AirDAC's gas page (Fig. 9).
- 9.10.4.9. Save a print screen of the AirDAC's gas page in a PowerPoint file.
- 9.10.4.10. Record the sampling time (Start & Stop), sampling location, ammonia concentration readings from the instrument & AirDAC, and the instrument model in the field notes using Table 3.

Table 3. Bag Test Table

Bag Test (30 ppm NH3) 11/10/2004			Bag Test TEC 17C			
Time		Sampling Location	Instrument Reading ppm	AirDAC Reading ppm	Average from Data File ppm	Percent Difference
Start	Stop					
15:33:30	15:43:30	Fan 2	27.7	27.53	27.49	1.35%
15:54:05	16:04:00	Fan 9	27.2	27.03	26.7	4.18%
16:08:30	16:18:30	Fan 15	27.6	27.44	27.44	1.53%
16:24:08	16:34:08	Fan 22	27.2	27.14	27.12	2.67%
16:40:29	16:50:30	Fan 41	28.1	27.97	27.93	0.23%
16:56:43	17:06:56	Fan 35	29	28.84	28.82	3.43%
17:15:30	17:25:30	Fan 29	29.1	28.93	28.84	3.50%
17:43:00	17:53:00	Ambient	28.8	28.6	28.58	2.57%
		Average			**27.865**	**2.43%**

- 9.10.4.11. Switch to the next location.
- 9.10.4.12. Repeat steps 9.10.5.4 to 9.10.5.10 until all sampling locations have been tested. If necessary, refill empty Tedlar bags with the known ammonia gas concentration again until all the locations have been tested.
- 9.10.4.13. Switch back to Auto Sampling Mode in AirDAC.

9.10.5. Averaging the ammonia concentrations from the 15-s data file

- 9.10.5.1. Go to Data file
- 9.10.5.2. Copy and paste the copy of the current 15-s data file in the data file
- 9.10.5.3. Open the copy of current 15-s data file with Excel.
- 9.10.5.4. Locate the start and stop times for each location during the bag test in the 15-s data file.
- 9.10.5.5. Average the ammonia concentration readings for the last two minutes of the Tedlar bag sampling.
- 9.10.5.6. Using Table 3, enter the average ammonia concentrations for each sampling location into the field notes.
- 9.10.5.7. Close the copy of the 15-s data file without saving.
- 9.10.5.8. Save the field notes.
- 9.10.5.9. Table 3 calculates the percent difference from average ammonia concentration reading from all sampling locations for each sampling location.
- 9.10.5.10. If the percent difference is greater than 5 % for any sampling location, take the following corrective action(s), and retest that sampling location (repeat Sections 9.10.5.4 to 9.10.5.10), until the percent difference is less than 5 %.
  - 9.10.5.10.1. Check and tighten all connections for the sampling line that has a leak.
  - 9.10.5.10.2. Check for holes or damage to the sampling line.
  - 9.10.5.10.3. Check to make sure that the filter holder closed tightly
  - 9.10.5.10.4. Check the GSS for leakage or loose connections
  - 9.10.5.10.5. Check Tedlar bag for leaks
  - 9.10.5.10.6. Check the connects between the GSS and the gas analyzers
  - 9.10.5.10.7. Check the connection between the sampling location and the Tedlar bag
- 9.10.5.11. Check the Tedlar bags for damage that might cause leaks (holes, cuts, a bad or loose valve, etc.).
- 9.10.5.12. Evacuate Tedlar bags and store in a safe place until needed for the next bag test.

10. Data and Records Management

- 10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
- 10.2. Manage all data according to SOP B5.
- 10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Strike out all errors in writing with a single line. Initial and date all such corrections.

11. Quality Assurance and Quality Control

11.1. Review the daily measurement data for the GSS sampling pressure and flow rate to identify abnormal readings. Some common problems that can be identified by the pressure and airflow data are listed in Table 4.

11.1.1. Change the filters in the filter holders inside the barns according to the QAPP.

11.1.2. Conduct a leakage test using procedures described in Sections 9.9 or 9.7.3 whenever sampling tubes are relocated or connections are disturbed or changed.

11.1.3. Conduct the quick GSS leak tests described in Sections 9.7.4.3 every two weeks or whenever it is considered necessary.

11.1.4. Keep minimum sampling airflow about 0.5 L/m higher than the maximum sample airflow drawn by all analyzers and the manual port. If additional analyzers connected to the GSS that increase sample air demand, adjust the flow restrictor between the sampling pump and the mass flow meter to increase the sampling flow rate.

Table 4. Possible sampling system problems related to GSS pressure and airflow data.

Pressure	Airflow	Related locations	Possible problem and solution
Low	Low	One or several	An overloaded air filter or a blockage in the sampling line. Change the filter and clean the blockage.
High	Low	All locations	Sampling pump loses vacuum. Replace worn diaphragm and fix loose check valves inside pump.
High	High	One or a few	Leakage in the sampling line or GSS.
Low	High	All	Leakage in the GSS.
Unstable	Unstable	One	Solenoid not receiving stable power due to DO channel problem. Change DO channel or module.

12. References

12.1. Heber, A.J., J.-Q. Ni, B.L. Haymore, R.K. Duggirala, and K.M. Keener. 2001. Air quality and emission measurement methodology at swine finishing buildings. Transactions of ASAE 44(6):1765-1778.

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12.3. SOP A5. 2006. Measurement of Fan Static Pressure in Livestock Buildings with Setra Model 267 Differential Pressure Transducer. Standard Operating Procedure A5. Purdue Ag Air Quality Lab.

12.4. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.

12.5. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

12.6. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.7. SOP E1. 2006. Temperature Measurement Using Thermocouples. Standard Operating Procedure E1. Purdue Ag Air Quality Lab.

12.8. SOP U1. 2006. On-farm Instrument Shelters for Barn Sources. Standard Operating Procedure U1. Purdue Ag Air Quality Lab.

12.9. SOP U2. 2006. Installation of Barn Measurements. Standard Operating Procedure U2. Purdue Ag Air Quality Lab.

12.10. SOP U3. 2006. Heated Raceway. Standard Operating Procedure U3. Purdue Ag Air Quality Lab.

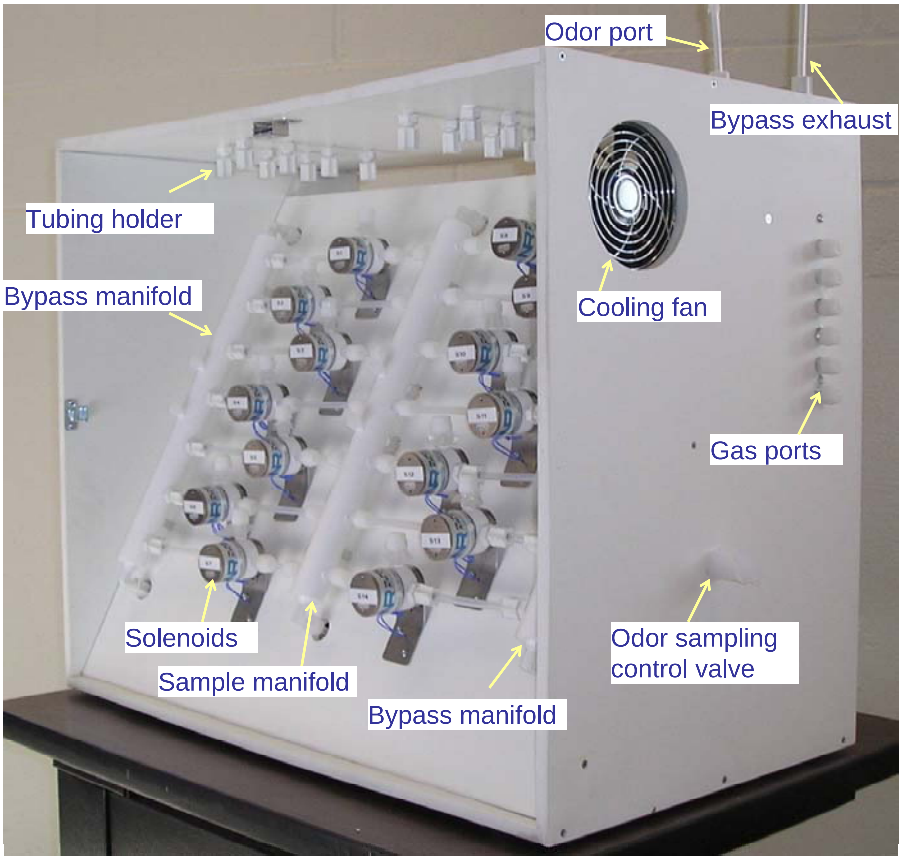


Figure 1. Open-cover view of the multi-point Gas Sampling System (front).

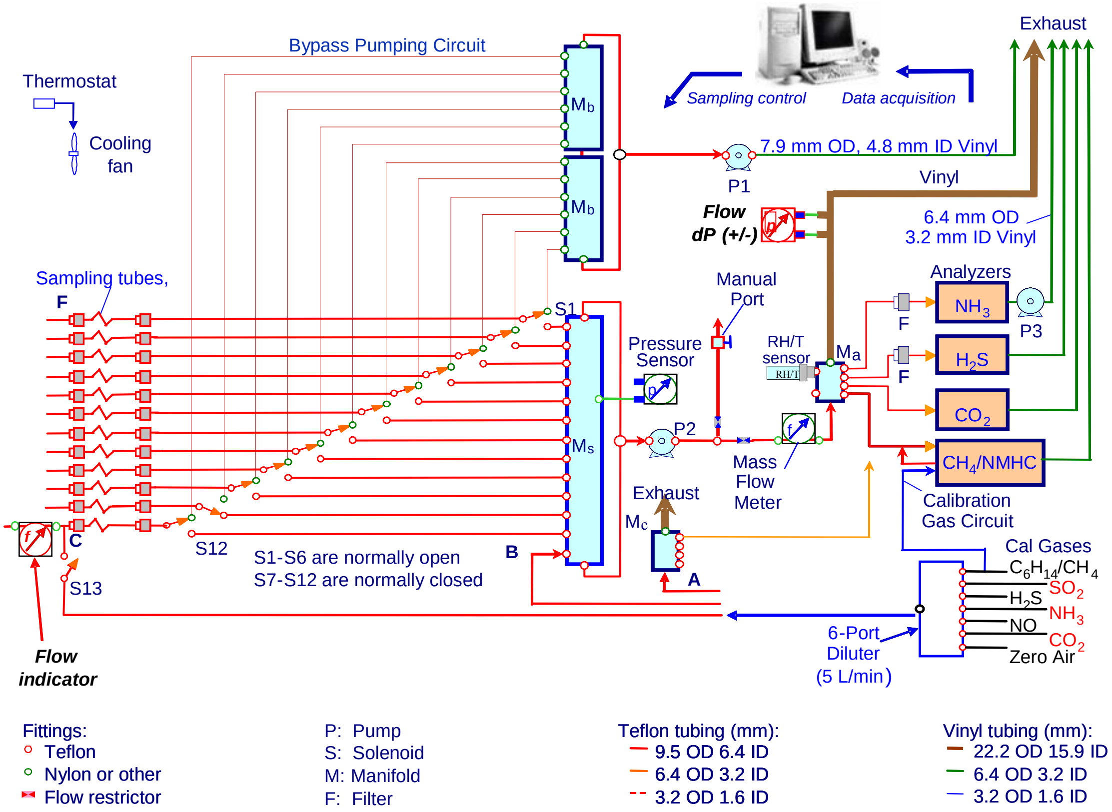


Figure 2. Schematic of PAAQL Gas Sampling System.

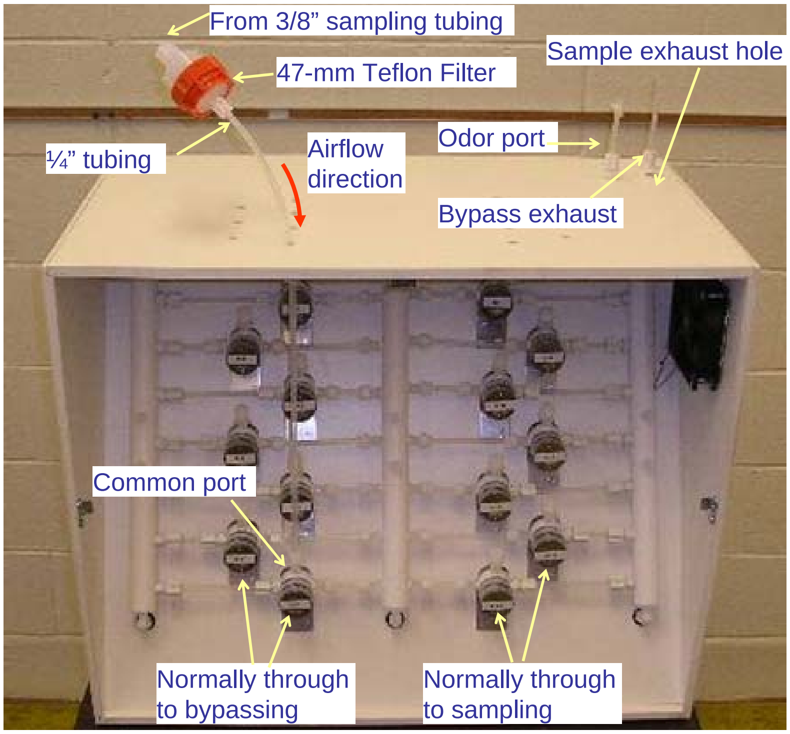


Figure 3. Connection of sampling filter holders and air inlets (only one shown as an example).

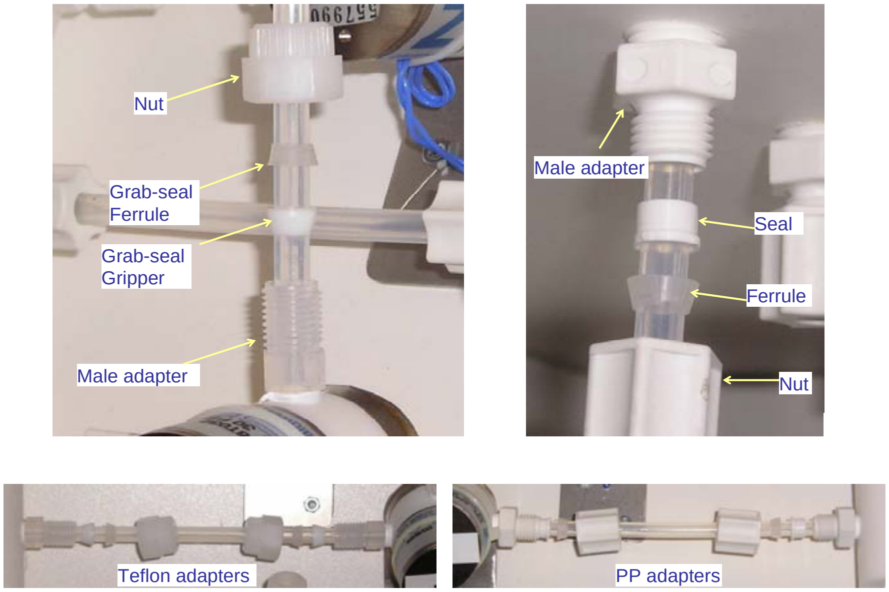


Figure 4. Connection of sampling tube to the Grab-seal Teflon fitting (left) at the solenoid and through the White PP (right) fitting as the tube holder on top panel of the GSS.

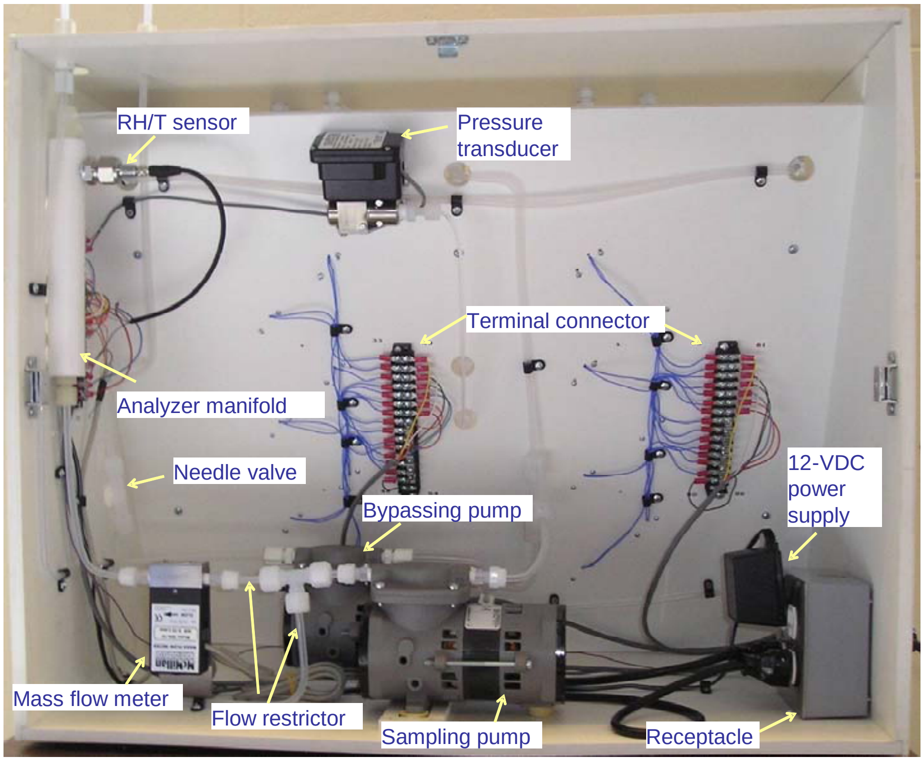
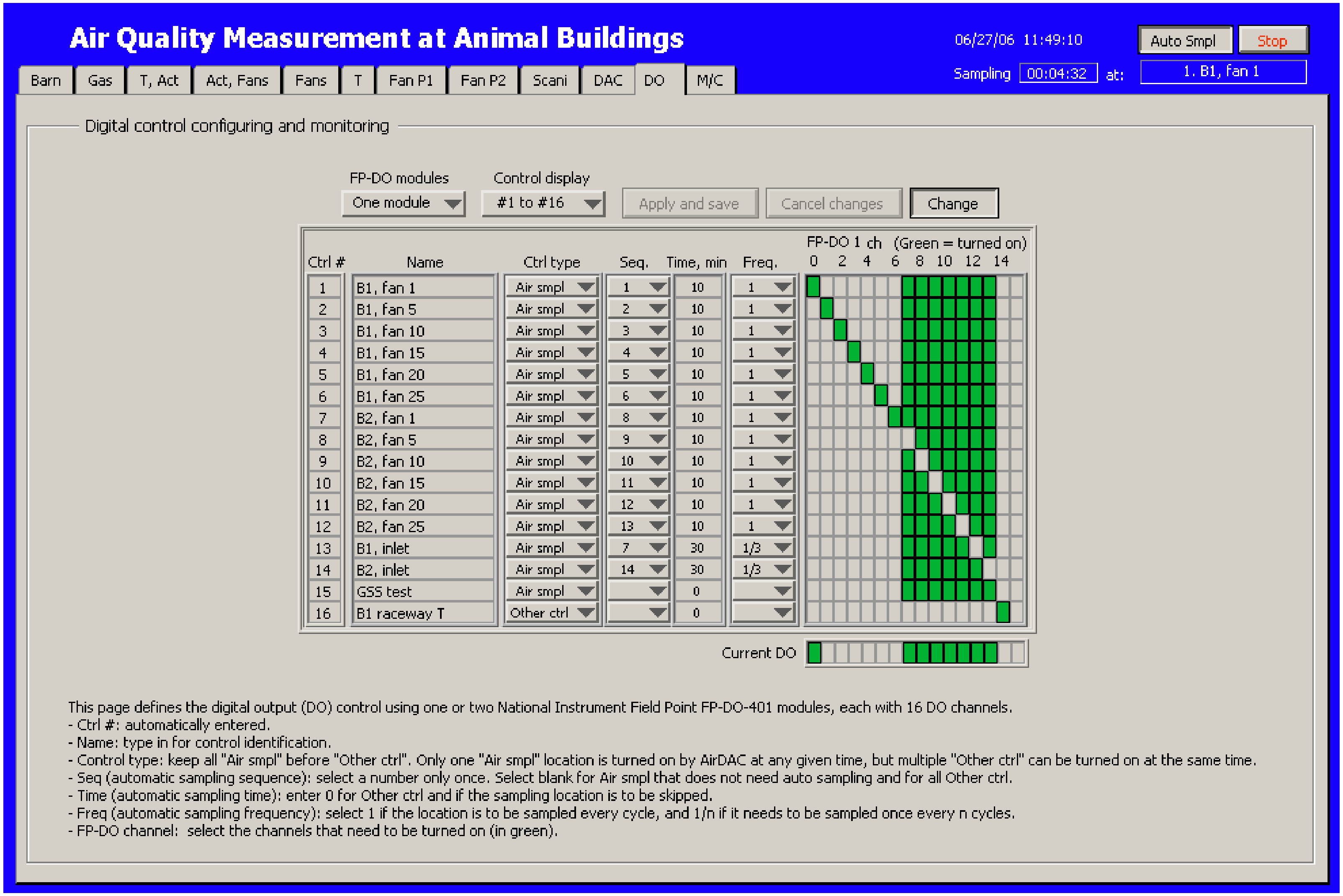


Figure 5. Open-cover view (back) of the multi-point gas sampling system.



Sampling 00:04:32 at: 1, B1, fan 1

Digital control configuring and monitoring

FP-DO modules: One module

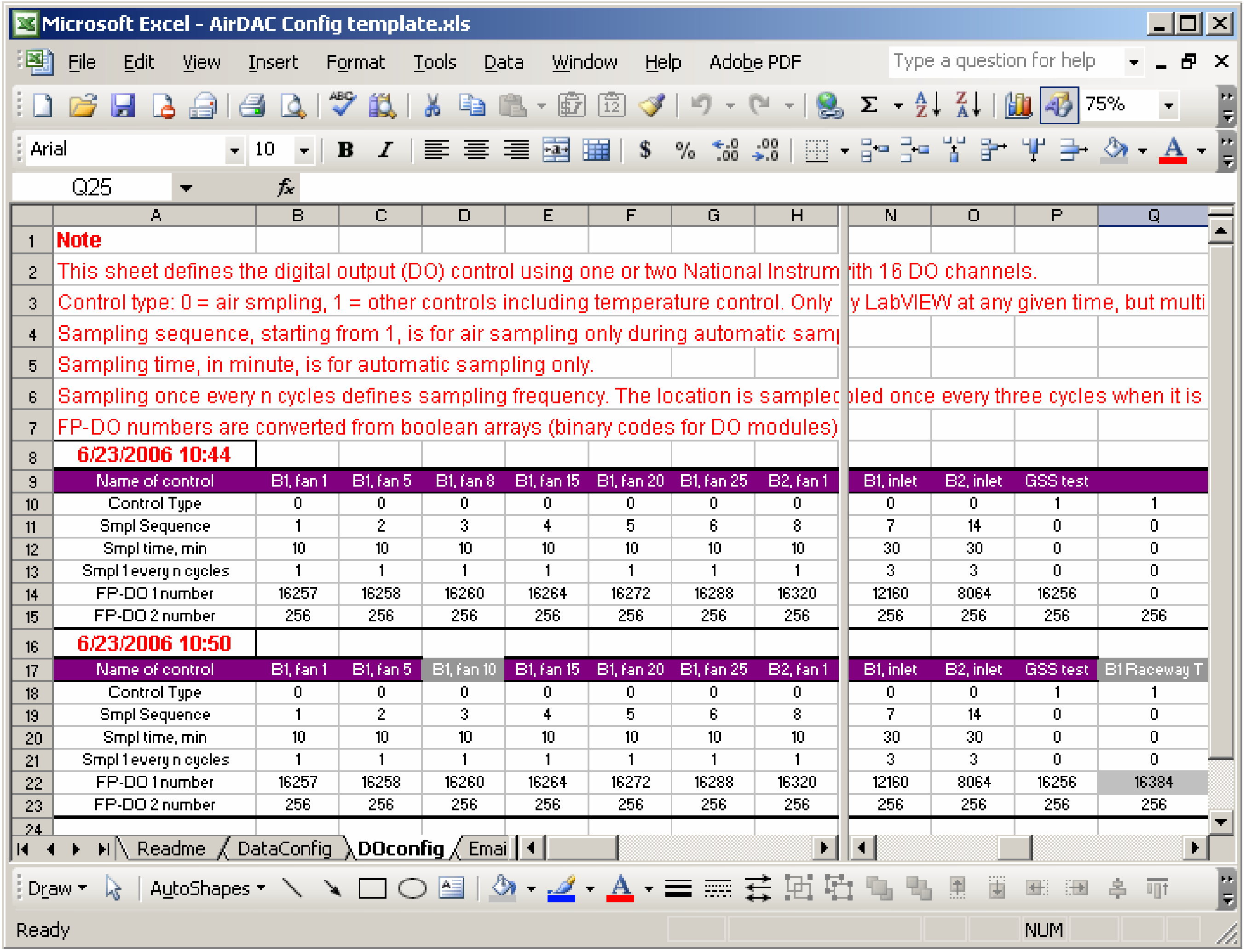
Control display: #1 to #16

Ctrl #	Name	Ctrl type	Seq.	Time, min	Freq.	FP-DO 1 ch (Green = turned on) 0 2 4 6 8 10 12 14
1	B1, fan 1	Air smpl	1	10	1	🟩⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
2	B1, fan 5	Air smpl	2	10	1	⬜🟩⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
3	B1, fan 10	Air smpl	3	10	1	⬜⬜🟩⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
4	B1, fan 15	Air smpl	4	10	1	⬜⬜⬜🟩⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
5	B1, fan 20	Air smpl	5	10	1	⬜⬜⬜⬜🟩⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
6	B1, fan 25	Air smpl	6	10	1	⬜⬜⬜⬜⬜🟩⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
7	B2, fan 1	Air smpl	8	10	1	⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩🟩⬜⬜
8	B2, fan 5	Air smpl	9	10	1	⬜⬜⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩⬜⬜
9	B2, fan 10	Air smpl	10	10	1	⬜⬜⬜⬜⬜⬜⬜🟩⬜🟩🟩🟩🟩🟩⬜⬜
10	B2, fan 15	Air smpl	11	10	1	⬜⬜⬜⬜⬜⬜⬜🟩🟩⬜🟩🟩🟩🟩⬜⬜
11	B2, fan 20	Air smpl	12	10	1	⬜⬜⬜⬜⬜⬜⬜🟩🟩🟩⬜🟩🟩🟩⬜⬜
12	B2, fan 25	Air smpl	13	10	1	⬜⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩⬜🟩🟩⬜⬜
13	B1, inlet	Air smpl	7	30	1/3	⬜⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩⬜🟩⬜⬜
14	B2, inlet	Air smpl	14	30	1/3	⬜⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩⬜⬜⬜
15	GSS test	Air smpl		0		⬜⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜
16	B1 raceway T	Other ctrl		0		⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜⬜🟩⬜

Current DO 🟩⬜⬜⬜⬜⬜⬜🟩🟩🟩🟩🟩🟩🟩⬜⬜

This page defines the digital output (DO) control using one or two National Instrument Field Point FP-DO-401 modules, each with 16 DO channels.
- Ctrl #: automatically entered.
- Name: type in for control identification.
- Control type: keep all "Air smpl" before "Other ctrl". Only one "Air smpl" location is turned on by AirDAC at any given time, but multiple "Other ctrl" can be turned on at the same time.
- Seq (automatic sampling sequence): select a number only once. Select blank for Air smpl that does not need auto sampling and for all Other ctrl.
- Time (automatic sampling time): enter 0 for Other ctrl and if the sampling location is to be skipped.
- Freq (automatic sampling frequency): select 1 if the location is to be sampled every cycle, and 1/n if it needs to be sampled once every n cycles.
- FP-DO channel: select the channels that need to be turned on (in green).

Figure 6. An example of AirDAC configuration for GSS control.



Note

This sheet defines the digital output (DO) control using one or two National Instrum ith 16 DO channels.

Control type: 0 = air smpling, 1 = other controls including temperature control. Only y LabVIEW at any given time, but multi

Sampling sequence, starting from 1, is for air sampling only during automatic sam

Sampling time, in minute, is for automatic sampling only.

Sampling once every n cycles defines sampling frequency. The location is samplec bled once every three cycles when it is

FP-DO numbers are converted from boolean arrays (binary codes for DO modules)

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Name of control	B1, fan 1	B1, fan 5	B1, fan 8	B1, fan 15	B1, fan 20	B1, fan 25	B2, fan 1	B1, inlet	B2, inlet	GSS test	
Control Type	0	0	0	0	0	0	0	0	0	1	1
Smpl Sequence	1	2	3	4	5	6	8	7	14	0	0
Smpl time, min	10	10	10	10	10	10	10	30	30	0	0
Smpl 1 every n cycles	1	1	1	1	1	1	1	3	3	0	0
FP-DO 1 number	16257	16258	16260	16264	16272	16288	16320	12160	8064	16256	0
FP-DO 2 number	256	256	256	256	256	256	256	256	256	256	256

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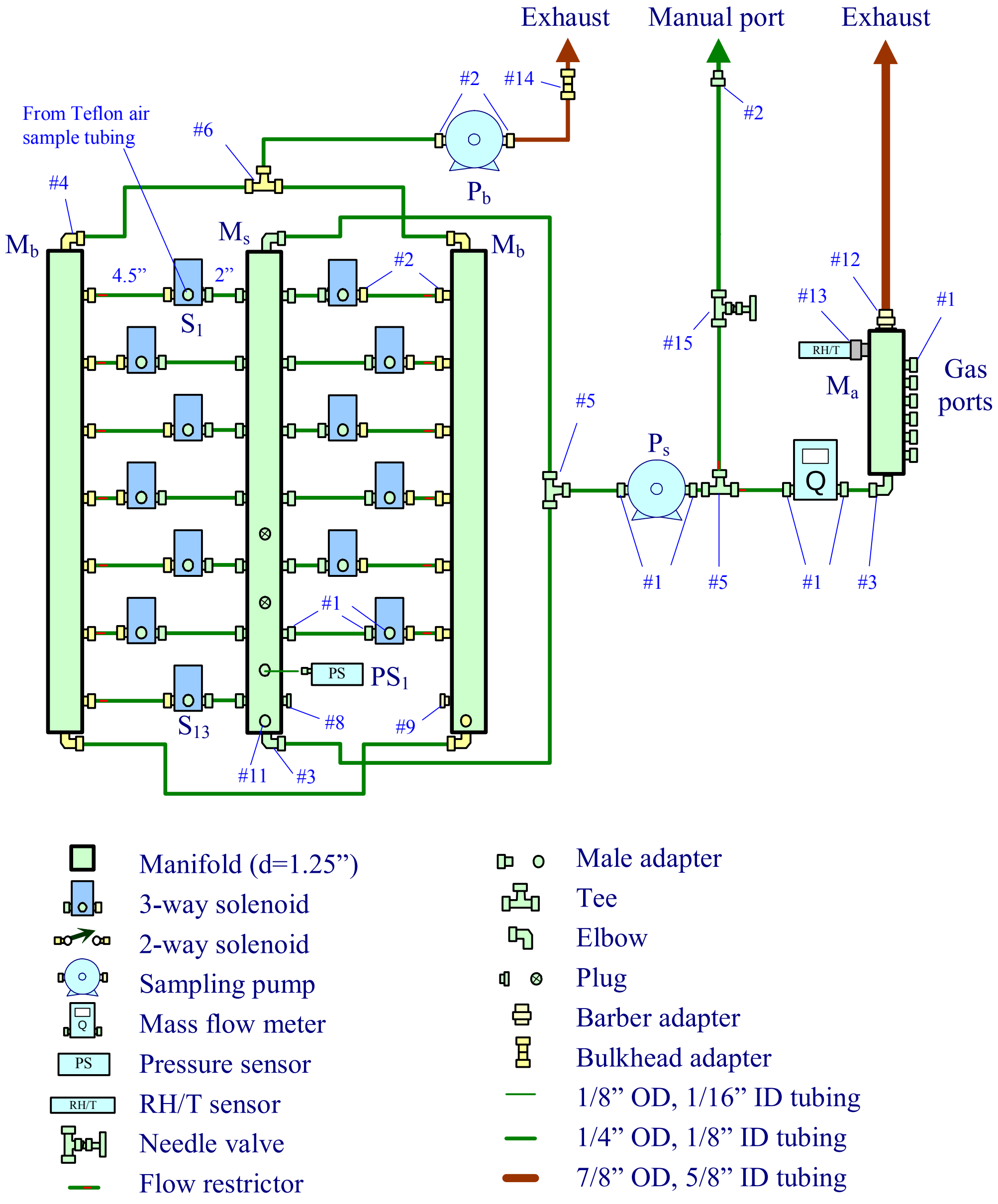
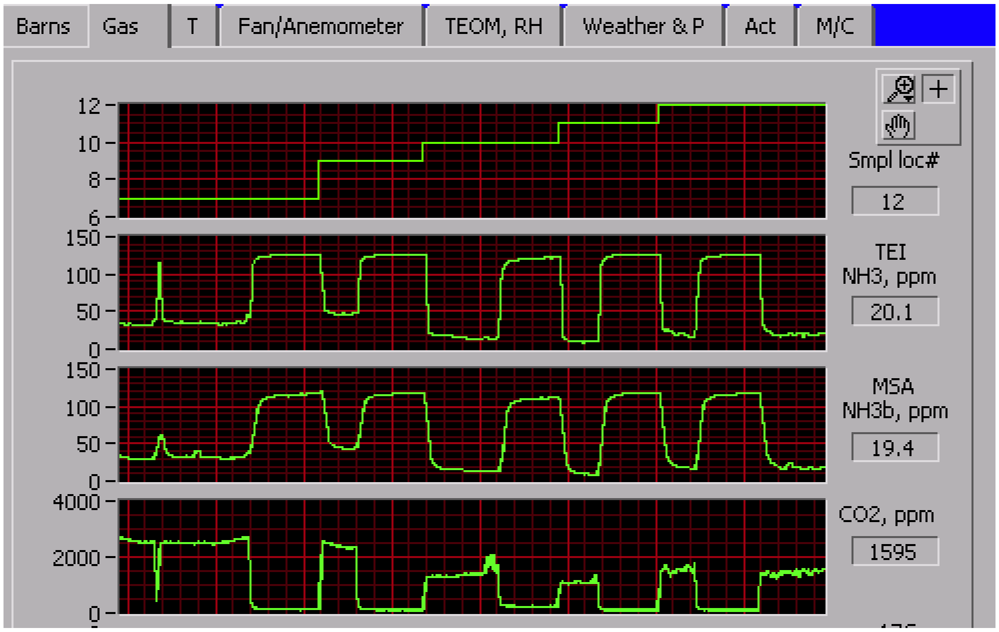
Name of control	B1, fan 1	B1, fan 5	B1, fan 10	B1, fan 15	B1, fan 20	B1, fan 25	B2, fan 1	B1, inlet	B2, inlet	GSS test	B1 Raceway T
Control Type	0	0	0	0	0	0	0	0	0	1	1
Smpl Sequence	1	2	3	4	5	6	8	7	14	0	0
Smpl time, min	10	10	10	10	10	10	10	30	30	0	0
Smpl 1 every n cycles	1	1	1	1	1	1	1	3	3	0	0
FP-DO 1 number	16257	16258	16260	16264	16272	16288	16320	12160	8064	16256	16384
FP-DO 2 number	256	256	256	256	256	256	256	256	256	256	256

Figure 7. An example of the recorded AirDAC DO configuration in the Excel file. The grey-colored cells indicate latest changes.



Fitting color: Light green = Teflon; Yellow = White PP or nylon; Gray = Stainless steel
Tubing color: Green = Teflon; Brown = other material

Figure 8. Sampling system diagram. Fitting # is specified in the GSS instructions. Note that the 14th solenoid (lower right) has been omitted to show the pressure sensor (PS) behind it.



Smpl loc# 12

TEI NH3, ppm 20.1

MSA NH3b, ppm 19.4

CO2, ppm 1595

Figure 9. Responses of the two ammonia gas analyzers to a test using ammonia-filled bags at five sampling locations.

COMPRESSED GAS CYLINDERS

Standard Operating Procedure (SOP) G2

COMPRESSED GAS CYLINDERS

Standard Operating Procedure (SOP) G2

Prepared by

Congna Li, Juan Carlos Ramirez, and Claude A. Diehl

Reviewed by

Bill W. Bogan and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Gas cylinders are used to transfer certified gas standards to research labs where gas concentration measurements are conducted. They are also used to supply fuel for flame ionization detectors, carrier gases for gas chromatographs, dilution gases for programmable diluters, and concentrated gases for gas injection systems. The following general facts about compressed gas cylinders are relevant to this SOP:

1.1.1. Gas standards typically have a defined, finite shelf life, and a specific expiration date.
1.1.2. Gas cylinders contain a finite volume of gas that may need to be replenished.
1.1.3. Gas cylinders are typically rented so money is saved by returning them promptly.
1.1.4. Gas cylinders generally look alike which challenges identification procedures.
1.1.5. Missing cylinders must be replaced at a significant replacement charge.
1.1.6. The time between purchase and delivery are relatively long.
1.1.7. The high pressure inside a gas cylinder represents a potential safety hazard.
1.1.8. The contents of a gas cylinder can range from very safe to extremely hazardous.
1.1.9. A gas-specific pressure regulator is required for each cylinder.
1.1.10. Managing gas cylinders requires a significant amount of labor.
1.1.11. They may be exposed to the extremes of indoor and outdoor temperatures.

2. Summary of Method

This SOP covers the necessary procedures, cautions and documentation for selecting, purchasing, receiving, transporting, storing, using, terminating, and returning gas cylinders. The compressed gas cylinder inventory will be scientifically selected, carefully controlled, and professionally handled to reduce cost, ensure safety, and improve data quality. Gas regulators will be properly selected and installed on each cylinder to prevent leakage and ensure safe delivery of the gases. Following this method will ensure proper documentation of the cylinders and the regulators that are used with the cylinders.

3. Definitions of Terms and Acronyms

3.1. ABE: Agricultural and Biological Engineering
3.2. CGA: Compressed Gas Association.
3.3. PAAQL: Purdue Agricultural Air Quality Laboratory
3.4. REM: Office of Radiation and Environmental Management at Purdue University
3.5. Compressed Gas: Any material or mixture having in the container either an absolute pressure exceeding 40 psia (3 bar) at 70°F (21°C).
3.6. Requested Concentration: The gas concentration requested by the customer when purchasing a standard gas.
3.7. Balance Gas: The material ("component") making up the majority of a mixture.
3.8. Blended Concentration: The concentration measured by the blending process. The numerical concentration assigned to a component based on the results of blending.

- 3.9. Blend Tolerance: The degree of agreement between the Blended Concentration and the Requested Concentration.
- 3.10. Crawl: Rise above a set delivery pressure during operation of a regulator.
- 3.11. Accuracy: The statistical agreement of a measured value with its true value
- 3.12. Expiration date: The stated date after which a gas concentration is no longer valid or legal to use for calibration purposes.
- 3.13. Traceability: Basis for establishing the true value of a standard or pathway back to the true value. For example, it is the relationship between a measured value and an established element of the National/International Measurement System.
- 3.14. Two-Stage Pressure Reducing Regulator: A regulator which reduces high-pressure to low pressure and controls the low or outlet pressure with two stages of pressure reduction. Used when more stability of operation is required.
- 3.15. Stability: The ability to maintain a constant concentration value over a defined time within statistical significance
- 3.16. Gas Mixture Grades
  - 3.16.1. EPA Protocol Grade: EPA Protocol Gases are manufactured and analytically certified in strict accordance with the most recent EPA traceability guideline document entitled “EPA Traceability Protocol for Assay and Certification of Gaseous Standards”. EPA protocol certified standards meet or exceed gas standards specified in U.S. regulations 40CFR60 and 40CFR75.
  - 3.16.2. Primary Grade: Specialty gas, high resolution, gravimetric mixture with certification accuracy of either 1% relative, or 0.02% absolute, whichever is less. Often referred to as NIST-Traceable By Weight.
  - 3.16.3. Certified Grade: Working standards prepared either by partial pressure or gravimetrically. Certification accuracies may range from ±2% to ±5%.
  - 3.16.4. Unanalyzed Grade: The unanalyzed grade is used when the minor component accuracy does not have to be less than 10%.

4. Health and Safety

- 4.1. Always use the smallest size cylinder required to perform the work.
- 4.2. Cylinders of compressed gases must be handled as high potential energy sources.
- 4.3. Cylinders on wheeled carts must be capped and secured by an approved cylinder support strap or chain. The cart must be an approved cylinder cart. Do not attempt to take a loaded cylinder cart up or down a stairway.
- 4.4. Secure uncapped cylinders independently to a solid element of the lab structure. Do not “gang” cylinders behind a single chain, and do not use carts to support uncapped or in-use cylinders.
- 4.5. Transporting cylinders
  - 4.5.1. Move cylinders by hand trucks or carts that are designed for this purpose. Always use a cylinder cart equipped with a chain restraint.
  - 4.5.2. During transportation, properly secure cylinders to prevent them from falling or striking each other.
  - 4.5.3. Do not move a cylinder with a regulator connected to it.
  - 4.5.4. Never transport a gas cylinder without its valve protection cap firmly in place.

4.5.5. Keep both hands on the cylinder cart during transport.

4.5.6. Follow applicable federal and state regulations when transporting cylinders on open roads. Provided that no more than 440 lbs (>220lbs of flammable gas and >220lbs of other gases including container weights) are being transported, the gases are classified as “Materials of Trade”, and are not subject to placards and other restrictions that would normally be associated with transporting larger quantities of compressed gas.

4.6. Securing cylinders

4.6.1. Place cylinder in an upright position against a cylinder rack located against the wall.

4.6.2. Place the straps around the cylinder.

4.6.3. Insert the strap through the buckle and pull tight.

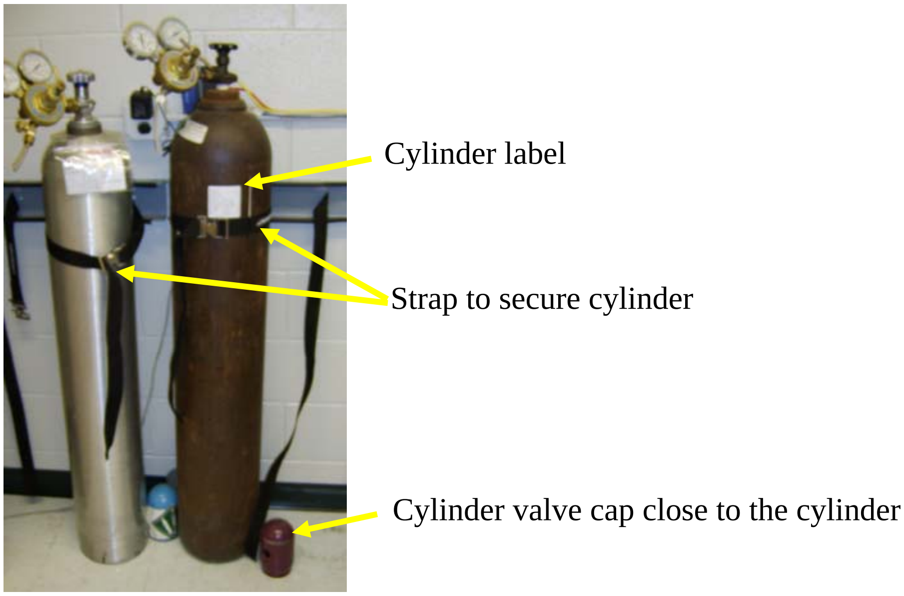


Figure 1. Gas cylinders safely located for use.

4.7. Storage of cylinders

4.7.1. Storage Area. Store gas cylinders in a ventilated and well-lit area, away from combustible materials. Store cylinders containing flammable gases away from oxygen cylinders and other oxidants. Separate by a fire-resistant wall, or locate them at least 20 feet apart from each other.

4.7.2. Storage Area Conditions. Storage areas should be located away from sources of excess heat, open flame or ignition, and not located in closed or subsurface areas. The area should be dry, cool and well-ventilated.

4.7.3. Securing Cylinders in Storage. Always hold cylinders in place with a chain or another type of fastener such as a bench or wall clamp. While in storage, cylinder valve protection caps must be firmly in place.

4.7.4. Cylinders may be stored flat on the ground, if vertical storage is not possible, provided they are secured as described in 4.7.3.

4.7.4.1. Note that this applies only to storage. Cylinders may not be transported or used while horizontal.

4.7.5. For cylinders at remote sites, the conditions in 4.7.1 and 4.7.2 will be followed as closely as possible. Sections 4.7.3 and 4.7.4 will be followed strictly, including at remote sites.

4.8. Never tamper with safety devices in valves or cylinders.

4.9. Use only a cylinder cap wrench to loosen and unscrew cylinder caps; do not strike cylinder caps when attempting to loosen them.

4.10. Oil or grease on the high pressure side of an oxygen cylinder can cause an explosion. Do not lubricate an oxygen regulator or use a fuel gas regulator on an oxygen cylinder.

4.11. Wear goggles or safety glasses with side shields when handling compressed gases.

4.12. Eyewash fountains, safety showers, gas masks, respirators, and/or resuscitators should be located nearby but out of the immediate area that is likely to become contaminated in the event of a large release of gas.

4.13. Fire extinguishers, preferably a combination of water- and CO_2-based types, should be kept close at hand, and should be checked periodically to ensure their proper operation.

4.14. Always use appropriate gauges, fittings, and materials compatible with the particular gas. Regulators must be compatible with gas cylinders (do not use adapters). Each cylinder and regulator have connection fittings that are designated by a CGA number. CGA numbers can be stamped on the cylinder and regulator and listed on the producer’s label. CGA numbers are typically (but not always) stamped on the regulator just above the threads of the cylinder connection (Fig. 2). Table 1 shows some examples of CGA connection numbers and some examples of the gases used with these connections.

4.15. MSDS information sheets will be kept in a 3-ring binder located near the cylinders.

4.15.1. MSDS information will also be kept on-site for any gases which are stored and/or used at remote locations.

Table 1. Cylinder Valve Outlets and CGA Connections.

Examples of Gases	CGA Connection #
Ammonia	705
Carbon Dioxide	320
Butane, ethylene oxide, propane, propylene	510
Air (industrial grade)	590
Carbon monoxide, ethylene, methane, hydrogen	350
Hydrogen sulfide, hydrogen chloride	330
Nitrogen, helium, argon, noble gases	580
Nitrogen dioxide, sulfur dioxide	660
Oxygen	540

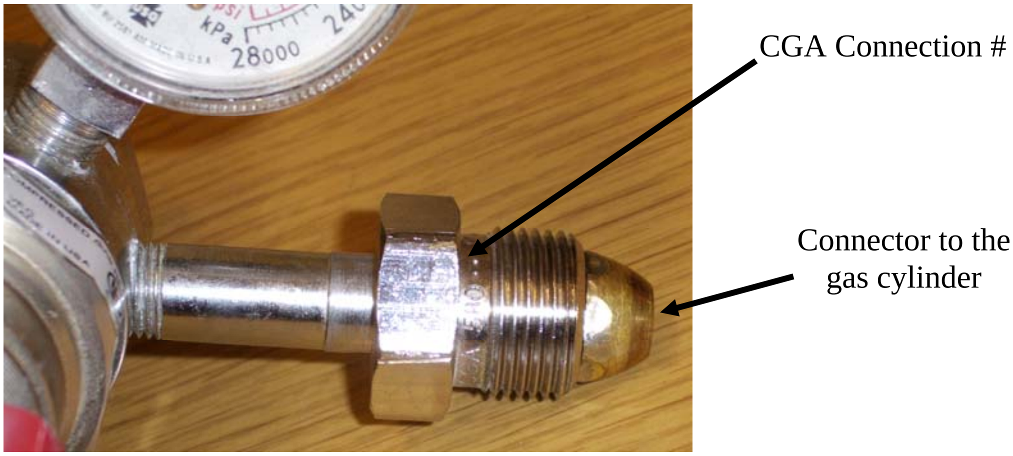


Figure 2. Photo of a gas pressure regulator (CGA 580) showing the connector to the gas cylinder. The CGA number can be found on the side of the nut closer to the regulator.

4.16. When work is planned with toxic, corrosive, or reactive gases, consult the MSDS and/or institutional safety office for information concerning specific handling requirements for the gas involved. Generally, these gases will need to be used and stored with local exhaust ventilation, such as a lab hood, gas cabinet, or a ventilated OFIS that is designed for that purpose.

4.17. Check the regulator and cylinder valve for evidence of damage or contamination.

4.18. Do not apply Teflon tape between the regulator and the cylinder connections. Bits of Teflon tape can get blown into the regulator, causing a leak, valve malfunction or erroneous reading.

  4.18.1. If a leak-free connection cannot be established between the regulator and the cylinder, inspect the regulator and cylinders threads for possible damage or contamination. If regulator components (adapter threads, washers, and/or fittings) are damaged, they should be replaced. Any regulator which cannot be made leak-free should be replaced.

4.19. If an OFIS at a field site (farm) contains cylinders, notify the producer and/or appropriate staff that there are compressed cylinders within the OFIS and describe the contents of the compressed cylinders. This is especially important in case of a fire, so that the producer will stay away from the OFIS, and properly notify responding emergency personnel.

5. Cautions

5.1. Do not allow cylinder temperature to exceed 125°F (52°C), or to drop to -30°C or lower, since many types of steel will lose their ductility and impact strength at lower temperatures.

5.2. Store empty cylinders separately from full cylinders, and clearly identify them as such. Leave some pressure (>50 psi) in a depleted cylinder to prevent air backflow that would allow moisture and contaminants to enter the cylinder.

5.3. Flammable gases have reverse threads, meaning that the connection is tightened by turning the nut counterclockwise. You can always tell a reverse thread connection because the nut that you tighten has a line inscribed around its circumference.
5.4. Do not use an expired cylinder for a Level 1 Precision Check. In other words, never adjust an analyzer based on data obtained from an expired cylinder.

6. Personnel Qualifications

6.1. Personnel should be trained in the handling of cylinders and also in the updating of the web-based cylinder control file before initiating the procedure alone.
6.2. Personnel handling any compressed gas should be familiar with the potential hazards before using the gas.
6.3. Personnel should address potential emergencies and the safe and proper measures necessary to avoid these emergencies.
6.4. Personnel should identify several scenarios that could result in gas leaks or other emergencies to be totally prepared to respond adequately.

7. Equipment and Supplies

7.1. Gas cylinders
  7.1.1. EPA maintains a web site which documents the performance of major gas-cylinder vendors, based on the results of a round robin test conducted every two years.
  7.1.2. Consider the following parameters when selecting cylinders:
    7.1.2.1. Certification accuracy
    7.1.2.2. Blend tolerance
    7.1.2.3. Shelf life
    7.1.2.4. Delivery time
    7.1.2.5. Reanalysis tolerance
    7.1.2.6. Requested concentration
7.2. Gas regulators appropriate for each gas (Section 4.14)
7.3. Labels to identify each cylinder (Section 8.1.7)
7.4. An adjustable or combination cylinder wrench to connect and disconnect the regulator to the cylinder.
7.5. Cylinder hand truck
7.6. Cylinder brackets
7.7. Cylinder return labels (Section 8.8.4)

8. Procedures

8.1. Receiving gas cylinders (PAAQL)
  8.1.1. Cylinders are delivered to the ABE shop’s gas cylinder receiving station by Purdue’s Gas Cylinder Control Office.
  8.1.2. Upon delivery, the cylinders should be picked up by PAAQL staff, after verifying that there is a plastic seal on the cylinder valve. If there is no seal, make a note and contact the company.

8.1.3. Write the cylinder-stamped number on the form by the gas cylinder rack, and sign the form to indicate that the cylinder has been received.
8.1.4. A delivery sheet or packing slip is attached to every cylinder to verify that the proper cylinder is delivered (gas type, amount of gas, cylinder ID).
8.1.5. Sign and date the delivery sheet.
8.1.6. Place the original delivery sheet in the ABE Business Office's inbox and a copy of the delivery sheet in the loose leaf cylinder notebook in the section corresponding to the year received and the company that supplied the cylinder. This notebook is kept on top of the manual's file cabinet in room ABE-102E.
8.1.7. Attach a cylinder label (Fig. 3) to the cylinder upon receipt, with the following information filled out:

Gas ____________________________
Concentration ____________________
Initial Pressure ________________psi
CGA No. _______________________
Cylinder No. _____________________
Date Received ___________________
Expiration Date __________________
Date:__________Pressure:_______psi
Date:__________Pressure:_______psi
Date:__________Pressure:_______psi
Date:__________Pressure:_______psi
Date:__________Pressure:_______psi

Figure 3: A cylinder label.

8.2. Receiving gas cylinders (Field sites)
8.2.1. Cylinders are delivered to a specified location (e.g. the field site itself, a subcontracting university or other entity, etc) by the supplier's local vendor/agent.
8.2.2. Upon delivery, the cylinders should be picked up by study personnel (PAAQL or otherwise), after verifying that there is a plastic seal on the cylinder valve. If there is no seal, make a note and contact the company.
8.2.3. If necessary, transport the cylinder to the field site, observing all cautions listed in Section 4.5.
8.2.4. Write the cylinder-stamped number on the form by the gas cylinder rack and sign the form to indicate that the cylinder has been received.
8.2.5. A delivery sheet or packing slip will be attached to every cylinder by the supplier to verify that the proper cylinder is delivered (gas type, amount of gas, cylinder ID).
8.2.6. Sign and date the delivery sheet.
8.2.7. File a copy of the delivery sheet on-site in a binder or loose-leaf notebook (Section 8.1.6).

8.2.8. Fill out a cylinder label (Fig. 3), and attach it to the cylinder.

8.3. Installing pressure regulators

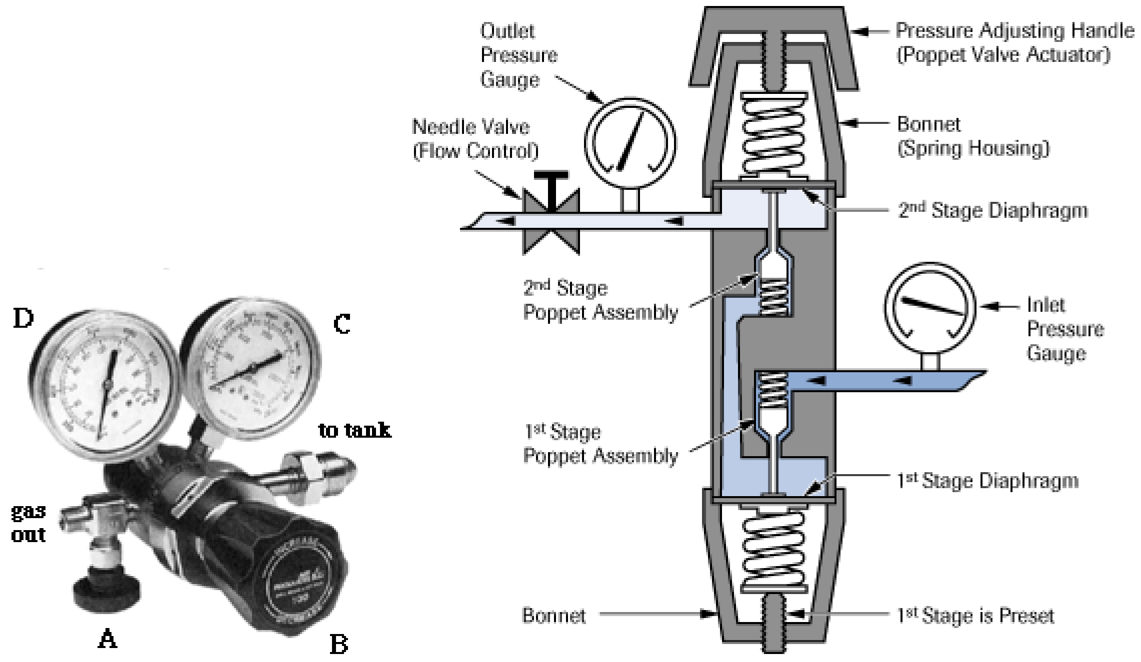
8.3.1. Make sure the cylinder is properly secured, and that the regulator is the correct one for the cylinder, and that any special hazards of the gas are known.

8.3.2. Remove the cylinder valve cap (counterclockwise). Place it somewhere nearby.

8.3.3. Some regulators (on lecture bottles and certain corrosive gases) require a Teflon washer to be inserted between the tank outlet and regulator. Check to see if this is required before continuing to the next step.

8.3.4. Make sure that the regulator's needle valve (A) (Fig. 4) is shut. Screw it clockwise until it seats. Do not over tighten it or you can damage the valve seat.

8.3.5. Make sure that the regulator's pressure adjusting handle (B) (Fig. 4) is shut. Turn it counterclockwise until it is almost completely unscrewed. If you unscrew it completely, just put it back in.



(a) (b)

Figure 4. (a) A two –stage pressure regulator and its components. A: Needle valve for outlet flow control. B: Pressure adjusting handle (Poppet Valve Actuator). C: Inlet pressure gauge. D: Outlet pressure gauge. (b) Schematic diagram of a two-stage pressure regulator.

8.3.6. Turn the regulator onto the tank by hand until it is almost finger tight.

8.3.7. Use an adjustable wrench or cylinder wrench to tighten the regulator onto the cylinder.

8.4. Operation of pressure regulator

8.4.1. Open the tank valve slowly (counterclockwise (CCW)). Watch the tank pressure on the regulator's inlet pressure gauge (C) (Fig. 4).

8.4.2. Slowly turn the pressure adjusting handle (B) on the regulator until the regulator's outlet pressure gauge (D) is at the desired pressure level (Fig. 4).
8.4.3. Open the regulator's needle valve (A) to regulate flow with this valve.
8.4.4. Check your system for leaks using Snoop (a commercial product) or some soapy water. Snoop is preferred since it leaves no residue.
8.5. FTIR validation of gas concentration
8.5.1. If the composition of the gas in a cylinder is to be checked by FTIR, this procedure should be conducted according to SOP G12 ("FTIR Verification of Gas Cylinder Composition").
8.6. Shut down of pressure regulator
8.6.1. Shut the tank valve on the gas cylinder.
8.6.2. Slowly open the needle valve (A) on the regulator.
8.6.3. Watch the pressure gauges C and D drop to zero.
8.6.4. Open the regulator's pressure adjusting handle (B) (turn it clockwise) to ensure that all pressure is released.
8.6.5. After relieving all the gas pressure, turn the regulator pressure adjusting handle (B) CCW as far as it will go to close the regulator, and also close the needle valve (A).
8.7. Disconnecting a pressure regulator
8.7.1. Use a wrench to disconnect the regulator from the gas cylinder.
8.7.2. Replace the protective cylinder cap immediately.
8.8. Cylinder return
8.8.1. Prior to returning the cylinder, place a return label on the cylinder and date it. (Fig. 5)
8.8.2. The cylinder should be returned to the cylinder collection rack in the ABE shop.
8.8.3. Place an "Empty Cylinder" ring on the cylinder.
8.8.4. Enter the returned cylinder number and date on the form.

Return To: General Stores

From: Al Heber
Department of Ag and Bio Engineering
1146 ABE

Date:

Figure 5: Return label for gas cylinders.

9. Troubleshooting

9.1. Check regulators periodically to ensure proper and safe operation. This periodic check will vary depending on gas service and usage. The procedure for checking out any regulator is as follows:

9.1.1. Be sure gauges read zero when all pressure is drained from the system.

9.1.2. Open the cylinder valve and turn the pressure adjusting handle counterclockwise; the inlet pressure gauge will read the cylinder pressure.

9.1.3. Starting at Section 9.1.1, close the cylinder valve after reading the cylinder pressure, if the pressure drops after one (1) hour of monitoring the inlet pressure, there is a leak between the inlet pressure gauge and the cylinder valve.

9.1.4. Starting at Section 9.1.1, close the regulator’s outlet needle valve then wait 1 hour; the outlet pressure gauge should not indicate a pressure increase. A pressure increase would indicate leakage across the internal valve system.

9.1.5. Turn the pressure adjusting handle clockwise until a nominal delivery pressure is indicated. Inability to attain a proper delivery-pressure setting or abnormal adjustment of the screw indicates improper operation, which may be attributed to blockage of the gas passage or a leak in the low-pressure side of the regulator. Continued wear on a regulator valve-and-seat assembly will cause a rise above a set delivery pressure, termed *crawl*. A regulator exhibiting crawl should not be used.

9.1.6. Close cylinder valve and observe pressure on both inlet and delivery sides of the regulator after 1 h. A drop in the pressure reading after this period of time may indicate a leak in the system, possibly at the inlet or through the needle valve, safety devices, or diaphragm.

9.1.7. An excessive fall in delivery pressure under operating conditions and normal flow indicates an internal blockage.

9.1.8. Any deviation from the normal in the preceding checkout will require servicing by reputable repair personnel.

10. Data and Records Management

10.1. Use the information on the delivery sheet to update the PAAQL Cylinder Inventory webpage. To update this webpage you must:

10.1.1. Open the “odor” drive (permission to access this drive is required).

10.1.2. Open the “public-web” folder.

10.1.3. Open the “cylinder” folder

10.1.4. Open the “PAAQL Cylinder Inventory.htm” file.

10.1.5. To edit the “PAAQL Cylinder Inventory.htm” webpage:

10.1.5.1. Click on “File”.

10.1.5.2. Click “Edit with Microsoft Excel”.

10.1.5.3. Add the following data to the PAAQL Cylinder Inventory web page:

10.1.5.3.1. Gas name

10.1.5.3.2. Balance gas

10.1.5.3.3. Gas analyzer that cylinder is assigned for calibration

10.1.5.3.4. Cylinder number (this is the engraved number only)

- 10.1.5.3.5. Cylinder style
- 10.1.5.3.6. Cylinder volume
- 10.1.5.3.7. Supplier of the gas cylinder
- 10.1.5.3.8. Purchase order number
- 10.1.5.3.9. Person who requested the order
- 10.1.5.3.10. Date issued
- 10.1.5.3.11. Date received
- 10.1.5.3.12. Date tested
- 10.1.5.3.13. Date returned
- 10.1.5.3.14. Cylinder expiration date
- 10.1.5.3.15. Initial pressure, psi
- 10.1.5.3.16. Final pressure, psi
- 10.1.5.3.17. CGA number (this can be found on the cylinder valve)
- 10.1.5.3.18. Gas concentration,
- 10.1.5.3.19. Certified accuracy, %
- 10.1.5.3.20. Project
- 10.1.5.3.21. Location
- 10.1.5.3.22. Cylinder cost
- 10.1.5.3.23. Monthly cost
- 10.1.5.3.24. Total cost to date

10.1.5.4. Update the following data each month on the PAAQL Cylinder Inventory:

- 10.1.5.4.1. Location
- 10.1.5.4.2. Pressure test
- 10.1.5.4.3. Pressure test date
- 10.1.5.4.4. Monthly cost (see demurrage report)
- 10.1.5.4.5. Total cost to date (see demurrage report)

10.1.5.5. The PAAQL Cylinder Inventory web page is color coded.

- 10.1.5.5.1. The cylinders that have been recently returned have a purple color.
- 10.1.5.5.2. Cylinders that are in ABE are in yellow.
- 10.1.5.5.3. Cylinders that are on site are in dark blue.
- 10.1.5.5.4. Cylinders not currently in the inventory but still on the demurrage report are in red.
- 10.1.5.5.5. Cylinders that were apparently returned but yet cylinder rental charges are accruing are in green.

10.2. Initiate an order for a replacement cylinder well in advance of a cylinder’s running out (i.e. dropping below 150 psi, as per Section 5.4).

10.2.1. Each time a cylinder is used, record the pressure remaining at the end of use. Keep a graph tracking pressure vs. date to allow projection of when pressure will reach the 150 psi minimum limit.

10.2.2. Allow sufficient time to meet the following requirements:

- 10.2.2.1. Replacement cylinders will be compared to the old cylinder using the applicable gas analyzer. Leave sufficient gas in the old cylinder to conduct this test.
- 10.2.2.2. If the replacement cylinder is outside the acceptable specifications, there must be sufficient gas remaining in the old cylinder to operate until an acceptable cylinder is received.

10.2.2.3. In general, a new purchase order should be initiated two months in advance before the current cylinder is empty or expires, if such gas is needed on a continuous basis.

10.2.3. Email notification of new order will be sent to the personnel responsible for the project.

11. Quality Control and Quality Assurance

11.1. Personnel handling any compressed gas will be trained to be aware of potential hazards before using the gas, to address potential emergencies and the safe and proper measures necessary to avoid these emergencies, and to identify several scenarios that could result in gas leaks or other emergencies to be totally prepared to respond adequately.

11.2. Regulators and cylinder valves should be checked periodically to ensure proper and safe operation.

11.3. The PAAQL Cylinder Inventory webpage will be used to update the information for all the cylinders in the current inventory and the most recent cylinders that have been returned.

11.4. Do not calibrate with a span gas if its cylinder pressure is below 150 psi.

12. References

12.1. Purdue University, "Chemical Hygiene Plan and Hazardous Materials Safety Manual, Version 2003.06.a revised June 2003. Retrieved from http://www.purdue.edu/rem/home/booklets/CHP2003.pdf

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12.3. *Design and Safety Handbook for Specialty Gas Delivery Systems*. Scott Specialty Gases, 2004.

12.4. *Gas and Equipment Catalogue*, Matheson Tri Gas Company, 2004.

12.5. Interactive Learning Paradigms. The Glassware Gallery: Gas Regulators. http://www.ilpi.com/inorganic/glassware/regulators.html. Accessed online 12/27/2005.

MEASUREMENT OF CARBON DIOXIDE (CO2) WITH THE MSA MODEL 3600 INFRARED GAS MONITOR

Standard Operating Procedure (SOP) G3

MEASUREMENT OF CARBON DIOXIDE (CO_2) WITH THE MSA MODEL 3600 INFRARED GAS MONITOR

Standard Operating Procedure (SOP) G3

Prepared by
Ji-Qin Ni and Juan Carlos Ramirez

Reviewed by
Bill W. Bogan, Frank M. Mitloehner (Univ. of California-Davis), and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Measurements of carbon dioxide (CO_2 in confined animal buildings (CAB) is a useful means to determine if the buildings are properly ventilated. Excess (i.e. above atmospheric) CO_2 indicates that the building is not being ventilated well enough to remove metabolically-generated gases.

1.2. The photoacoustic method is useful for measuring CO2 in CAB because of the low interference of water vapor compared with NDIR.

1.3. Detection limit is 50 ppm. This instrument is not degraded in the presence of silicon or sulfur compounds, the last of which are often present at many CAB.

1.4. The range at livestock facilities is from normal atmospheric concentrations (typically 375-380 ppm) to 10,000 ppm inside the barns.

1.5. This procedure applies only to the MSA Model 3600 Infrared Gas Monitor.

1.6. The short-term stability is ±1% and the long term including linearity is ±5% in 18 months. Its response time is 12 s to read 97% of a step change in CO2 concentration.

2. Summary of Method

Carbon dioxide (CO_2) concentration in air is measured using photo-acoustic infrared detection with a commercial analyzer (Model 3600 Infrared Gas Monitor, Mine Safety Appliances, Pittsburgh, PA). With this method, a gas sample is drawn continuously at a constant flow rate of 0.8 L/min taken from the GSS analyzer manifold (SOP G2), and introduced into an acoustic cell, where it is exposed to pulsing infrared light of specific wavelength. If the sample contains the gas of interest, it will absorb an amount of infrared light proportional to the concentration of gas present in the sample. When gas molecules absorb this infrared light, their temperature rises as the molecules increase in kinetic energy; this results in a pressure wave inside the acoustic cell. The audible pressure pulses corresponding to the light pulses are detected by a very sensitive microphone located inside the chamber (MSA, 2001) and are proportional to the concentration of CO_2 molecules.

3. Definitions of Terms and Acronyms

3.1.	AirDAC	Air Data Acquisition and Control program
3.2.	CAB	Concentrated animal building
3.3.	DAC	Data acquisition and control
3.4.	FS	Full scale
3.5.	GSS	Gas sampling system
3.6.	MSA	Mine Safety Appliances, Inc.
3.7.	NDIR	Non-dispersive infrared
3.8.	OFIS	On-farm instrument shelter
3.9.	QAPP	Quality Assurance Project Plan
3.10.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.11.	RH	Relative humidity

4. Health and Safety

4.1. Be careful when working with the electrical power connections.
4.2. Properly vent analyzer exhaust to avoid exposure to noxious gases in the sample.

5. Interferences

5.1. The following compounds or parameters interfere with the CO2 reading:
  5.1.1. Methane (CH_4) causes a 4.2-ppm increase in the CO_2 reading per 1% CH_4 present. However, CH_4 concentrations above 0.05% are rare in CAB, so this interference is negligible.
  5.1.2. Carbon monoxide (CO), sulfur dioxide (SO_2), nitric oxide (NO), and ozone (O_3) each cause an approximate 0.5-ppm increase in the CO_2 reading per 1% present. However, concentrations of these gases are negligible in CAB compared to 1%.
  5.1.3. Temperature interferences are <0.4% FS per °C (<0.22% FS per °F). Since the analyzer and the GSS are kept inside the temperature controlled OFIS (82°F ± 8°F, SOP U1), the magnitude of this effect should be <2% of FS (<200 ppm).
  5.1.4. Humidity causes an increase of 0.05% FS per 1% RH, if the RH is below 20%. The interference is lower above 20% RH, and drops to near-zero above 40% if the instrument was calibrated with methane-spiked span gas. Use only methane-spiked span gases (Section 7.4) during calibration to avoid this interference. Zero gas does not need to contain methane.
  5.1.5. Pressure can cause an increase of 0.1% of FS per mBar. Since the analyzer draws from the analyzer manifold of the GSS, which is maintained at a constant pressure (slightly above atmospheric pressure), the pressure will not vary by as much as 1 mBar. This interference is thus negligible unless there is a malfunction in either the OFIS airflow or the GSS.
  5.1.6. N_2, O_2, Air, and He each have no photoacoustic effect, and therefore do not cause any interference.

6. Personnel Qualifications

6.1. Personnel should be trained in the use of the instrument before initiating the procedure. Training requires about three hours.
6.2. Read the entire instrument manual and this SOP before operating this analyzer.
6.3. Personnel should also be trained to interpret the analyzer output signal, converted concentration data, and correction of concentrations based on calibration.

7. Equipment and Supplies

7.1. Carbon dioxide analyzer (Model 3600, Mine Safety Appliances, Pittsburgh, PA)
7.2. Rack and rack mounts.
7.3. Keep the following spare parts on hand at each site:
  7.3.1. Replacement Solenoid Assembly. Part No. 100027655
  7.3.2. Pump assembly, Part No. 806808

7.3.3. Dampener, Part No. 459928
7.3.4. Finite filter Model IDN-6G
7.3.5. Flow switch assembly, Part No. 696606

7.4. Calibration gases (exact composition and specifications to be described in the QAPP for the particular project)

7.4.1. CO_2 in N_2 with 2.5% CH_4
7.4.2. Zero air

7.5. Appropriate regulators for calibration gas cylinders (SOP G2)

8. Procedure

8.1. Setup

8.1.1. Check analyzer carefully to assure it is free of visible defects or damage.
8.1.2. Securely mount the analyzer vertically on the instrument rack or wall.
8.1.3. Connect the analog signal (4-20 mA) output of the analyzer at output terminals 7 (+) and 8 (-) (Fig. 2-3 in Model 3600 Manual) to the data acquisition system.
8.1.4. Connect the GSS analyzer manifold to the analyzer inlet with ¼” ID Teflon tubing and connect the analyzer outlet to the air exhaust of the on-farm instrument shelter with ¼” ID PVC or other tubing.
8.1.5. Power up the analyzer, turn on its internal pump, and allow the analyzer to warm up for at least 5 minutes before checking the concentration readings.
8.1.6. Enter the analyzer’s analog signal and measurement ranges into the AirDAC software so that concentration reading can be displayed, converted and recorded.

8.2. Gas Analyzer Calibration

8.2.1. Reference gases

8.2.1.1. Carbon dioxide (CO_2) in nitrogen (N_2) with 2.5% methane (CH_4) with CO_2 concentration and certification specified by the QAPP. The CH_4 acts to help the CO_2 molecules to convert their higher energy states from infrared photon absorption through collisions into thermal then acoustic energy. Also, CH_4 allows the Model 3600 to be properly calibrated without humidity present. For safety reasons, do not introduce a concentration above 2.5% CH_4 to the Model 3600.
8.2.1.2. Zero air, which can be purchased as Continuous Emission Monitoring Zero Air.

8.2.2. Follow SOPs G8 and G9 for calibration and precision checks. The number of points and the gas concentrations for the multipoint calibrations (SOP G8) and precision checks (SOP G9) are specified in the project’s QAPP. Procedures for zero and span gases are the same, so “reference gas” is used herein to denote either gas.

8.2.2.1. Zero/precision checks

8.2.2.1.1. Documents responses to zero gas and a selected span gas.
8.2.2.1.2. No analyzer adjustments are made or maintenance conducted during a check.

8.2.2.2. Analyzer adjustments are conducted only when:

8.2.2.2.1. Stabilized reading of the reference gas is outside the tolerances specified in Sections 10.3 (span gases) or 10.4 (zero gas).
8.2.2.2.2. If analyzer is adjusted, then record the analyzer’s responses to both zero and span gases in an as-found zero-precision check (SOP G8) immediately prior to adjusting the analyzer, even before the analyzer’s first use. The as-found

responses are used to validate data since the previous calibration or previous zero/precision check.

- 8.2.3. Introduce the calibration reference (zero or span) gas and adjust the gas analyzer, if necessary. The procedure to introduce the reference gas is as follows:
  - 8.2.3.1. Record calibration date and start time in the lab notebook.
  - 8.2.3.2. Start flow of reference gas to the analyzer. See SOP G1 (Gas Sampling System) for various options of delivering the reference gas to the analyzer). The QAPP for a particular project will state which method is to be used.
  - 8.2.3.3. Record pertinent gas delivery parameters, e.g. pressure, flow, temperature, relative humidity (SOP G1).
  - 8.2.3.4. Wait 10 min for the display to stabilize and record the time and concentrations shown on the gas analyzer display by AirDAC in the field notebook.
  - 8.2.3.5. If, during a precision check (SOP G9), the stabilized reading of the reference gas is outside the tolerances specified in Sections 10.3 (span gases) or 10.4 (zero gas), then adjust the analyzer.
  - 8.2.3.6. If analyzer adjustment is needed (See Section 8.2.2.1) then:
    - 8.2.3.6.1. Open front door of the Model 3600.
    - 8.2.3.6.2. Adjust only the zero or span screw (Fig. 1b), as appropriate based on the gas being tested, until the concentration is within ±50 ppm of the certified reference gas concentration.
    - 8.2.3.6.3. As per SOP G9, follow this adjustment with a multipoint calibration.
  - 8.2.3.7. Stop flow of reference gas to the gas analyzer.
  - 8.2.3.8. Record calibration date and end time in the lab notebook.
  - 8.2.3.9. Repeat the steps in Sections 8.2.3.2 through 8.2.3.6 for each reference gas.
  - 8.2.3.10. Return analyzer to gas sampling mode.
  - 8.2.3.11. Return AirDAC to automatic sampling.

8.3. Troubleshooting

- 8.3.1. Troubleshooting guidelines are in Table 5-1 of the instrument manual.
  - 8.3.1.1. Check wiring and power connections if there is no signal or power.
  - 8.3.1.2. Check pump if there is no flow or concentrations too low.
  - 8.3.1.3. Check filter and replace if dirty.
  - 8.3.1.4. Check flow path integrity if reference gas concentration cannot be reached or sample flow rate is low.
  - 8.3.1.5. Clean or replace leaking solenoids. Solenoids (Fig. 2) that cannot close properly will cause a leakage into the acoustic cell, resulting in slow response and inability to reach the span gas value.

8.4. Data acquisition, calculations & data reduction requirements

- 8.4.1. Monitor a 4-20 mA analog output using AirDAC.
- 8.4.2. Report data with 3 significant digits.
- 8.4.3. Follow SOP B4 to correct gas concentrations for calibration and air density.

8.5. Computer hardware & software

- 8.5.1. AirDAC (SOP B2)
- 8.5.2. ARDIS (SOP B3)
- 8.5.3. CAPECAB (SOP B6)

9. Data and Records Management

9.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record with a record book designated for the method, and include copies of the electronic record.
9.2. Manage data according to SOP B5 “Management of Barn Data”.
9.3. Document all data and information (e.g., sample collection method used) on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

10. Quality Control and Quality Assurance

10.1. Conduct gas analyzer checks at a frequency specified by the QAPP. A typical frequency is weekly, but some QAPP may require a different frequency. This will include zero gas and one or more span concentrations.
10.2. Report QC data using a control chart in an Excel spreadsheet (SOP Q1).
10.3. Conduct gas analyzer multipoint calibration when the precision check of the gas analyzer with a span gas drifts more than 5% from the established baseline value.
10.4. Conduct gas analyzer calibrations when the precision check reading with a zero gas drifts more than 2% of full scale from the established zero baseline.
10.5. The calibration gas should be certified using EPA protocol (1% certification).
10.6. Check the response time every month, or at a frequency specified by the QAPP. The manual indicates that the instrument response to a step-change is 97% in 12 s.
10.7. Measure the gas analyzer inlet flow rate every six months.
10.8. Perform leak check in sample line and flow components and fittings when the equipment is installed, and then every six months. Plug the inlet and verify that the exhaust flow is zero using a flow meter.
10.9. Monitor sampling manifold temperature, relative humidity and pressure.

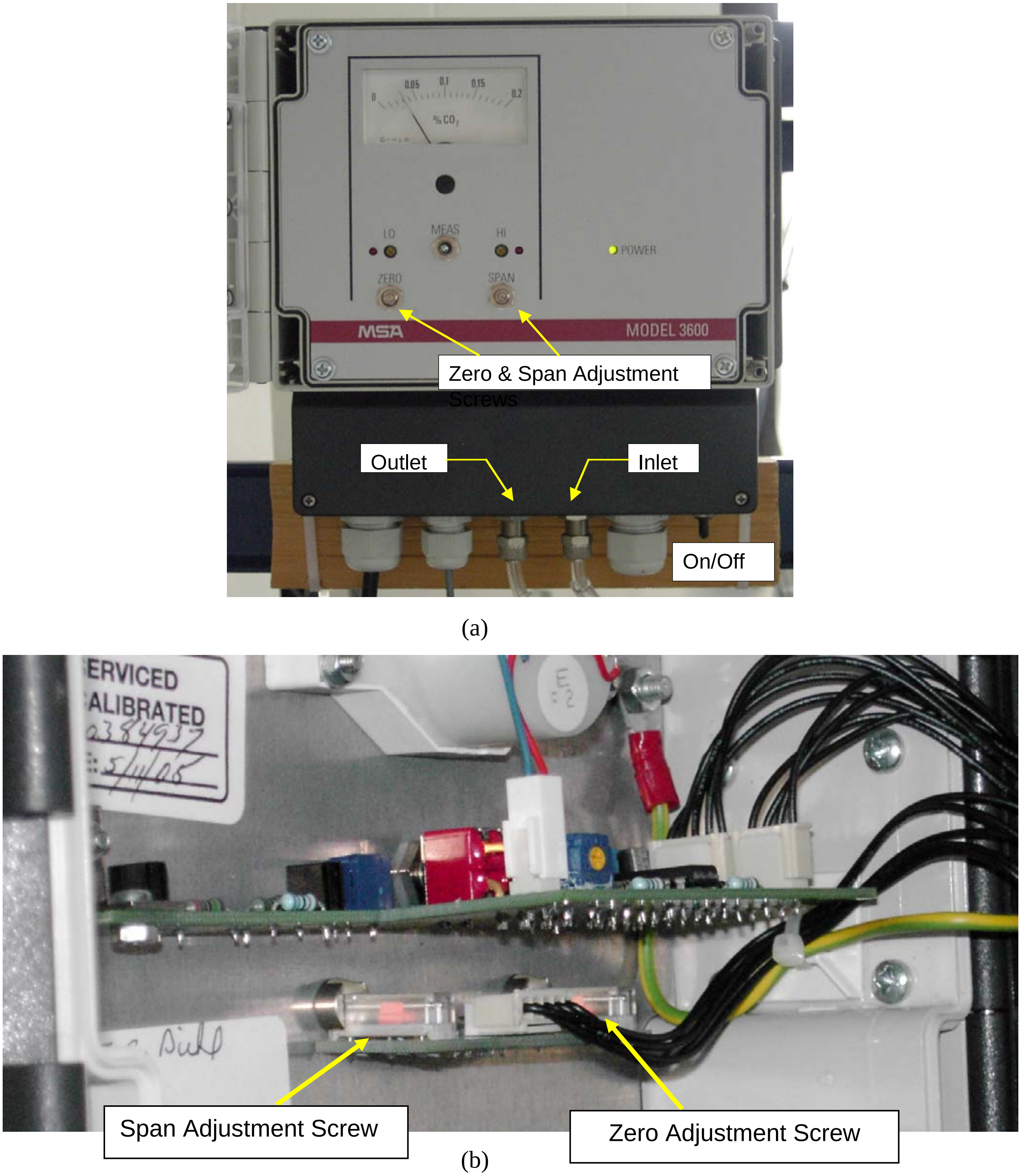
11. References

11.1. Mine Safety Appliances. 1993. MSA Model 3600 Infrared Gas Monitor Instruction Manual. (L) Rev. 2. [media.msanet.com/NA/USA/PermanentInstruments/HVACMonitors/Model3600InfraredGasMonitor/800031Rev2.pdf]. Accessed 11/7/05.
11.2. Roczko, A. 2001. MSA Photoacoustic Infrared Technology for Detection of Refrigerant Gases. [media.msanet.com/NA/USA/PermanentInstruments/HVAC Monitors/ChillgardLERefrigerantMonitor/PhotoacousticRefrigerantWhitePaper.pdf] Accessed 11/7/05.
11.3. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
11.4. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.
11.5. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.

11.6. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
11.7. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
11.8. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
11.9. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.
11.10. SOP G8. 2006. Multi-Point Calibration of Gas Analyzers. Standard Operating Procedure G8. Purdue Ag Air Quality Lab.
11.11. SOP G9. 2006. Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.
11.12. SOP Q1. 2006. Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1. Purdue Ag Air Quality Lab.
11.13. SOP U1. 2006. On-Farm Instrument Shelters for Barn Sources. Standard Operating Procedure U1. Purdue Ag Air Quality Lab.

12. Contact Information

12.1. Distributor: J&M Instrument Co., 7050 Greybudd Dr., Indianapolis, IN, 317-290-9127
12.2. Manufacturer Technical Support: 1-888-421-8324 http://www.msanorthamerica.com/customerservice.html.
12.3. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.



(a)

(b)

Figure 1. Location of zero and span screws from outside (a) and inside (b) the analyzer. Note: The analyzer in this picture has a 2,000 ppm range.

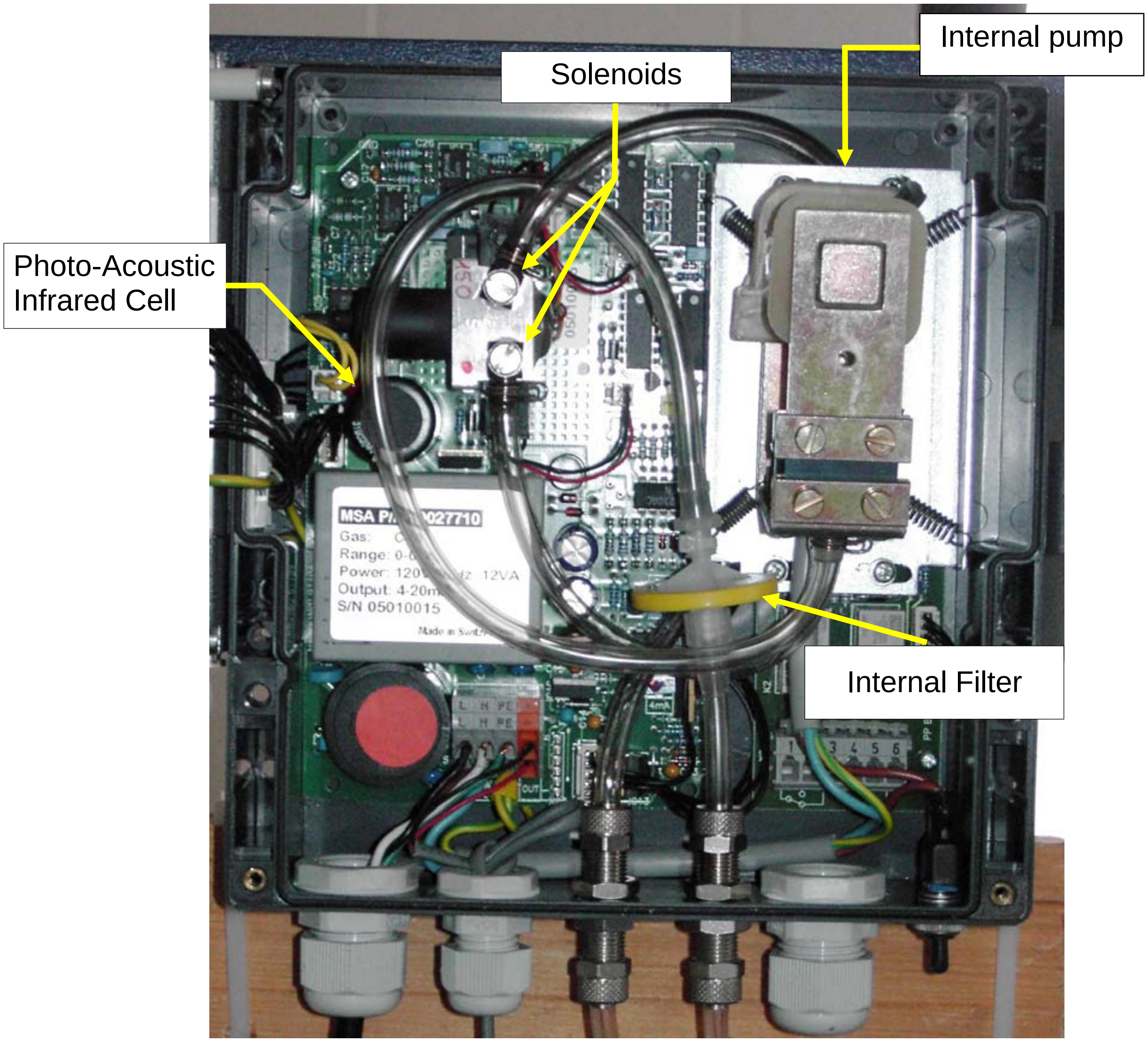


Figure 2. Location of key components of the analyzer.

MEASUREMENT OF AMMONIA (NH_3) USING THE TEC MODEL 17C CHEMILUMINESCENCE ANALYZER

Standard Operating Procedure (SOP) G4

MEASUREMENT OF AMMONIA (NH_3) USING THE TEC MODEL 17C CHEMILUMINESCENCE ANALYZER

Standard Operating Procedure (SOP) G4

Prepared by

Bill W. Bogan, Juan Carlos Ramirez, and Claude A. Diehl

Reviewed by

Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The purpose of this procedure is to present the methodology and instrumentation used to measure automatically and sequentially concentrations of ammonia (NH_3) emissions at animal feeding operations (AFO), specifically at the barns.

1.2. This procedure applies only to the Thermo Electron Model 17C Chemiluminescence NH_3 Analyzer.

1.3. The chemiluminescence method is useful for measuring NH_3 in barn air due to its low minimum detection limit, short response time and wide measurement range.

  1.3.1. The detection limit of the method is 1 ppb.

  1.3.2. The 90% response time to a step change in NH_3 concentration is 120 sec.

1.4. The standard range is from 0 to 100,000 ppb (0 to 100 ppm); adjusting the photomultiplier tube voltage can extend this range to 0 - 200 ppm.

1.5. The stated precision of the TEC 17C is 0.5% of full scale.

2. Summary of Method

The chemiluminescence NH_3 analyzer (Model 17C, Thermal Environmental Instruments (TEC), Franklin, MA) is a combination NH_3 converter and an NO-NO_2-NO_x analyzer (See Fig. 1). The air sample containing ammonia is pulled into the analyzer using an external vacuum pump. The ammonia in the air sample is oxidized to nitric oxide (NO) with a stainless steel catalytic converter at 825°C. The NO is further oxidized with ozone (O_3) in the analyzer's reaction chamber producing nitrogen dioxide (NO_2) molecules in an excited state that emit radiation as they return to a lower energy state (Equation 1). The intensity of the emitted radiation is proportional to the concentration of NO.

$$NO + O_3 \rightarrow NO_2 + O_2 + hv \quad (1)$$

where O_2 is oxygen and hv represents photons, particles of light energy, or radiation energy that is generated by NO_2 in an excited state returning to the ground state. The emitted radiation is detected by a photomultiplier tube (PMT), which in turn generates an electronic signal that is processed into a gas concentration reading. Sample air is drawn at a flow rate of 0.6 L/min from the converter into the NH_3 analyzer through a particulate filter, a glass capillary, and a solenoid valve. The solenoid valve routes the sample either directly into the reaction chamber (NO mode), through the molybdenum converter at 325°C and the reaction chamber (NO_x mode), or through the stainless steel catalytic converter and the reaction chamber (N_t mode). Ammonia concentration is calculated based on the difference between the readings obtained by the N_t and NO_x modes. The response time of the 17C is decreased if operated only in the N_t mode.

3. Definitions of Terms and Acronyms

3.1.	DAC	Data acquisition and control
3.2.	GSS	Gas sampling system
3.3.	MSDS	Material safety data sheet
3.4.	OFIS	On-farm instrument shelter
3.5.	PAAQL	Purdue Agricultural Air Quality Laboratory

3.6.	PMT	Photomultiplier tube
3.7.	QAPP	Quality Assurance Project Plan
3.8.	RH	Relative humidity
3.9.	TEC	Thermo Electron Corporation

4. Health and Safety

4.1. The exhaust stream leaving the reaction chamber will have significant concentrations of ozone and oxides of nitrogen. Incorrect connections between the analyzer and the vacuum pump, and between the vacuum pump and the exhaust could cause a significant health and safety hazard.

4.1.1. Ozone at 0.3 ppm for 30 min can cause eye and skin irritation, headache, nausea, and changes in pulmonary function (lung impairment and breathing difficulty). Death may occur from prolonged exposure at 2 ppm or short exposures (1 to 4 h) at 10 ppm (See the MSDS for Ozone located in the OFIS).

4.1.2. Oxides of nitrogen (nitric oxide (NO) and nitrogen dioxide (NO_2)) can cause eye and skin irritation, headache, nausea, and changes in pulmonary function (lung impairment and breathing difficulty) within 72 h of exposure (See the MSDSs for NO and NO_2 located in the OFIS).

4.2. Some of the internal components of the 17C work at high temperatures. Let the 17C cool down before touching or accessing those parts.

4.3. Be careful when working with the electrical power connection.

5. Cautions

5.1. Monitor the NH_3 conversion efficiency (NH_3 coefficient, See Section 9.4.3) of the 17C. A conversion efficiency < 80% (coefficient < 0.8) will cause the ammonia scrubbers to become clogged more rapidly, requiring extra expense and down time while the scrubbers are changed. If the coefficient drops below 0.8, see Section 9.4.3.

5.2. Failure of the permeation dryer due to contamination of the inner tubing (Section 11.8.2) can lead to a non-linear response.

5.2.1. Use antistatic wrist strap or discharge your body's electrostatic charge to a grounded metallic frame before touching any internal components of the 17C to avoid damage of the electronic components by electrostatic discharge. For further information, see Chapter 7 ("Servicing") of the 17C manual.

6. Interferences

6.1. Nitrogen dioxide (NO_2) at approximately 100 ppb causes a small (3 to 6%) negative response (i.e. an underestimate of NH_3 concentrations) (USEPA/Battelle 2004a & b).

6.1.1. NO_2 levels in barns are expected to be negligible.

6.2. Diethylamine at approximately 100 ppb causes a response approximately 50% of that seen with NH_3 at the same concentration (i.e. an overestimate of NH_3 concentrations equal to 50% of the diethylamine concentration) (USEPA/Battelle 2004a & b). Other alkylamines which are likely to be present at livestock sites (e.g. methylamine, dimethylamine, ethylamine) may present similar interferences.

6.2.1. Amine levels in barns are expected to be negligible compared to those of NH_3.

7. Personnel Qualifications

7.1. Personnel must be trained in the use of the 17C before initiating the procedure. Training requires about three hours.
7.2. Each analyst must read and understand the entire 17C manual and this SOP before operating the 17C.
7.3. Personnel must be able to interpret the analyzer output signal, converted concentration data, and correction of concentrations based on calibration.

8. Equipment and Supplies

8.1. Chemiluminescence NH_3 analyzer (Model 17C, Thermo Electron Corporation, Franklin, MA)
8.2. Rack and rack mounts
8.3. Keep the following spare parts at each remote site:
  8.3.1. Ammonia scrubbers, Part Nos. 10157, 10158, 10159
  8.3.2. Capillary – 10 mil long, Part No. 4121
  8.3.3. Ozone capillary, Part No. 4119
  8.3.4. O-ring for capillary, Part No. 4800
  8.3.5. Fuse - 5 amp, Part No. 4523
  8.3.6. Fuse - 3 amp slo-blo, Part No. 4510
8.4. Keep the following spare parts in a central stock at PAAQL:
  8.4.1. Stainless steel converter cartridge, Part No. 10155
  8.4.2. Solenoid valve, Part No. 8119
  8.4.3. Molybdenum (Moly) converter cartridge, Part No. 9269
  8.4.4. Thermocouple - Moly, Part No. 9204
  8.4.5. Thermocouple, Part No. 10170, or equivalent
  8.4.6. Bandheater - Moly (110 volt), Part No. 9261
  8.4.7. Pump, Part No. 9456, or equivalent
  8.4.8. Pump repair kit, Part No. 9464
  8.4.9. Permeation dryer assembly, Part No. 60800
8.5. Calibration gases: Ammonia, nitric oxide, zero gas (exact specifications and compositions to be defined in the QAPP)

9. Procedures

9.1. Gas Analyzer Setup
  9.1.1. Carefully check analyzer and converter for visible defects or damage.
  9.1.2. Securely mount the analyzer and converter in the instrument rack.
  9.1.3. Using 1/4″ OD Teflon tubing, connect “NO OUT”, “NO_x OUT”, and “N_t OUT” bulkheads on the rear panel of the converter to “NO IN”, “NO_x IN”, and “N_t IN” bulkheads, respectively, on the analyzer rear panel (Fig. 1).
  9.1.4. Connect the analyzer and converter with the communication cable.
  9.1.5. Connect the GSS analyzer manifold to the “SAMPLE” bulkhead on the rear panel of the converter, using a 1/4″ OD (1/8″ ID) Teflon tube less than 10′ long.
    9.1.5.1. Allow enough slack to permit movement of the instrument rack.
    9.1.5.2. Use tubing that is clean, dry, and uncontaminated.

9.1.6. Connect the vacuum inlet (stainless steel fitting) of the twin-headed vacuum pump to the analyzer's "CHAMBER" bulkhead. See Section 4.1.

9.1.7. Connect the vacuum pump exhaust port to the OFIS air exhaust with 1/4″ OD (1/8″ ID) PVC tube that is less than 10′ long.

9.1.8. Connect the analyzer's analog output port to the data acquisition system using shielded cable. See Table 2-1 of the 17C manual for recommended cable types.

9.1.8.1. Properly ground the shielded analog output cable.

9.1.8.1.1 Remove about 1.8 cm of insulation from the end of the cable.

9.1.8.1.2 Fold back the shielding. If necessary, use electrical tape or shrink tubing to hold shielding in place. Expose a minimum of 1.5 cm of shielding.

9.1.8.1.3 Strip each signal wire.

9.1.8.1.4 Connect shielded cable to the slots on the 8-position header, as shown in Figure 2-5 of the 17C manual.

9.1.9. Plug in the sample pump, turn on the analyzer, converter and ozonator, and run Model 17C overnight before calibrating.

9.1.10. Set operating ranges and averaging times to appropriate settings (Table 1). See Chapter 3 of the 17C manual for more details about 17C parameters. Fig. 2 in the manual includes a menu flow chart.

Table 1. Appropriate settings for the TEC 17C.

Parameter	Range
Internal temperature, °C	15 - 45
Chamber temperature, °C	47 - 51
Capillary temperature, °C	48 - 50
Cooler temperature, °C	-10 to -1
NO_2 converter temperature, °C	325 - 350
NH_3 converter temperature, °C	775 - 825
Pressure, mm Hg	50 - 300
Sample flow, L/min	0.30 - 0.90
Ozonator flow, L/min	0.05 - 0.25

9.1.11. Set averaging time to 10 s for fastest dynamic response.

9.1.12. Set to "Auto" mode using the front panel (Fig. 2).

9.1.13. Set to a single range mode by turning off option switches 4 and 5.

9.1.14. Select and enter the values for NO, NO_2, NO_x, Nt, and NH_3 ranges. The ranges of the gases depend on the time of year and type of livestock, as shown in Table 2.

9.1.15. Enter the analog signal and measurement ranges into the AirDAC software so that concentrations can be displayed, converted and recorded.

9.2. Gas Analyzer Calibration

9.2.1. Reference calibration gases

9.2.1.1. Nitric oxide (NO) in N_2: EPA Protocol (±1% analytical accuracy) if NO is primary data. Exact composition specified in the QAPP.

9.2.1.2. NH_3 in air: Oxygen is required to convert NH_3 to NO. The ammonia standard should have a analytical accuracy of ±1%. Exact composition specified in the QAPP.

9.2.1.3. Zero air, typically referred to as Continuous Emission Monitoring Zero Air.

Table 2. Expected range (ppm) for each analyte, as a function of livestock species and season.

	Swine		**Poultry**		**Dairy**	
	Expected Maximum Concentration					
Gas	**Summer**	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
NH_3	20	50	50	200	10	30
NO	< 1	< 1	< 1	< 1	< 1	< 1
NO_2	< 1	< 1	< 1	< 1	< 1	< 1
NO_x	< 1	< 1	< 1	< 1	< 1	< 1
N_t	20	50	50	200	10	30
	Proper Range Setting for 17C					
	Summer	**Winter**	**Summer**	**Winter**	**Summer**	**Winter**
NH_3	20	50	50	200	10	30
NO	1	1	1	1	1	1
NO_2	1	1	1	1	1	1
NO_x	1	1	1	1	1	1
N_t	20	50	50	200	10	30

9.2.2. Calibrate the 17C following SOPs G8 (multipoint calibrations) and G9 (zero/precision checks).
  9.2.2.1. Set the averaging time to 60 s for calibration.
  9.2.2.2. Adjustment of the analyzer. A precision check is to be performed before any adjustment of the analyzer. The number of points and gas concentrations for multipoint calibrations and precision checks are specified in the Quality Objectives of the QAPP.
  9.2.2.3. Record calibration or precision check date and time in field notes (Table 4).
  9.2.2.4. Record 17C pressure, sample flow, and ozone flow at each point (Table 3).
  9.2.2.5. Start flow of reference gas to the analyzer. See SOP G1 for delivery options.
  9.2.2.6. Record pertinent gas delivery parameters (Concentration and flow rate (SOP G11))
  9.2.2.7. Wait a minimum of 10 min for the display to stabilize.
  9.2.2.8. Record the time and concentrations shown on the 17C display, and by AirDAC, in the field notebook.
  9.2.2.9. If the stabilized concentration during a precision check deviates from zero by 2% of full scale and / or the baseline concentration by 10% or more, adjust the gas analyzer calibration as follows:
    9.2.2.9.1 Zero adjustment
      9.2.2.9.1.1 Choose “Calibration” from the Main Menu, and choose “Calibrate Zero” from the Calibration Menu.
      9.2.2.9.1.2 Press **“**ENTER” to set the NO, NO_x, and N_t readings to zero.
      9.2.2.9.1.3 Press “RUN**”** to return to the Run Screen.
    9.2.2.9.2 Precision adjustment
      9.2.2.9.2.1 Choose “Calibration” from the Main Menu, and choose “Calibrate NO, NO_x, or, NH_3” from the Calibration Menu.
      9.2.2.9.2.2 The first line of the Calibrate NO, NO_x, or, NH_3 screen displays the current NO, NO_x, or, NH_3 reading.

9.2.2.9.2.3 Enter the actual NO, NO_x, or, NH_3 calibration gas concentration on the third line of the display. Position the cursor using the ← and → buttons. Adjust each digit in the reading using the ↑ and ↓ buttons.
9.2.2.9.2.4 Press "ENTER" when the concentration is correct.
9.2.2.9.2.5 Stop gas flow and record the time.
9.2.3. Repeat the steps in Section 9.2.2 for each reference gas.
9.2.4. Set the analyzer's averaging time back to 10 s.
9.2.5. Return analyzer to gas sampling mode. This includes setting AirDAC to auto sample.

9.3. Gas Analyzer Precision Checks
9.3.1. Repeat steps 9.2.2.3 through 9.2.5, but skip adjustment steps (Sections 9.2.2.9. through 9.2.2.9.2.5) and 9.2.4.
9.3.2. Check soon after any repair or maintenance to verify that problem has been solved.
9.3.3. Use QAPP-specified frequency, replications and reference gas concentrations.

9.4. Adjustment of the measurement range of the analyzer
9.4.1. Run a precision check (SOP G9)
9.4.2. Introduce NH_3 to the GSS using the Environics diluter
9.4.2.1. Use 180 ppm of NH_3 to set the measurement range for NH_3 to 200 ppm
9.4.2.2. Use 90 ppm of NH_3 to set the measurement range for NH_3 to 100 ppm
9.4.3. Wait until measurement (reading) stabilizes or after 10 min.
9.4.4. Remove the TEC 17C NH_3 analyzer cover.
9.4.5. Locate the blue PMT high voltage power supply (the only blue box in the analyzer).
9.4.5.1. Using a small standard screwdriver, adjust adjustment screw on the top of the box.
9.4.5.1.1 When introducing NH_3 at 180 ppm, turn the screw counterclockwise until the analyzer's reading is stabilized at 90 ppm.
9.4.5.1.2 When introducing NH_3 at 90 ppm, turn the screw clockwise until the analyzer's reading is stabilized at 90 ppm.
9.4.6. Place the TEC 17C NH_3 analyzer cover back on the analyzer.
9.4.7. Perform the following after adjusting the measurement range of the analyzer:
9.4.7.1. Precision Check (SOP G9)
9.4.7.2. Multipoint Calibration (SOP G8)
9.4.7.3. Precision Check to establish a new baseline for the control chart (SOP Q1)

9.5. Maintenance
9.5.1. Clean the dust filters on the back of the analyzer and converter on a regular basis. This can range from weekly to monthly, depending on the dust level in the OFIS.
9.5.2. Track the operating pressure of the 17C in its control chart (See SOP Q1). Replace the ammonia scrubbers when frequent analyzer adjustments are required (i.e. when the unit repeatedly drifts outside the 10% tolerance limit – usually the lower bound due to reduced sensitivity – around the certified concentration of the precision check gas), and when pressure is increasing (Fig. 3).
9.5.2.1. These two factors indicate salt buildup within the analyzer's stainless steel cross and/or exhaust tubing (Fig. 4).
9.5.2.1.1 Clean the stainless steel cross and/or exhaust tubing as necessary.
9.5.2.1.2 Conduct a zero & precision span check before and after cleaning.
9.5.2.2. Replace scrubbers more frequently when measuring high ammonia concentrations.

9.5.3. Check the NH_3 coefficient (found in the "CALIBRATION FACTORS" Menu) on a weekly basis, and record in the electronic field notes. See Section 5.1.1 if the NH_3 coefficient is < 0.8. If the coefficient drops below 0.8:
  9.5.3.1. Ensure that there are no leaks in the sampling system that may be resulting in loss of NH_3.
  9.5.3.2. If no leaks or other problems can be found with the sampling system, contact the manufacturer to troubleshoot the N_t converter.

9.6. Troubleshooting
  9.6.1. Troubleshooting guidelines are in Chapter 6 of the 17C manual.
    9.6.1.1. Check wiring and power connections and fuse if there is no signal or power.
    9.6.1.2. Check pump if there is no flow or no exhaust, or if concentrations are too low.
    9.6.1.3. Check filter and replace if dirty.
    9.6.1.4. Check flow path integrity if span concentration is unattained, or if flow rate is low.
    9.6.1.5. If the cooler will not hold its set temperature, check the dust filters, and make sure that the temperature inside the OFIS is not too high (> 95°F).

9.7. Data acquisition, calculations & data reduction requirements
  9.7.1. Monitor a 0-10 VDC analog output signal using AirDAC.
  9.7.2. Report all data with 3 significant digits.
  9.7.3. Follow SOP B4 to correct gas concentrations for calibration and air density.

9.8. Computer hardware & software
  9.8.1. AirDAC (SOP B2)
  9.8.2. ARDIS (SOP B3)
  9.8.3. CAPECAB (SOP B6)

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information (e.g., sample collection method used) on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance

11.1. Verify compositions of all calibration gases by FTIR, according to SOP G12.

11.2. Conduct zero and one or more precision checks at the QAPP-specified frequency.

11.3. Conduct a gas analyzer calibration every 180 d (six months), or at the QAPP-specified frequency.
  11.3.1. The precision of the replicate points in this calibration should be ±5%, unless another value is specified in the QAPP.
  11.3.2. The correlation coefficient (R2) of the linear regression for the calibration should be ≥98%, unless another value is specified in the QAPP.

11.4. Conduct a gas analyzer calibration whenever the zero check is > ±5% of full scale different than the baseline zero, or at a limit specified by the QAPP.

11.5. Conduct a gas analyzer calibration whenever the precision check deviates from the baseline concentration by more than 10%, unless the QAPP indicates otherwise.

11.6. Perform a “bag test” with a known concentration of NH_3 (as described in SOP G1) every 60 days, or at the frequency designated in the QAPP.

11.7. Check response time every six months.

11.8. Perform preventative maintenance according to the schedule provided in Chapter 5 of the 17C manual, as follows:

  11.8.1. Check the inner tubing of the permeation dryer once per year to see if a dark yellow to brownish discoloration is present, change the permeation dryer.

  11.8.2. Check converter and analyzer capillaries for particulate deposits (pg. 5-2), and replace as necessary.

  11.8.3. Inspect and clean photomultiplier tube cooler fins (pg. 5-3) every 6 mos (minimum).

12. References

12.1. 17C Manual. TEC Model 17C Chemiluminescence NH3 Analyzer Instruction Manual. Thermo Electron Corporation, Franklin, MA.

12.2. USEPA/Battelle. 2004a. ETV Joint Verification Statement. Model 17C Ammonia Analyzer. [http://www.epa.gov/etv/pdfs/vrvs/01_vs_thermo.pdf]. Accessed 1/27/2006.

12.3. USEPA/Battelle. 2004b. ETV Joint Verification Report. Model 17C Ammonia Analyzer. [http://www.epa.gov/etv/pdfs/vrvs/01_vr_thermo.pdf]. Accessed 1/27/2006.

12.4. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

12.5. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.

12.6. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.

12.7. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.8. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.

12.9. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.

12.10. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.

12.11. SOP G8. 2006. Multi-Point Calibration of Gas Analyzers. Standard Operating Procedure G8. Purdue Ag Air Quality Lab.

12.12. SOP G9. 2006. Zero and Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.

12.13. SOP G11. 2006. Operation of the Environics® Computerized Gas Dilution System. Standard Operating Procedure G11. Purdue Ag Air Quality Lab.

12.14. SOP Q1. 2006. Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturer: Thermo Environmental Corporation (www.thermo.com), 8 West Forge Parkway, Franklin, MA 02038, Technical Support: 1-508-520-0430

13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

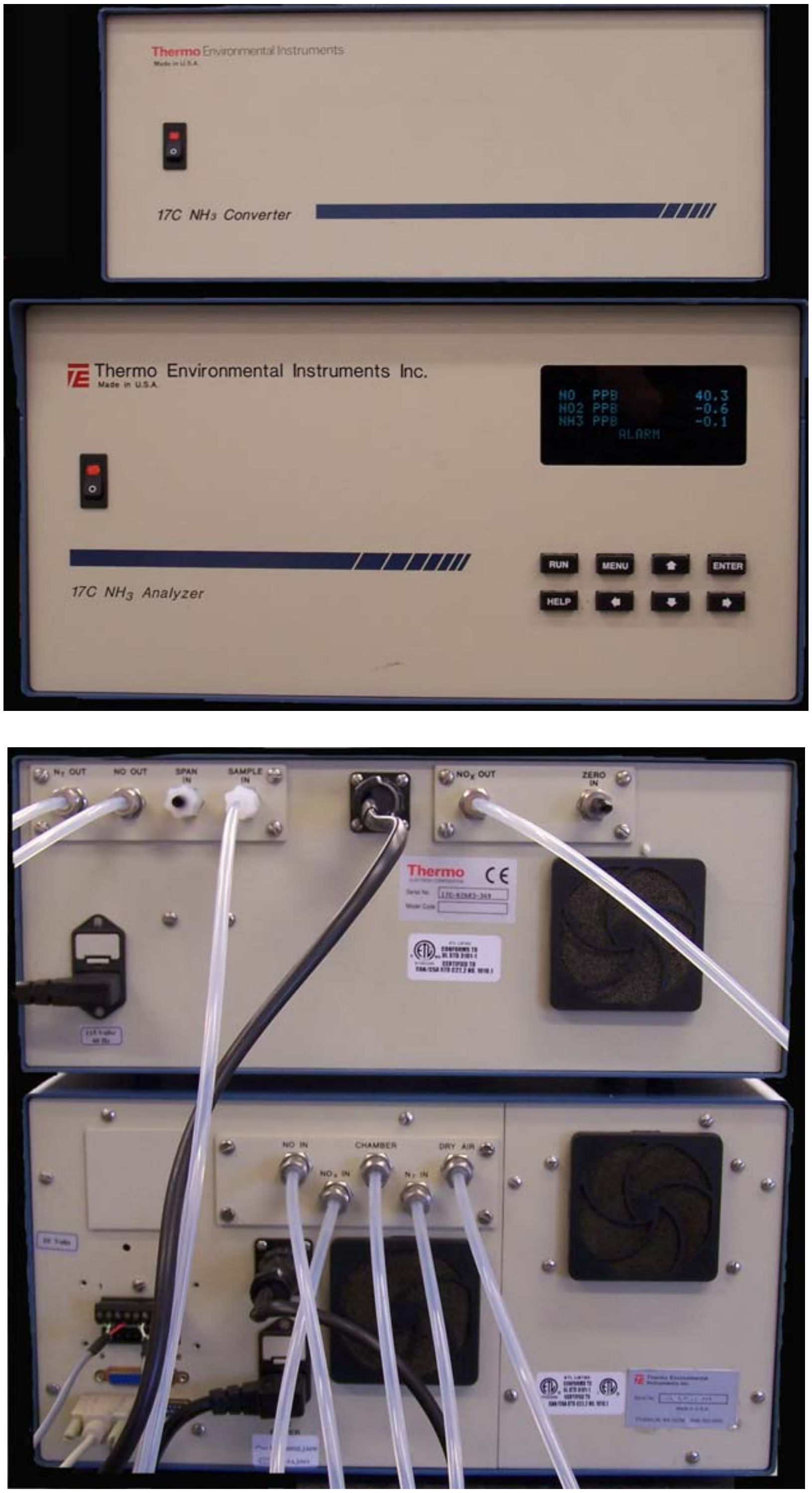


Figure 1: The front and back of the TEC 17C Ammonia Analyzer.

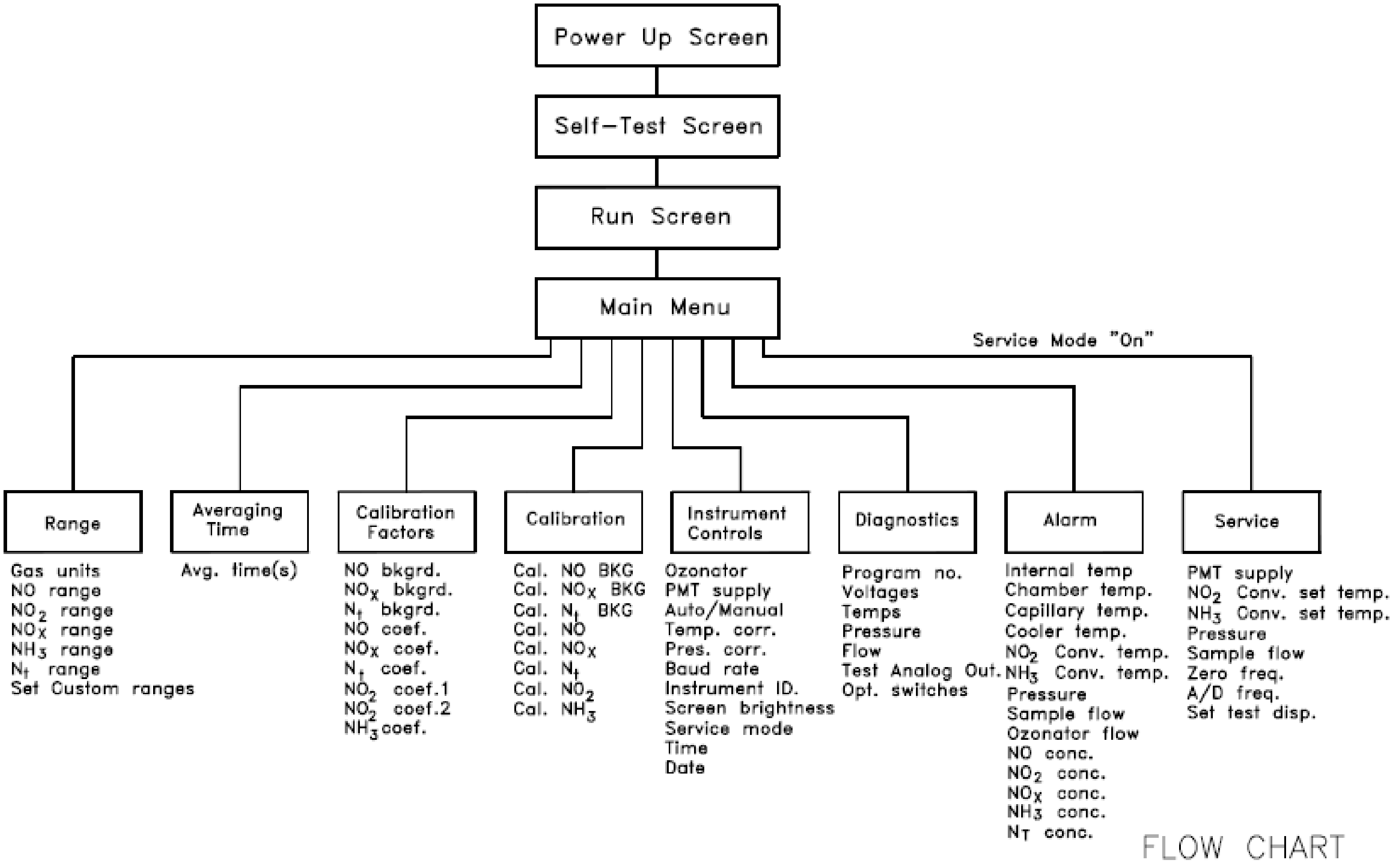


Figure 2: The Menu Flow Chart for the TEC 17C.

Table 3. Operating parameters for the TEC 17C ammonia analyzer, as entered in the electronic field notes.

TEC 17C Analyzer's Operating Parameters		Today's Zero-Span Check		Previous Zero-Span Check 3/07/2006	
3/12/2006	Pressure	92.4	mm Hg	90.5	mm Hg
	Sample Flow	0.323	Lpm	0.321	Lpm
	Ozone Flow	0.194	Lpm	0.172	Lpm

Table 4.Calibration table as used in the electronic field notes.

Ammonia Calibration							
3/7/2006				Concentration	Instrument	AirDAC	AirDAC
Started	Stopped	Instrument	Gas	ppm	Reading	ppm /ppb	vdc or mA
3/7/2006 11:37	3/7/2006 11:50	TEC 17C	CEM Zero	0	0.769	0.406	0.0871
3/7/2006 11:51	3/7/2006 12:14	Adjusted TEC 17C					
3/7/2006 12:14	3/7/2006 12:21	TEC 17C	CEM Zero	0	0.595	0.071	0.0071
3/7/2006 12:21	3/7/2006 12:31	TEC 17C	NH3	40.6	6.32	6.47	0.6467
3/7/2006 12:31	3/7/2006 12:43	Adjusted TEC 17C					
3/7/2006 12:43	3/7/2006 12:48	TEC 17C	NH3	40.6	40.7	40.77	4.0770

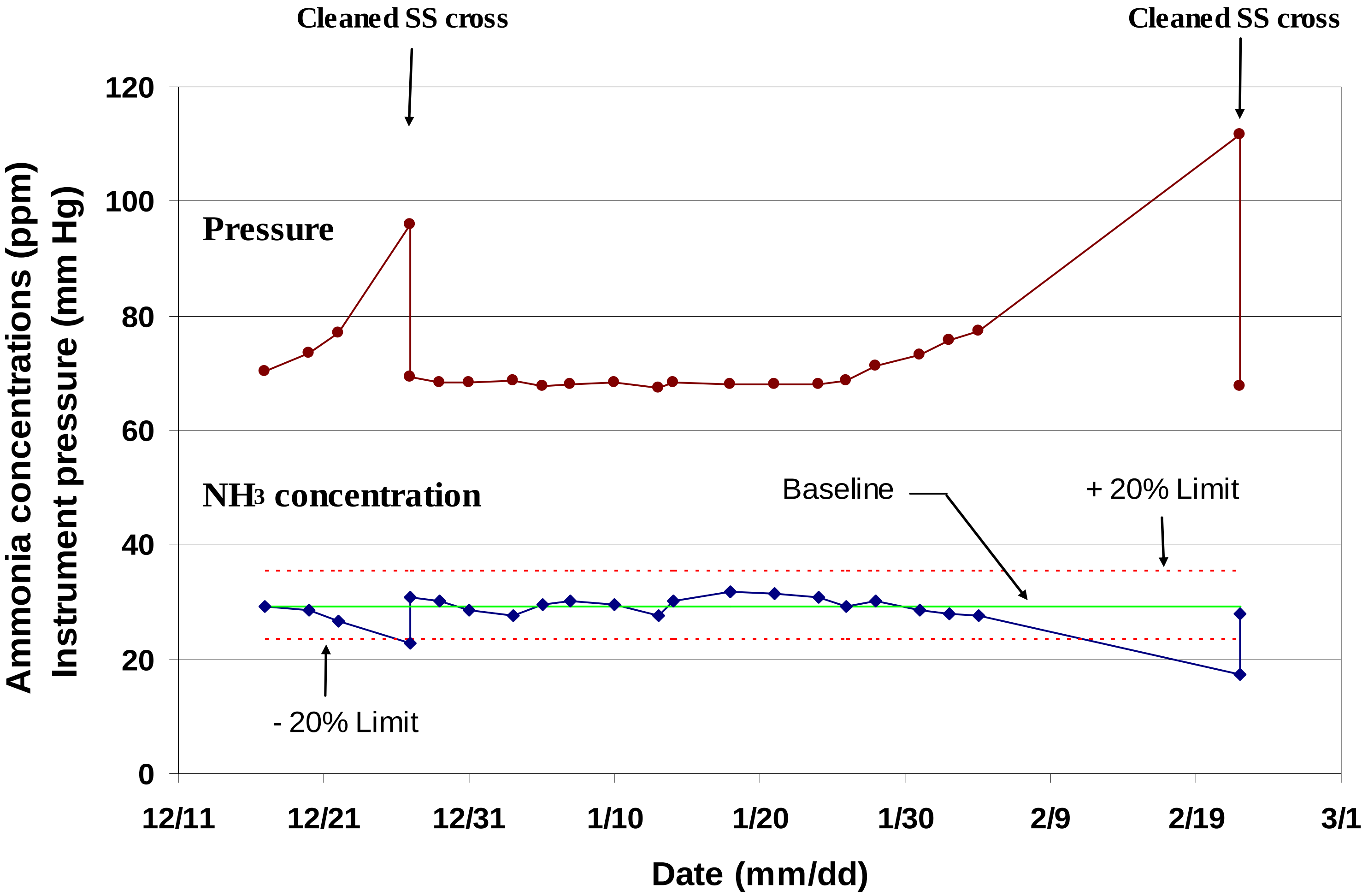
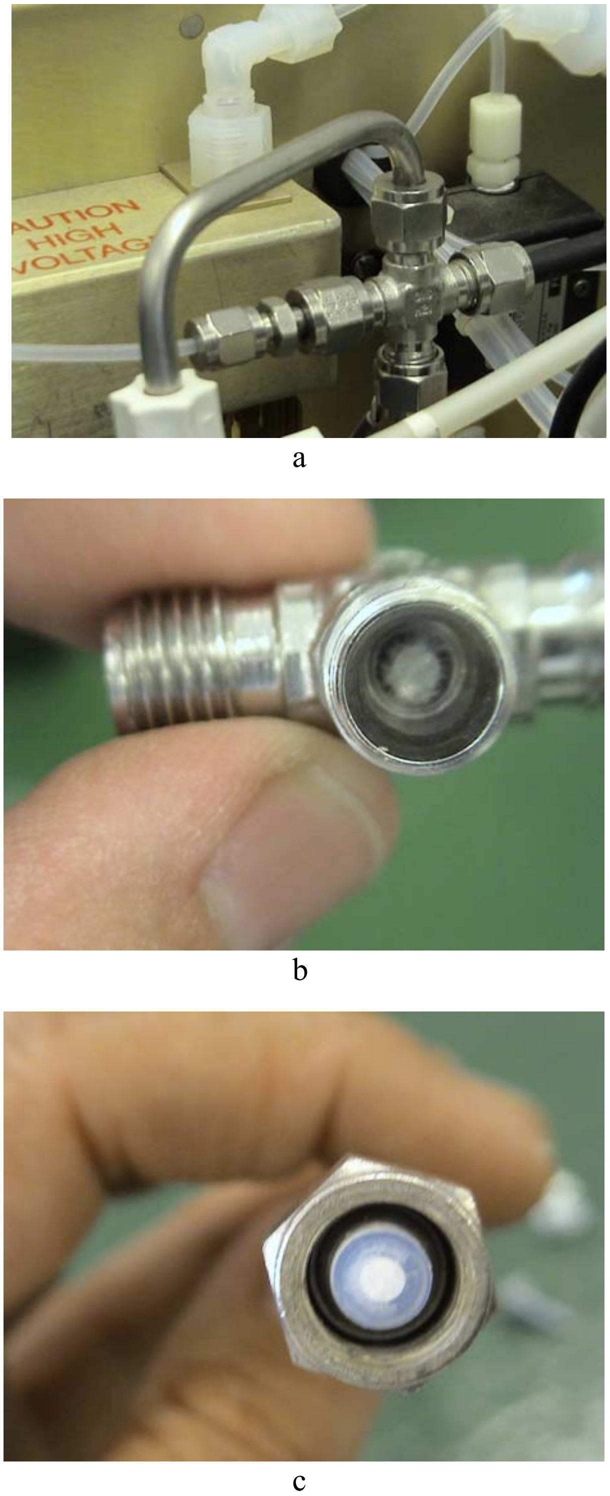


Figure 3. Graph, adapted from a TEC 17C control chart, showing NH_3 concentrations recorded during precision checks and operating pressure. Sharp increases in pressure, corresponding to decreased sensitivity (out-of-bounds low readings) indicate a need to clean out salt deposits (in this case, from the stainless steel cross).



a

b

c

Figure 4. Location of the 17C stainless steel cross (a), and buildup of ammonia salts in the stainless steel cross (b) and exhaust tubing (c).

MEASUREMENT OF HYDROGEN SULFIDE (H2S) WITH THE THERMO ELECTRON CORPORATION MODEL 450I PULSED-FLUORESCENCE ANALYZER

Standard Operating Procedure (SOP) G5

MEASUREMENT OF HYDROGEN SULFIDE (H_2S) WITH THE THERMO ELECTRON CORPORATION MODEL 450I PULSED-FLUORESCENCE ANALYZER

Standard Operating Procedure (SOP) G5

Prepared by

Claude A. Diehl, Bill W. Bogan, Richard H. Grant and Matt T. Boehm

Reviewed by

Ji-Qin Ni and Albert J. Heber

Effective Date: November 6, 2006
Rev. 1.0 Effective Date: March 17, 2008

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

- 1.1. The purpose of this procedure is to present the methodology and instrumentation used to automatically and sequentially measure hydrogen sulfide (H_2S) emissions from barns, other buildings or open sources at confined animal feeding operations (CAFO).
- 1.2. This procedure applies only to the Model 450I Pulsed Fluorescence H_2S/SO_2 Analyzer (Thermo Electron Corporation, Franklin, MA).
- 1.3. The pulsed fluorescence method is useful for measuring hydrogen sulfide (H_2S) in air, due to its suitable detection limit, response time, and measurement range.
  - 1.3.1. The detection limit of the method is:
    - 1.3.1.1. 6 ppb (when using a 10-s averaging time)
    - 1.3.1.2. 2 ppb (60-s averaging time)
    - 1.3.1.3. 1.5 ppb (300-s averaging time)
  - 1.3.2. The 90% response time to a step change in H_2S concentration is:
    - 1.3.2.1. 80 s (10-s averaging time)
    - 1.3.2.2. 110 s (60-s averaging time)
    - 1.3.2.3. 320 s (300-s averaging time)
  - 1.3.3. The measurement range of the Model 450I is from 0 to 10,000 ppb (10 ppm).
- 1.4. The stated precision of the 450I is 1% of reading or 1 ppb (whichever is greater).

2. Summary of Method

Hydrogen sulfide in sample air entering the 450I is converted to sulfur dioxide (SO_2) in a converter operating at 300-400°C (1).

$$H_2S \rightarrow SO_2 \qquad (1)$$

The sample flows directly to the hydrocarbon kicker when the 450I measures SO_2, or flows through the converter first, then to the hydrocarbon kicker when the 450I measures H_2S (Fig. 1) Any hydrocarbon present in the sample permeates through the tube wall of the hydrocarbon kicker, and is removed from the sample. SO_2 passes through the hydrocarbon kicker into the fluorescence chamber (the L-shaped box at the center right of Fig. 1).

The sample containing SO_2 is pulsed with ultraviolet (UV) light by a high-intensity xenon lamp. SO_2 molecules absorb at one wavelength and become excited (SO_2^*); they then decay to a lower energy state by emitting UV light at a different wavelength (2).

$$SO_2 + h\nu_1 \rightarrow SO_2^* \rightarrow SO_2 + h\nu_2 \qquad (2)$$

Emitted UV light is proportional to SO_2 concentration and is detected and converted to an electrical current by a PMT detector.

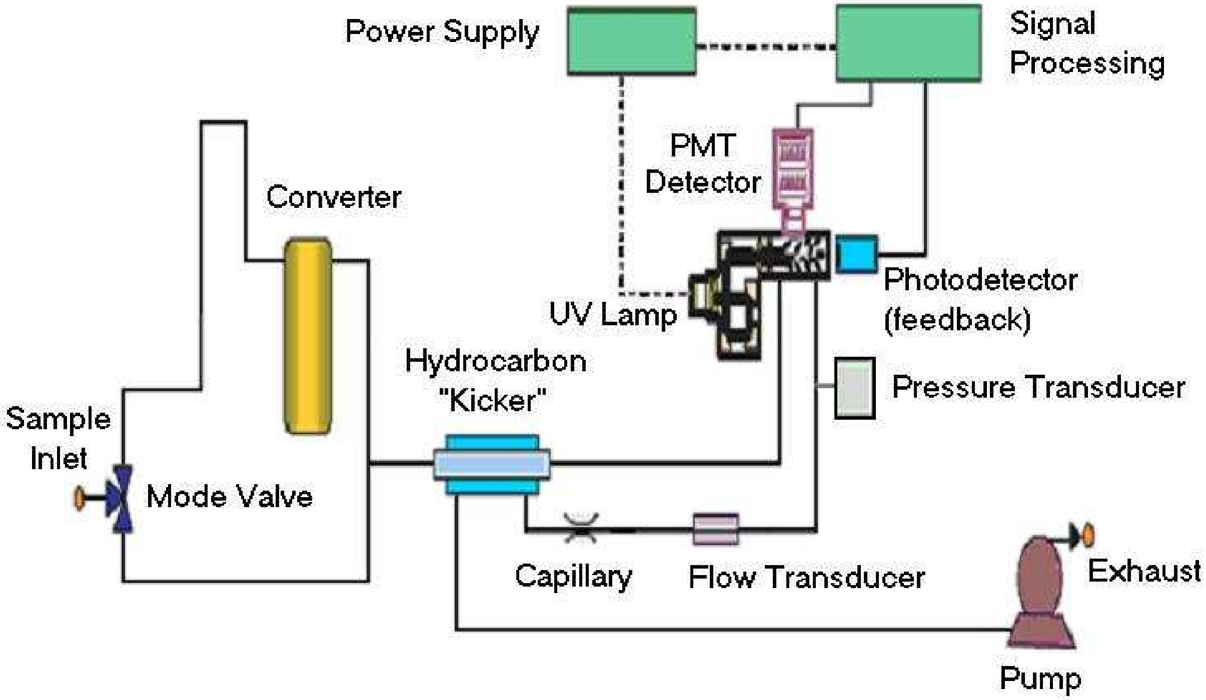

Figure 1. Flow schematic of the 450I.

3. Definitions of Terms and Acronyms

AirDAC	Data acquisition and control software for barn applications (SOP B2)
CS	Combined sulfur (H_2S + SO_2)
CAFO	Confined animal feeding operation
GSS	Gas sampling system (SOP G1)
Hydrocarbon kicker	A membrane tube in the 450I that removes aromatic hydrocarbons based on their ability to pass through the membrane. SO_2 molecules pass through the hydrocarbon kicker unaffected.
QAPP	Quality Assurance Project Plan
OFIS	On-farm instrument shelter (SOP U1)
PAAQL	Purdue Agricultural Air Quality Laboratory
PMT	Photomultiplier tube

4. Health and Safety

4.1. Be careful when working with the electrical power connection.
4.2. The converter of the Model 450I contains high-temperature elements (300-400°C), and should not be touched.
4.3. Properly vent analyzer exhaust to avoid exposure to noxious gases in the sample.
4.4. Prevent leaking of the calibration gases into the working environment.

5. Cautions

5.1. Use antistatic wrist strap or discharge your body’s electrostatic charge to a grounded metallic frame before touching any internal components of the 450I to avoid damage of the electronics by static discharge. See Chapter 7 (“Servicing”) of the 450I manual.

6. Interferences

6.1. Compounds that interfere with fluorescence-based H_2S measurements are as follows:

Interferences	**Effect on H_2S Readings**
Methyl mercaptan	0.8 ppm increase per 1 ppm of CH_3SH
Dimethyl disulfide	0.5 ppm increase per 1 ppm of CH_3SSCH_3
Dimethl sulfide	< 0.1 ppm increase per 1 ppm of CH_3SCH_3
NO	Increase of < 3 ppb at 500 ppb NO
m-xylene	Increase of < 1 ppb at 200 ppb *m*-xylene
Water	< 2% of reading per 2% humidity ratio

6.1.1. The effect of humidity will typically be less than 3% of reading. For example, the difference in humidity ratio between saturated air at 30°C (86°F) and saturated air at 0°C (32°F) is approximately 2.3%

6.1.2. H_2S is expected to be present at one or two orders of magnitude higher than dimethyl sulfide or dimethyl disulfide; thus, the relative magnitude of these interferences should be minor. Dimethyl sulfide and dimethyl disulfide can be monitored with the Innova Model 1412 Multi-Gas Monitor (SOP G7).

6.1.3. Concentrations of NO and *m*-xylene are expected to be negligible.

7. Personnel Qualifications

7.1. Personnel should be trained in the operation, maintenance and calibration of the analyzer before initiating the procedure. Training requires about three hours.

7.2. Each analyst must read and understand the entire analyzer manual and this SOP before operating the Model 450I.

7.3. Personnel should also be trained to interpret the analyzer output signal, converted concentration data, and correction of concentrations based on calibration.

8. Equipment and Supplies

8.1. Hydrogen sulfide analyzer (Model 450I, Thermo Electron Corporation)

8.2. H_2S-to-SO_2 converter (Model 340, Thermo Electron Corporation)

8.3. Keep the following spare parts at each site:

- 8.3.1. 20-mil capillary, Part No. 4126
- 8.3.2. O-ring capillary, Part No. 4800
- 8.3.3. Teflon tubing (1/4″ OD x 1/8″ ID) for connecting analyzer to GSS and exhaust port
- 8.3.4. 4-conductor cable (shielded, 22-gauge)

8.4. Keep the following spare parts in a central stock at PAAQL:
  8.4.1. 20-mil capillary, Part No. 4126
  8.4.2. O-ring capillary, Part No. 4800
  8.4.3. Pump, 110 VAC, Part No. 8550
  8.4.4. Pump repair kit, Part No. 8606
  8.4.5. Flash lamp, Part No. 8666
  8.4.6. Particulate filter assembly, Part No. 60100
  8.4.7. Converter assembly, 120 VAC, Part No. 450P702-1
  8.4.8. Power supply board, Part No. 10570
  8.4.9. Trigger pak, Part No. 8774
  8.4.10. Flash intensity board, Part No. 8884
  8.4.11. Flasher supply board, Part No. 9681
  8.4.12. Temperature control board, Part No. 8765
  8.4.13. PMT high voltage power supply, Part No. 9901
  8.4.14. Temperature control board (converter), Part No. 9889
  8.4.15. Teflon tubing (1/4″ OD x 1/8″ ID) for connecting analyzer to GSS and exhaust port
  8.4.16. 4-conductor cable (shielded, 22-gauge)

8.5. Calibration gas cylinders: Hydrogen sulfide (H_2S), sulfur dioxide (SO_2), zero gas (see the QAPP for exact specifications and compositions), with appropriate regulators (SOP G2)
  8.5.1. In projects where SO_2 is not a primary measurement, it may still be used to check the converter efficiency (Section 9.3).

9. Procedure

9.1. Model 450I Analyzer setup
  9.1.1. Check the exterior of the analyzer (Fig. 2) carefully to assure it is free of visible defects or damage.
    9.1.1.1. Remove the instrument cover to expose the internal components (Fig. 3).
    9.1.1.2. Remove any packing material, check for possible shipping damage and ensure that all connectors and circuit boards are firmly attached.
    9.1.1.3. Replace the instrument cover.
  9.1.2. Securely mount the analyzer in the instrument rack.
  9.1.3. Connect the analyzer manifold in the GSS to the “SAMPLE” bulkhead (Fig. 2) on the instrument’s rear panel using ¼” OD (1/8” ID) Teflon tubing less than 10’ long. Allow enough slack to permit movement of the instrument rack.
  9.1.4. For barn applications:
    9.1.4.1. Connect the “EXHAUST” bulkhead to the OFIS air exhaust with 1/4″ OD (1/8″ ID) tubing less than 10′ long, which is unimpeded and free of kinks or blockages.
    9.1.4.2. Connect a 4-conductor, 20- or 22-gage shielded cable to the designated channels of the FieldPoint analog input module (SOP B1). Properly ground the shield of the analog output cable.
    9.1.4.3. Connect the other end of the 4-conductor cable to the analyzer’s analog outputs for SO_2 and H_2S (not to the CS analog output).
      9.1.4.3.1. Remove about 1.8 cm of insulation from the other end of the cable. Fold back the shielding. If necessary, use electrical tape or shrink tubing to hold

shielding in place. Expose a minimum of 1.5 cm of shielding. Strip each signal wire and connect them to the terminals (1) through (4) of the 8-position header of the 450I (Fig. 4) according to the wire connection to the data acquisition hardware

9.1.5. For open source applications:

9.1.5.1. Connect the “EXHAUST” bulkhead to the GSS bypass air exhaust with 1/4″ OD (1/8″ ID) tubing such that total tubing length is less than 10′ long. Tubing must be unimpeded and free of kinks or blockages.

9.1.5.2. Connect a null modem RS232 cable from the RS232 connector of the data-collecting computer to the “RS232/485” connector at the back of the instrument.

Figure 2. Front (top) and back (bottom) views of the TEC 450I.

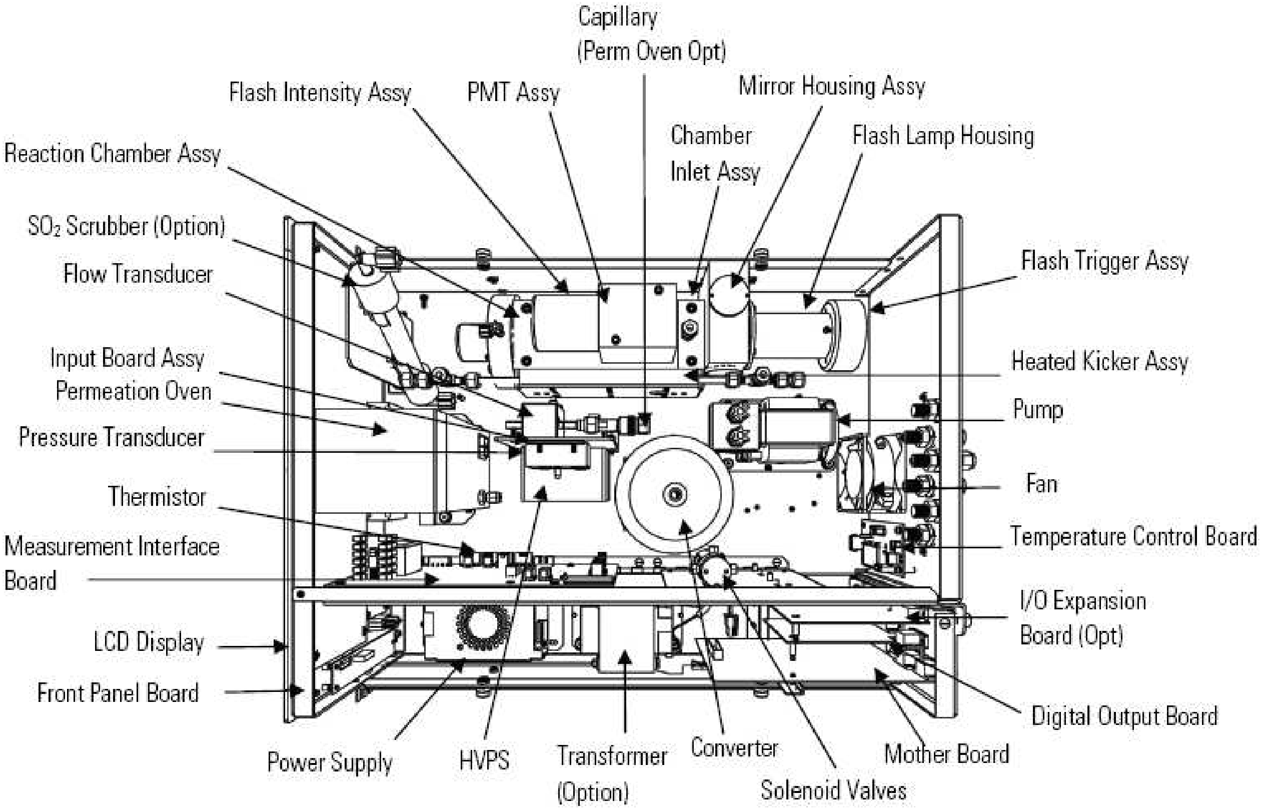

Figure 3. Internal schematic of the TEC 450I analyzer.

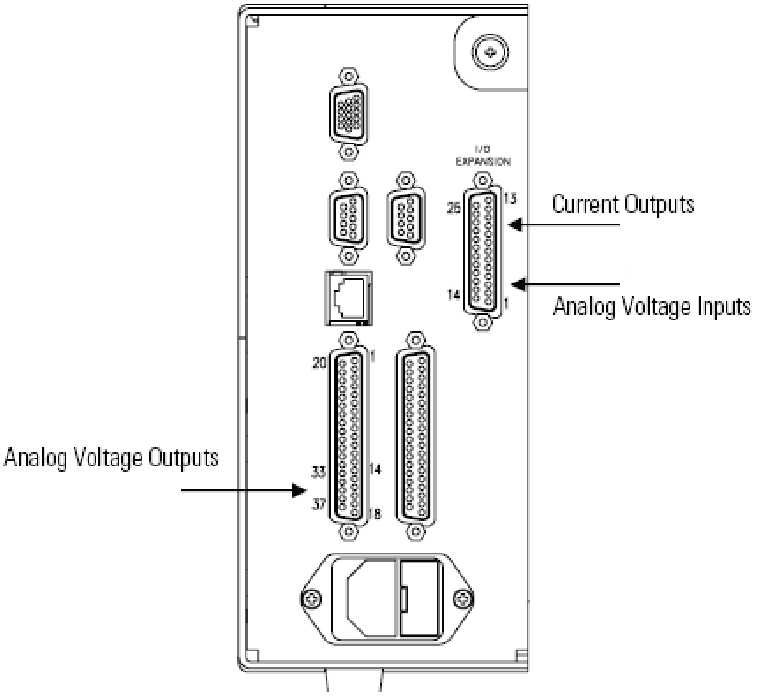

Figure 4. Connectors on the 450I rear panel (left side of Fig. 2 lower panel).

9.1.6. Plug the 450I power cord into a 110VAC power source, turn on its power, and allow a minimum of 90 min for the unit to warm up and stabilize before calibrating.

9.1.7. Operate the instrument menu (Fig. 5) to navigate to the screens necessary to set the instrument control settings (Table 1) and to check the operating parameters and ranges (Table 2), as described in detail in Chapter 3 of the instrument manual. An alarm message will appear in the screen on the front panel of the instrument when any of these parameters is operating outside the set limits.

Table 1. TEC 450I Instrument settings.

Parameter	**Setting**
Gas Units	ppb
Measurement Mode	Automatic Mode
Averaging Time	60 s
Temperature Correction	ON
Pressure Correction	ON
Flash Lamp	ON
Baud Rate	9600
Service Mode	OFF
Time	Current
Date	Current
Converter Temperature	352°F

Table 2. TEC 450I instrument operating parameters and ranges.

Parameter	**Range**
Pressure (mm Hg)	400 – 1000
Sample Flow (L/min)	0.350 – 1.400
Lamp Voltage (V)	500 – 1200
Lamp Frequency (Hz)	10,000 – 50,000
Converter Temperature (°C)	300 – 400
Internal Temperature (°C)	15 – 45
Chamber Temperature (°C)	43 – 47

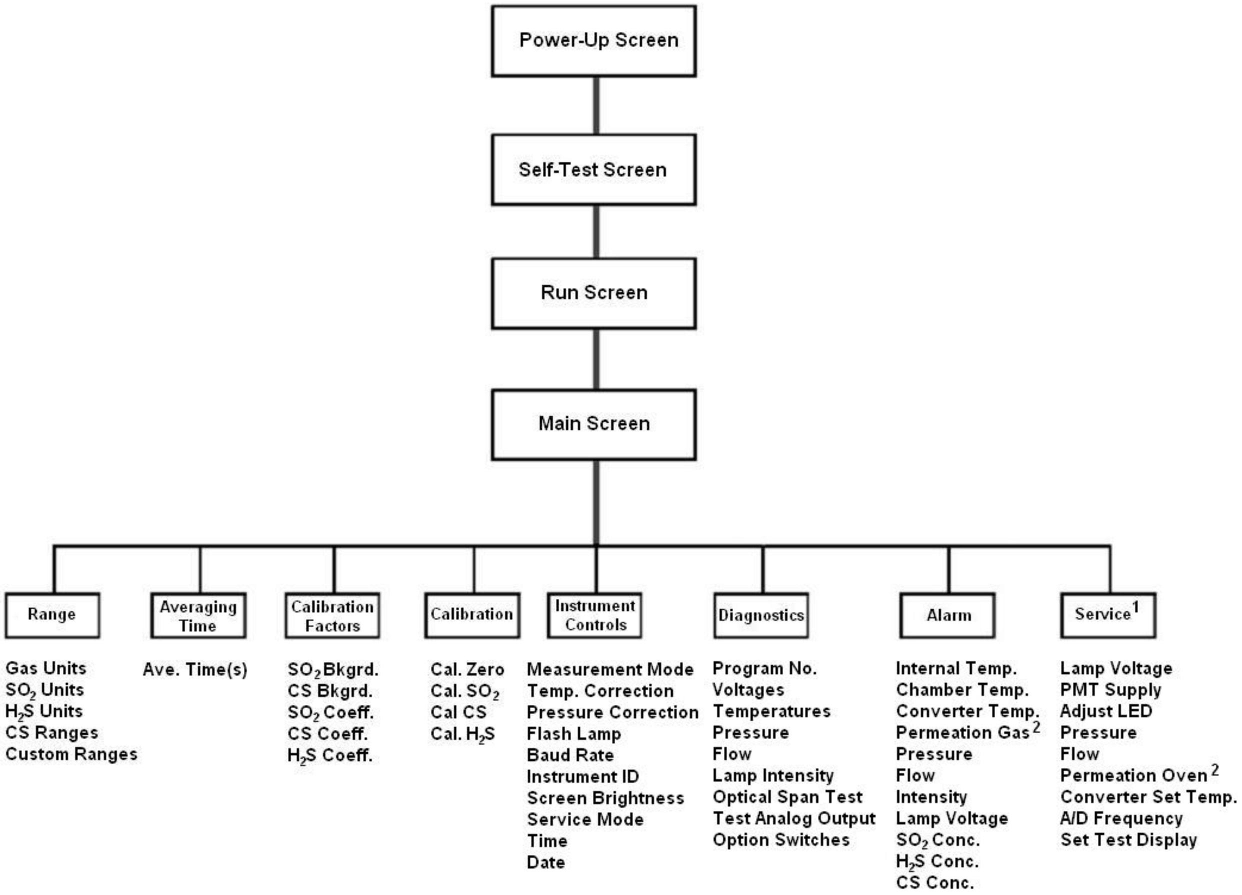

Figure 5. Partial flow chart of the TEC 450I menu from the instrument manual. Notes: 1 – Option only appears when the Service Mode is ON. 2 – Appears only when optional Permeation Oven is installed.

9.1.8. For barn measurements:

9.1.8.1. The analyte (H_2S, SO_2, CS) measurement ranges for the 450I are from 0 to 10,000 ppb. The analyte measurement range settings for each site are listed in the QAPP.

9.1.8.2. Enter the analyzer's analog signal ranges (0 to 10 VDC) and H_2S and SO_2 measurement ranges into the DAQ table in the AirDAC software (SOP B2) so that concentration reading can be displayed, converted and recorded.

9.1.9. For open source measurements:

9.1.9.1. Using iPort software, set data logging settings in instrument

9.1.9.1.1. Under "Main Menu->Instrument Controls->Datalogging settings":

9.1.9.1.1.1. Set "Select SREC/LREC" to "LREC"

9.1.9.1.1.2. Under "Select Content", make sure the following appears

"FIELD 1	H2S"	
"FIELD 2	SO2"	
"FIELD 3	INTT"	(corresponds to INT TEMP)
"FIELD 4	RCTT"	(corresponds to CHAMBER TEMP)
"FIELD 5	CONVT"	(corresponds to H2S CNV TEMP)
"FIELD 6	PRES"	(corresponds to CHAMBER PRES)
"FIELD 7	SMPLFL"	(corresponds to SAMPLE FLOW)
"FIELD 8	PMTV"	(corresponds to PMT VOLTS)
"FIELD 9	LMPV"	(corresponds to FLASH VOLTS)
"FIELD 10	LMPI"	(corresponds to FLASH REF)
"FIELD 11	NONE"	
……….		
"FIELD 32	NONE"	

9.1.9.1.1.3. Select any fields that are incorrect and modify as necessary. The item type for fields 1 and 2 is "CONCENTRATIONS" while that for the remaining 8 fields is "OTHER MEASUREMENTS"

9.1.9.1.1.4. *If changes were made to any of the above fields and* ***if all data on the instrument have been saved to the LAN:*** Go to "Main Menu->Instrument Controls->Datalogging Settings->Commit Content"; You will be asked to confirm that you want to commit content. <u>Only say "YES" if you are positive that all data logged on the analyzer have been saved</u>

9.1.9.1.1.5. Check configuration of the data logging at "Main Menu->Instrument Controls->Datalogging Settings->Configure Data logging"
-LOGGING PERIOD, MIN should be set to 1 MIN
-MEMORY ALLOCATION SHOULD BE SET TO 100%
-DATA TREATMENT should be set to AVG

9.1.9.1.1.6. Check the time zone setting; "Main Menu->Instrument Controls->Timezone"; should be set to UTC(GMT).

9.1.9.1.1.7. Set Ethernet communications at "Main Menu->Instrument Controls->Communication Settings->TCP/IP Settings->"
->USE DHCP: OFF
->IP ADDR: 192.168.0.15
->NETMASK: 255.255.255.0
->GATEWAY: 192.168.0.1
->NTP Server: 132.239.1.6

9.1.9.1.1.8. If any value is modified, turn the instrument off and back on again.

9.1.9.2. Using the iPort software, prepare instrument for transmission and storage of the analyzer's quality assurance and gas concentration measurements

9.1.9.2.1. Under "File->Preferences>instrument":

9.1.9.2.1.1. Set "size" to FULL

9.1.9.2.1.2. Set "Data Record Loading" to "Save to File" and "Create"

9.1.9.2.2. Under "Comm->Connect", assure settings are:
Location: H2Sanalyzer
Com: (set to correct value)

Baud Rate: 115200
Len: 8
Stop: 1
Parity: N
Handshake: None
Polling Config: 45 (this is the instrument ID)

9.1.9.2.3. Click on “OK” and respond “YES” to attach instrument.

9.1.9.2.4. Real-time data file save is set up under “Instrument->Load Records”: Click on “Real time” and click “Save to file”. Remove dash and spaces from the default file name (before the date and before the time compoents) and add the path and site code before the filename (e.g. C:\NAEMS\Data\OK4A\Period3\H2S\OK4A), and click “OK”

9.1.9.3. Verify that the output file is being produced in the desired location and check the contents by right clicking and opening with ‘Windows Notepad’. File should appear as:

```
;;
;; C:\NAEMS\Data\450I0103082156.dat Thu Jan 03 21:57:05 2008
;;
;; Model 450I- (prog iSeries 450I 01.05.06.165)
;;
Time   Date    Flags      h2s      so2     intt     rctt    convt     pres   smplfl     pmtv     lmpv     lmpi
14:53  01-03-08 LL------    1.052  9.36528  10.8132  32.8277   322.29  661.186  1.06992 -647.131  808.951       89
14:54  01-03-08 LL------  1.48701  8.50626  10.9028  33.1631  324.389  656.023  1.06526 -647.131   809.76       88
14:55  01-03-08 LL------  1.40748  7.61518  11.0148  33.4469  327.276  663.312  1.07233 -647.131  809.356       87
14:56  01-03-08 LL------ 0.247904  7.33171  11.1044  33.8854  326.751  658.149  1.06647 -647.131  810.973       88
14:57  01-03-08 LL------ 0.142362  7.49943  11.2164   34.066  323.865  663.312  1.07233 -647.131  808.143       88
14:58  01-03-08 LL------ 0.912892  7.91842  11.2612  34.1692  322.552  656.023  1.06492 -646.761  809.356       89
14:59  01-03-08 LL------ 0.957739  8.52361  11.3956  34.4788  325.177  661.186  1.07026 -647.131  808.547       89
15:02  01-03-08 LL---LL-        0        0   11.642   35.132  323.602  661.489  1.07164 -647.131  808.547       88
15:03  01-03-08 LL------        0        0   11.754   35.352  323.077  655.719  1.06544 -646.761  807.738       88
```

9.2. Gas Analyzer Calibration

9.2.1. Reference calibration gases

9.2.1.1. Sulfur Dioxide (SO_2) in N_2 - exact composition as specified in the QAPP.

9.2.1.2. Hydrogen Sulfide (H_2S) in N_2 or air - exact composition as specified in the QAPP.

9.2.1.3. Zero air, also referred to as Continuous Emission Monitoring (CEM) Zero Air.

9.2.2. For barn measurements, set AirDAC to “Gas Cal” (Gas Calibration) and calibrate the 450I following SOPs G8 and G9

9.2.3. For open source measurements:

9.2.3.1. Start the 450I gas analyzer and let it warm up for at least 30 minutes.

9.2.3.2. Use Environics Series 4040 Gas Dilution System or TEC 146I dilutor to dilute H_2S levels if necessary.

9.2.3.2.1. Install gas line from exhaust of 450I to vent into trailer or outside

9.2.3.2.2. Install gas line from output port of dilutor to sample port of 450I, with a tee in the line to vent excess to outside through a flowmeter; this prevents over-pressurizing the 450I and verifies sufficient flow for 450I sampling.

9.2.3.2.3. Open both gas cylinders (calibration gas and zero air) to a pressure of 20 psi, then

9.2.3.2.4. Initial calibration gas is 0 ppm H_2S.

9.2.3.2.5. If using the Environics dilutor:

9.2.3.2.5.1. Attach gas lines of H_2S cylinder and Zero Air cylinder to ports 2 and 1 (respectively) of Environics dilutor.

9.2.3.2.5.2. Set the H_2S concentration in the Environics dilutor program to the chosen concentration according to SOP G11.

9.2.3.2.6. If using the TEC 146I dilutor:

9.2.3.2.6.1. Attach gas lines from calibration cylinder to port A (or other programmed Port), and from the zero air cylinder to Zero Air Port.

9.2.3.2.6.1.1. Connect gas line from zero air cylinder (for 0 ppm H_2S) to sample port of 450I, with a tee in the line that vents exhaust (this prevents over-pressurizing the 450I).

9.2.3.2.6.2. Set the H_2S concentration on the diluter (not 0 ppm) to the chosen concentration according to SOP C3.

9.2.3.2.7. Open flow valve of regulator. Flow calibration gas through the 450I and wait 5-10 min. for the H_2S concentration reading on the 450I to stabilize.

9.2.3.2.8. Repeat sections 9.2.3.2.4, 9.2.3.2.6 (Environics diluter) or 9.2.3.2.5, 9.2.3.2.6 (TEC 146i diluter) using calibration gas at appropriate concentration.

9.2.3.2.8.1. Record pressure, flow rate, lamp intensity, and lamp voltage from 450I on a form similar to Table 3.

9.2.3.2.8.2. Once stabilized record H_2S output concentration from dilutor and H_2S concentration reading on the 450I.

9.2.3.3. If multipoint calibration, repeat section 9.2.3.2 for each target concentration, running a zero test in between span checks (the four concentrations are 3ppm, 2ppm, 1ppm, and 0.5ppm) in decreasing concentration and record results on form similar to Table 3.

9.2.3.3.1. Calculate linear regression of instrument response to concentration and apply to records as a post-process.

9.2.3.4. If calibration verification check, repeat section 9.2.3.2 for zero and 0.5 ppm concentrations respectively.

Table 3 – Example Multi-point calibration form for Open source instruments

450I Gas Analyzer Multi-Point Calibration

Serial #	Time	Pressure	Flow	Lamp Int.	Lamp Volt.	H2S cyl. Conc.	Dilutor Conc.	450I H2S reading
						0		
						3 0		
						0		
						2 0		
						0		
						1 0		
						0		
						0 5		
						0		

9.2.4. Recording information during a calibration or precision check

9.2.4.1. Record the analyzer's responses to both zero and reference (precision check) gases before and after adjusting the analyzer. The recorded responses before adjustment (as-found responses), are used to correct the data since the previous calibration or previous precision checks.

9.2.4.2. Record 450I pressure, sample flow, lamp intensity, and lamp voltage in the electronic field notes in a table like Table 4.

9.2.4.3. For barn measurements: Record the start / stop (read) times, analyzer, calibration gas, calibration gas concentration, analyzer reading, AirDAC concentration reading, and AirDAC signal in the field notes like in Table 5 (Precision Checks) or Table 6 (Calibration)

9.2.4.4. For open source measurements: Record the start / stop (read) times, analyzer, calibration gas, calibration gas concentration, analyzer reading, data file concentration reading in the field notes like in Table 7 (Calibration Verification/Precision Checks).

9.2.5. Introduce reference gas. The number of points and gas concentrations for multipoint calibrations and calibration verification/ precision checks are specified in the Quality Objectives of the QAPP.

9.2.5.1. Start flow of reference gas to the analyzer. See SOP G1 for delivery options

9.2.5.2. Record date and time in the electronic field notes in a table like Table 5.

9.2.5.3. Record pertinent gas delivery parameters (SOP G1).

9.2.5.4. Wait a minimum of 10 min for the display to stabilize (The minimum of 10 min corresponds with the sampling time used for each location).

9.2.5.5. Record the time and concentrations shown on the 450I display, and in AirDAC (barn measurements), on provided form and Excel® spreadsheet form (open area measurements) and in the electronic or paper field notes. Update the control chart in accordance with SOP Q1.

Table 4. Recording of TEC 450I operating parameters.

Date	TEC 450I Operating Parameters			
	Pressure,	Sample Flow	Lamp Intensity	Lamp Voltage
	mm Hg	L/min	Hz	V
3/07/2006	558.6	0.996	21173	1095
3/12/2006	557.5	1.040	20998	1094
“	“	“	“	“
“	“	“	“	“

9.2.5.6. If the stabilized concentration during a precision check deviates from the control chart baseline calibration value by 10% or more, conduct a multipoint calibration in accordance with SOP G9 (barn measurements) or Section 9.2.3.3 of this SOP (open area measurements).

9.2.5.7. Stop gas flow and record the time.

9.2.6. Repeat the steps in Section 9.2.5.for each reference gas.

9.2.7. Return analyzer's display back to the run screen by pressing run.

9.2.8. For barn measurements, return the GSS back to normal sampling mode by setting AirDAC to auto sample.

9.3. Converter Efficiency Check

9.3.1. Following Section 9.2, calibrate the SO_2 and CS channels with the SO_2 calibration gas. Then, calibrate the H_2S channel with the H_2S calibration gas.

9.3.2. Navigate to the "Calibration Factors" Menu (Fig. 5). The H_2S coefficient shown here is the converter efficiency.

9.3.2.1. For example, if the H_2S coefficient is 0.905, the converter efficiency is 90.5%.

9.4. Maintenance

9.4.1. Preventive maintenance is covered in Chapter 5 of the 450I Instrument Manual.

9.4.1.1. Clean the dust filters on the back of the analyzer and converter on a regular basis. This can range from weekly to monthly, depending on the dust level in the OFIS.

9.4.1.2. If the lamp voltage is equal to or greater than 1200 V, lower the voltage by adjusting the potentiometer (R28) on the lamp power supply board (See Chapter 7 of the Instrument Manual for Servicing), or replace the lamp.

9.4.1.3. Run a leak test if the sample flow rate, as reported by AirDAC (barn measurements) or iPORT (open area measurements), is < 0.9 L/min.

9.4.1.3.1. Block the bulkhead labeled "SAMPLE" on rear panel with a leak-tight cap then wait 5 to 10 min.

9.4.1.3.2. Check the sample flow and pressure readings. There should be zero flow and less than 160 mm Hg pressure. If not, check to see that none of the fittings or threads of the input lines are cracked or broken.

9.4.1.4. Check the capillary tubes for particulate deposits within the bore. Clean or replace as necessary.

9.4.1.5. Conduct a zero & precision span check before and after any maintenance, except for cleaning of the dust filter.

9.5. Troubleshooting

9.5.1. Troubleshooting guidelines are in Chapter 6 of the 450I manual.

9.5.1.1. Check wiring, power connections, and fuses if there is no signal or power.

9.5.1.2. Check flow path integrity if span concentration cannot be attained, or if flow rate is low.

9.5.1.3. If there is no or low flow, check the capillary tube or internal pump.

9.5.1.4. Replace lamp if the lamp intensity is varying widely (ranging quickly from 10,000 to 50,000 Hz).

9.6. Data acquisition, calculations & data reduction requirements

9.6.1. Barn measurements: Monitor a 0-10 VDC analog output signal using AirDAC (SOP B2).

9.6.2. Open area measurements: Monitor measurements using iPort software.

9.6.3. Report all data with 3 significant digits.

9.6.4. Follow SOP B4 to correct gas concentrations for calibration and air density.

9.7. Computer hardware & software

9.7.1. Barn measurements:

9.7.1.1. DAQ hardware (SOP B1)

9.7.1.2. AirDAC (SOP B2)

9.7.1.3. ARDIS (SOP B3)

- 9.7.1.4. CAPECAB (SOP B6)
- 9.7.2. Open area measurements:
  - 9.7.2.1. LAN server (SOP U4)
  - 9.7.2.2. iPort software

10. Data and Records Management

- 10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
- 10.2. Manage all data according to SOP B5 (barn measurements) or SOP D1 (open area measurements).
- 10.3. Document all data and information (e.g., sample collection method used) on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.
- 10.4. Overstrike all errors in writing with a single line, and initial and date all such corrections.
  - 10.4.1. Open area measurements:
    - 10.4.1.1. LAN server (SOP U4)
    - 10.4.1.2. iPort software

11. Quality Control and Quality Assurance

- 11.1. Conduct zero and one or more precision checks at the QAPP-specified frequency.
- 11.2. Conduct multipoint calibrations at the QAPP-specified frequency
- 11.3. Conduct a multipoint calibration whenever a precision check indicates a drift of > ±10% from the baseline calibration value, unless otherwise stated in the QAPP for a particular project.
- 11.4. Conduct a multipoint calibration whenever the zero check is > ±5% of full scale different than the baseline zero, unless otherwise stated in the QAPP for the particular project.
- 11.5. Check response time every month for barn measurements, and every six months for open area measurements.
- 11.6. In cases where SO_2 is not a primary measurement, weekly zero/precision checks with SO_2 are not necessary. In these cases, the QAPP will dictate the frequency of converter efficiency checks, and the converter efficiency that must be maintained.
- 11.7. Perform preventative maintenance every six months, according to the schedule provided in Chapter 5 of the 450I manual.
  - 11.7.1. Visually inspect for obvious visible defects (loose connections and/or fittings, cracked or clogged Teflon lines, and excessive dust accumulation.
  - 11.7.2. Inspect the fan filter located on the back of the instrument weekly; clean as needed.
  - 11.7.3. The schedule for replacing the sample particulate filter is found in the QAPP.
  - 11.7.4. Measure the gas analyzer inlet flow rate every six months.
  - 11.7.5. Check the lamp voltage under the diagnostics menu. If the lamp voltage is 1200 V or higher, replace the lamp or adjust its voltage.
  - 11.7.6. Leak check the sample line and flow components and fittings every six months.

11.8. If troubleshooting of the analyzer reveals particulate deposits in the capillaries, these must be replaced.

12. References

12.1. iPort Instruction Manual. 2007. *i*Port Instruction Manual. Communications software for iSeries and C Series Instruments. Part#102606-00. Thermo Fisher Scientific, Franklin, MA.
12.2. TFS 450I Manual. 2006. Model 450I Pulsed Fluorescence SO_2- H_2S-CS Analyzer Instruction Manual. Part #103258-00. Thermo Fisher Scientific, Franklin, MA.
12.3. SOP B1. 2007. Data Acquisition and Control Hardware. Standard Operating Procedure B1, v. 1.0. Purdue Ag Air Quality Lab.
12.4. SOP B2. 2007. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B, v. 1.02. Purdue Ag Air Quality Lab.
12.5. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3, v. 0.0. Purdue Ag Air Quality Lab.
12.6. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5, v. 0.0. Purdue Ag Air Quality Lab.
12.7. SOP B6. 2007. Data Processing Software (CAPECAB). Standard Operating Procedure B6, v. 1.0. Purdue Ag Air Quality Lab.
12.8. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1, v. 0.0. Purdue Ag Air Quality Lab.
12.9. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2, v. 0.0. Purdue Ag Air Quality Lab.
12.10. SOP G7. 2008. Use of the INNOVA 1412 Photoacoustic Multi-Gas Monitor. Standard Operating Procedure G7, v. 1.0. Purdue Ag Air Quality Lab.
12.11. SOP G8. 2007. Multi-Point Calibration of Gas Analyzers. Standard Operating Procedure G8, v. 1.0. Purdue Ag Air Quality Lab.
12.12. SOP G9. 2006. Zero and Precision Checks of Gas Analyzers. Standard Operating Procedure G9, v. 0.0. Purdue Ag Air Quality Lab.
12.13. SOP G11. 2007. Operation of the Environics® Computerized Gas Dilution System. Standard Operating Procedure G11, v. 1.0. Purdue Ag Air Quality Lab.
12.14. SOP Q1. 2007. Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1, v. 1.0. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturer: Thermo Fisher Scientific (www.thermo.com), 8 West Forge Parkway, Franklin, MA 02038, Technical Support: 1-866-282-0430
13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

Table 5. TEC 450I Analyzer Precision Check - Barn Measurements.

Precision Checks							
3/12/2006				Concentration	Instrument	Lab View	Signal
Started	Stopped	Instrument	Gas	ppb	Reading	ppm /ppb	vdc or mA
4/28/2006 14:05	4/28/2006 14:15	TEC 450I (H2S)	CEM Zero	0	-3.1	2.55	0.0005
4/28/2006 14:05	4/28/2006 14:15	TEC 450I (SO2)	CEM Zero	0	0	0.98	0.0008
4/28/2006 14:16	4/28/2006 14:26	TEC 450I (H2S)	H2S	2080	2090	2101.22	2.090
4/28/2006 14:16	4/28/2006 14:26	TEC 450I (SO2)	H2S	2080	10	10.78	0.011
4/28/2006 14:27	4/28/2006 14:37	TEC 450I (H2S)	SO2	1900	-106	-107.74	-0.109
4/28/2006 14:27	4/28/2006 14:37	TEC 450I (SO2)	SO2	1900	1907	1904.71	1.912

Table 6. TEC 450I Analyzer Calibration Check- Barn Measurements.

Calibration (H2S)							
8/9/2005				Concentration	Instrument	Lab View	Signal
Started	Stopped	Instrument / Comments	Gas	ppb	Reading	ppb	vdc
8/9/2005 8:55	8/9/2005 9:10	TEC 450I	CEM Zero	0	-33	-38	0.059
8/9/2005 9:11	8/9/2005 9:22		H2S	4370	4570	4551	9.091
8/9/2005 9:23	8/9/2005 9:35	Recorded reading	CEM Zero	0	-25.7	-33	-0.049
	8/9/2005 9:37	Zero-ed instrument		0			
	8/9/2005 9:39	Recorded reading (9:39:19)		0	0	0	0.001
8/9/2005 9:11	8/9/2005 9:22	Recorded reading	H2S	4370	4540	4536	9.071
	8/9/2005 9:52	Adjusted instrument to H2S span of 4370 ppb					
	8/9/2005 9:53	Recorded reading (9:53:08)			4370	4371	8.741
8/9/2005 9:54	8/9/2005 10:06		CEM Zero	0	3.6	5.0	0.011
8/9/2005 10:06	8/9/2005 10:17		H2S	4370	4370	4376	8.751
8/9/2005 10:17	8/9/2005 10:28		CEM Zero	0	0.4	0	0.001
8/9/2005 10:28	8/9/2005 10:39		H2S	4370	4420	4416	8.831
8/9/2005 11:19	8/9/2005 11:29	Baseline	CEM Zero	0	-1.6	-2	0.001
8/9/2005 11:29	8/9/2005 11:39	Baseline	H2S	4370	4380	4361	8.771

Table 7. TEC 450I Analyzer Calibration Verification Check- Open Area Measurements.

3/12/2006			Concentration	Instrument Reading	Deviation from baseline	Site FOS
Started	Stopped	Gas	ppb			
4/28/2006 14:05	4/28/2006 14:15	CEM Zero	0	-3.1		
4/28/2006 14:05	4/28/2006 14:15	CEM Zero	0	0		
4/28/2006 14:16	4/28/2006 14:26	H2S	2080	2090		
4/28/2006 14:16	4/28/2006 14:26	H2S	2080	10		

MEASUREMENT OF METHANE AND NON-METHANE HYDROCARBONS WITH THE THERMO ELECTRON MODEL 55C ANALYZER

Standard Operating Procedure (SOP) G6

MEASUREMENT OF METHANE AND NON-METHANE HYDROCARBONS WITH THE THERMO ELECTRON MODEL 55C ANALYZER

Standard Operating Procedure (SOP) G6

Prepared by
Bill W. Bogan and Claude A. Diehl

Reviewed by
Albert J. Heber

Effective Date: November 6, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The purpose of this procedure is to present the methodology and instrumentation used to measure automatically and sequentially concentrations of methane and non-methane hydrocarbons (NMHC) at animal feeding operations (AFO), specifically at barns.
1.2. This procedure applies only to the Thermo Electron Corporation (TEC) Model 55C Methane and Non-Methane Hydrocarbons (NMHC) Analyzer.
1.3. The TEC Model 55C NMHC analyzer uses automated gas chromatographic (GC) method that is useful for measuring both methane and NMHC at low concentrations in a short time and a wide measurement range.
1.4. The detection limit of the method is 20 ppb for methane and 50 ppb for NMHC (as propane).
1.5. The range is from 0 to 2000 ppm
1.6. The analysis time is 70 s.

2. Summary of Method

The Thermo Electron Model 55C is a back-flush gas chromatography (GC) system which provides automated measurement of both methane and non-methane hydrocarbons. The back-flush GC method employed by the Model 55C is unique in that it provides a direct, accurate measurement of non-methane concentrations, even when these are present at low levels in the presence of methane at much higher concentrations. The Model 55C is an automated batch analyzer which repeatedly collects and analyzes small amounts of the sample stream drawn in by the pump.

The Model 55C's measurement of methane and non-methane hydrocarbons utilizes a proprietary gas chromatography column, developed specifically for this application, which is capable of achieving complete separation of methane from all other hydrocarbons, including C_2 compounds. Due to its low molecular weight and high volatility, methane moves faster than other organic compounds and is the first to emerge from the opposite end of the column. Upon leaving the column, the methane flows to the flame ionization detector, or FID, which uses a hydrogen flame to ionize organic molecules in the carrier gas. The methane is measured by the FID and its signal is converted into a concentration by comparison with the signal produced by a calibration gas. Once the methane peak has been detected, the flow of carrier gas through the column is reversed, and non-methane hydrocarbons remaining on the column are "back-flushed" out and carried to the FID for measurement.

As the NMHCs reach the FID, they create a signal that is proportional to the total NMHC concentration and can be converted to a ppm reading by comparison with the signal generated by a known standard. If the FID signal is continuously monitored with a chart recorder, the output will create a chromatogram showing one peak for methane (which reaches a maximum approximately 17 s after injection), and a second peak that represents the combined NMHC. The NMHC peak will generally be lower and wider than the methane peak, and its retention times can vary somewhat depending on operating conditions and sample composition. The total time required for analysis of one sample is about 70 s.

3. Definitions of Terms and Acronyms

3.1.	NMHC	Non-methane hydrocarbons
3.2.	DAC	Data acquisition and control
3.3.	FID	Flame ionization detector
3.4.	GSS	Gas sampling system
3.5.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.6.	TEC	Thermo Electron Corporation

4. Health and Safety

4.1. Be careful when working with the electrical power connection.
4.2. Unplug the instrument before servicing any internal component.
4.3. The instrument is supplied with a three-wire grounding cord. Under no circumstance should this grounding system be defeated or tampered with.
4.4. During operation, the sample intake, sample bypass, and FID exhaust bulkheads are extremely hot. Use appropriate caution when working with a hot instrument.
4.5. Properly vent analyzer exhaust (FID exhaust and sample bypass) to avoid exposure to noxious gases
4.6. Be careful when lifting the analyzer. The analyzer weighs 60 lb.

5. Cautions

5.1. Do not apply power to the Model 55C until all other installation procedures have been completed. An incorrect start-up sequence could damage the instrument.
5.2. Some internal components can be damaged by the discharge of static electricity. To avoid damaging internal components, wear an antistatic wrist strap that is properly connected to earth ground when servicing any internal components of the 55C. If an antistatic wrist strap is not available, be sure to discharge static electricity by touching a grounded metal object before touching any internal components. Note that when the 55C is unplugged, its chassis is not grounded.
5.3. Support gases, regulators, gas lines, gas scrubbers, and fittings must be carefully selected to provide the cleanest possible support gases to the instrument. Use of inappropriate gas supplies or hardware will have an adverse affect on performance (e.g. cause baseline instabilities that interfere with the detection of low hydrocarbon concentrations), and can contaminate the instrument with oils or other organic compounds.
  5.3.1. Use only regulators with stainless steel diaphragms (generally referred to as high purity regulators). Do not use general purpose, industrial, or welding regulators that usually have a rubber or polymeric diaphragm. Polymeric diaphragms tend to give off organic compounds.
  5.3.2. Use only pre-cleaned, GC-grade copper or stainless steel tubing, purchased from a GC supply house. Tubing can also be coated with non-reactive SilcoSteel coating. Gas lines made of plastic materials such as Teflon® can give off organic vapors and are sometimes permeable to permanent gases.

5.3.3. Use 1/4″ OD tubing and compression fittings (Gyrolock). It is important to use compression fittings. Do not mix different types of fittings, as this will cause leaks and unreliable performance of the TEC 55C analyzer.

5.3.4. Use either high-grade support gases (Section 8.5), or use appropriate gas scrubbers. Trace oxygen, hydrocarbons, and water vapor cause baseline instability and poor analyzer performance. Gas scrubbers are used to remove traces of oxygen, hydrocarbons, and water vapor from the support gases.

5.4. Actuator air must be delivered to the instrument at 40 to 45 psi. Air pressures in excess of 45 psi can reduce the service life of the valve actuator; pressures lower than 40 psi may cause erratic performance.

6. Interferences

6.1. Any hydrocarbon contamination of gases can lead to unstable baselines in the output chromatograph. Carrier gas must be completely free of hydrocarbons.

6.2. Depending upon composition of samples, it may be necessary to incorporate a delay so that other, non-hydrocarbon sample constituents can be flushed off the column to avoid interference with analyses of subsequent samples.

6.3. During calibration, methane concentration in span gas should never be less than approximately 1.5 ppm, as interference from oxygen can lead to inaccurate results.

6.4. Fluctuations of sample inlet pressures may cause problems with repeatability and accuracy of hydrocarbon measurements, unless the GSS is operating properly, and the analyzer manifold is maintaining a constant pressure.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument before initiating the procedure.

7.2. Each analyst must read and understand the entire instrument manual and this SOP before operating the analyzer.

7.3. Personnel should also be trained to interpret the analyzer output signal, converted concentration data, and correction of concentrations based on calibration.

8. Equipment and Supplies

8.1. Methane/Non-Methane Analyzer (Model 55C, Thermo Electron Corporation).

8.2. Keep a copy of the 55C Instrument Manuals at each field location.

8.3. Keep the following spare parts at each remote site:

8.3.1. Fuse, Part No. 14938

8.3.2. Fuse, transformer fuse, Part No. 14011

8.3.3. O-rings, Part No. 11032

8.3.4. O-rings, Part No. 11030

8.3.5. O-rings, FID kit Part No. 14818

8.4. Keep the following spare parts in a central stock at PAAQL:

8.4.1. Fuse, Part No. 14938

- 8.4.2. Fuse, transformer fuse Part No. 14011
- 8.4.3. O-rings, Part No. 11032
- 8.4.4. O-rings, Part No. 11030
- 8.4.5. O-rings, FID kit Part No. 14818
- 8.4.6. Ignitor glow plug, Part No. 10981
- 8.4.7. Ignitor assembly, Part No. 15018

8.5. Pre-cleaned, 1/4″ OD stainless steel or copper GC-grade tubing

8.6. Compression fittings (e.g. Gyrolock)

8.7. The following grades of gases are specified:

- 8.7.1. Combustion Air – Hydrocarbon-free air: Must be <0.1 ppm hydrocarbons
- 8.7.2. Actuator Air – Zero air
- 8.7.3. FID Fuel – Hydrogen: 99.999% or higher purity as a fuel
- 8.7.4. Carrier Gas – Ultrahigh purity nitrogen: 99.9995% pure (CEM grade) or higher
- 8.7.5. Calibration Gas –Should be a mixture of methane (not less than 2 ppm) and propane (not less than 1 ppm) with an analytical accuracy of ±1%.

8.8. Appropriate regulators for each gas cylinder (SOP G2)

9. Procedure

9.1. Instrument Setup

- 9.1.1. When unpacking the Model 55C, save all packing material. If it is ever necessary to ship the instrument for service, the original packing material should be re-used. It is especially important to cap all gas fittings and to wrap the instrument in plastic before shipment to avoid contamination of the gas lines with packing foam.
- 9.1.2. Check the exterior of the analyzer carefully to assure it is free of visible defects or damage.
  - 9.1.2.1. Remove the caps or plugs that cover the gas fittings on the rear panel.
  - 9.1.2.2. Remove the instrument cover to expose the internal components
  - 9.1.2.3. Remove any packing material, check for possible shipping damage and ensure that all connectors and circuit boards are firmly attached
  - 9.1.2.4. Replace the instrument cover

9.2. Connect the air, fuel, and carrier gas lines from the regulators on their respective cylinders to the rear panel bulkheads using 1/4″ OD line (Section 5.3.2) and the compression fittings supplied with the instrument.

- 9.2.1. In some models there may be two air inlets. In this case, the air inlet in the upper right quarter of the panel supplies the FID and the air inlet in the lower left quarter supplies the rotary valve actuator.

9.3. Connect the sample line from the GSS analyzer manifold to the bulkhead fitting labeled “SAMPLE INLET” using the 1/4″ compression fitting that is provided.

9.4. The sample should be presented to the Model 55C at a stable pressure near normal atmospheric levels. Connect the 55C to the analyzer manifold of the GSS (SOP G1) to accomplish this. The instrument’s internal pump can work against a vacuum of about 10 in of water, and will draw sample through at least 100-ft of 1/4″ OD sample line. The length of tubing between the analyzer manifold and the analyzer itself will be less than 20 ft.

9.5. Connect the FID Exhaust (located in the lower-right corner of the rear panel next to the sample inlet) to a suitable vent. Use as short a line as possible. The diameter should be as large as possible to prevent pressurizing the FID. Since the exhaust contains steam, configure the line to slope away from the instrument to drain condensation.

9.6. Connect the "BY-PASS" port to a suitable vent. The connection should be as short as possible and should open at near-atmospheric pressure.

9.6.1. Do not connect the sample by-pass and the FID exhaust port to the same line.

9.6.2. Check the label on the rear panel to confirm that the instrument is properly configured for the local power supply, and use the supplied cord to connect the Model 55C to the appropriate outlet.

9.7. Instrument start-up

9.7.1. Turn on all gas cylinders and adjust cylinder regulators to the following pressures:

Fuel (hydrogen)	60 psi
Support air	45 psi
Carrier gas	60 psi
Span gas (calibration gas)	15 psi
Air drive valve actuator	45 psi

9.7.2. Slightly loosen each fitting at the rear of the instrument for about 30 s to bleed off air trapped in the lines and scrubbers, and the retighten the fittings.

9.7.3. Turn on the main power switch and note whether any error messages are reported. After a brief diagnostic test, the 55C will enter the "warm-up" mode. The instrument will require about 90 min to reach its full operating temperature. In order to avoid contamination of the sampling system, the pump automatically shuts off during part of the warm-up period.

9.7.4. While the instrument is warming up, check and adjust the carrier gas and air pressures using the digital display and pressure regulator controls located on the left side of the Model 55C front panel. The correct parameters are as follows:

Air	24.5 psi
Carrier	33.0 psi
Fuel	33.5 psi
Fuel type	H_2
Detector oven	175 ºC
Column oven	70 ºC

9.7.4.1. Note that the fuel pressure will read "0" during warm-up because the fuel solenoid is automatically closed.

9.7.5. When the instrument has stabilized at the correct operating temperature, the fuel solenoid will automatically open and the Model 55C will attempt to light the FID.

9.7.5.1. If the ignition fails, the fuel will be shut off, and the front screen will prompt the user to press "ENTER" to try again.

    - 9.7.5.2. During the ignition cycle, check the fuel pressure, and if necessary, adjust to match the value shown in the table above.
    - 9.7.5.3. If the FID fails to light after repeated attempts, see the troubleshooting instructions in Chapter 5 of the instrument manual.
  - 9.7.6. Turn the pump on using the switch on the front panel, and then press the RUN button to start automatic analyses using the factory entered parameters and calibration.
- 9.8. Column Conditioning and Initial Burn-in
  - 9.8.1. Run the built-in column conditioning routine after the start-up procedure. The column conditioning procedure is as follows:
    - 9.8.1.1. Press the “MENU” key to interrupt normal operation.
    - 9.8.1.2. After the Main Menu appears, use the “DOWN ARROW” key to move the cursor to item No.7, “SERVICE”. Press “ENTER”.
    - 9.8.1.3. Move the cursor down to item No. 4, “CONDITION COLUMN”, and press “ENTER.”.
    - 9.8.1.4. The instrument will raise the oven temperature for 8 h to condition the column and clean out any accumulated hydrocarbons. After 8 h, the instrument will return to normal operating temperatures.
- 9.9. Running test chromatograms
  - 9.9.1. Following installation and burn-in, it is advisable to obtain a series of test chromatograms to ensure that the Model 55C is operating correctly. Generate test chromatograms at the installation of a new column or new instrument, or the setup of the instrument at a new location. In order to obtain chromatograms, it is necessary to connect the data acquisition (DAQ) system. Connect the DAQ system to channel 1 (pin 1: ground; pin 2: positive) of the Model 55 C analog voltage output to obtain chromatograms. In the initial test, the DAQ system’s sampling rate should be set to at least 10 Hz.
  - 9.9.2. Test chromatograms should include a blank, a zero air, and a span mix analysis, as follows:
    - 9.9.2.1. Blank: Disconnect the GSS line from the “SAMPLE INLET” fitting, turn off the pump, and run a series of five or more analysis cycles to inject and back-flush the carrier gas. During the first few cycles, the instrument may have methane and non-methane readings, but the chromatograms should appear flat after 2-3 cycles.
    - 9.9.2.2. Zero air: Attach a source of hydrocarbon-free air to the “SAMPLE INLET” fitting. Turn on the pump, then run a series of 5-7 analysis cycles. Be sure to include a vent, or atmospheric pressure dump, in the sampling system to prevent pressurizing the inlet. After a few cycles, the methane and non-methane peaks will go away, and only air peak remains. (Note: Many zero airs do not completely remove methane, thus it is normal to have a small methane peak near the air peak (oxygen peak)).
    - 9.9.2.3. Span gas: The mixture containing approximately 2 ppm each of methane and propane will provide a good test. The span gas should be attached to the “SAMPLE INLET” fitting, and the vent or atmospheric pressure dump should be included to prevent pressurizing the inlet.

9.9.3. Ideally, all test chromatograms should look similar, except for the presence or absence of peaks for methane, NMHCs, and oxygen (Fig. 1). Although spikes occurring at the time of injection and backflush are normal, the baseline should recover within 5 s and should otherwise appear flat and relatively noise free throughout the sample run. If test chromatograms do not meet these criteria, consult the troubleshooting guide in Chapter 5 of the instrument manual.

9.10. Operation

9.10.1. Establish the operating parameters using the menu-driven software, which can be accessed with the front panel or by using RS232 communication system.

9.10.2. The instrument has 6 modes: RUN, MENU, WARM-UP, CALIBRATION, CAL-CHECK, and MANUAL OPERATION.

9.10.2.1. RUN: RUN mode is the normal operation mode, in which the main display shows the analytical results of the most recent analysis cycle. Continuous or single-run operation can be selected from the software's "Run Parameters" menu. In single run, after one analysis, the machine stops. In continuous operation, the instrument automatically performs a series of measurements (at about 70 s per sample) until the user interrupts the run. Analysis may be interrupted by pressing the "MENU" button during a run cycle; at this point, "CANCELED" is displayed in the upper left corner of the main display screen.

9.10.2.2. MENU: Enter the MENU mode by pressing the "MENU" button. In the MENU mode, the instrument software can be accessed from the front panel, but the analytical cycle is stopped.

9.10.2.2.1. Do not press the "MENU" key during the measurement, as this will result in loss of data.

9.10.2.3. WARM-UP: From a cold start, the machine enters the WARM-UP mode until both ovens have stabilized at normal operating temperature. Press the "MENU" key to enter the operational parameters while the instrument is in this mode (Step 9.2.4). The total warm time is about 90 min.

9.10.2.4. CALIBRATION: The Model 55C can be switched into the CALIBRATION mode manually through the menu system, or automatically based on a user-defined calibration setup.

9.10.2.5. CALIBRATION CHECK: This mode is used to check the validity of the current calibration, and is accessed from the "CALIBRATION" menu. In a calibration check, the measurement results are compared to the expected results, but the instrument calibration factors are not adjusted.

9.10.2.6. MANUAL OPERATON: This mode is used in diagnostics and optimization. It is accessed through menu system. In this mode, the FID signal is shown on the fourth line of the main display, but no peak measurements are made.

9.10.3. Main Menu

9.10.3.1. Run Parameters

9.10.3.1.1. Operation mode: Set the operation mode to "Continuous", rather than "Single Measurement". In the latter mode, the instrument stops after each run and waits until the "RUN" button is pressed. Since it is being supplied with sample from the GSS, the former is the appropriate mode.

9.10.3.1.2. Instrument range: Used to set the measurement range for both the methane and non-methane channels. The two channels are adjusted independently and may be set to 0-20, 0-200 and 0-2000 ppm. Set AirDAC ranges for methane and non-methane hydrocarbons to match the instrument's ranges.

9.10.3.1.3. Recorder range: These are independent of the instrument range, and are continuously adjustable between 1 and 2000 ppm. The output voltage range for each analog signal is also adjustable, and may be set to any one of four different values.

9.10.3.1.4. Concentration alarms: Used to set the concentration values (in ppm) for methane and non-methane above which the instrument will trigger an alarm. The alarm system can turn on the internal speaker, and also includes a contact closure available on the rear panel.

9.10.3.1.5. Sampling time: For manual operation, the sampling time controls the pause time between pressing the RUN button and the sample injection. For continuous operation, the sampling time controls the pause between measurement cycles. Enter a value between 4 to 999 s that agrees with the sampling time specified in the QAPP or Site Monitoring Plan.

9.10.3.1.6. Response factor: Used to allow the user to set a multiplier that is automatically applied to the NMHC measurement before it is displayed or sent to the analog output. For most applications including measurements at CAFOs, set the response factor at 1.0.

9.10.3.1.7. Date and time: Use this feature to set the instrument's internal clock and calendar.

9.10.3.2. Calibration parameters

9.10.3.2.1. Gas concentration: Used to input the concentrations of methane and non-methane hydrocarbons in the calibration mixture.

9.10.3.2.2. Auto calibration: Allows user to determine whether or not automatic calibrations will be performed. Four options are available to choose.

9.10.3.2.3. Auto calibration check: Allows the operator to program the instrument to perform automatic span checks at some predetermined interval. Four options are available.

9.10.3.2.4. Auto verification: In most cases, set the auto verification to YES. This allows the instrument to verify a new calibration by automatically running a span check. Calibration cycles are repeated until two consecutive analyses agree to within 2%. If calibration repeatability is not achieved within 5 cycles, an error message and service alarm are generated, and the instrument continues to function using the last valid calibration. Data collected during consecutive cycles will be compared to determine calibration repeatability.

9.10.3.3. Calibration

9.10.3.3.1. Manual calibration: In this condition, the calibration solenoid opens, and the sampling system is filled with span gas. A complete measurement is then performed.

9.10.3.3.2. Manual calibration check: Used to check repeatability or accuracy of current calibration.

9.10.3.4. Utilities
- 9.10.3.4.1. Temperature: Used to display the FID temperature, the base temperature inside each oven, and the air temperature in the column oven.
- 9.10.3.4.2. Pressures: Used to display the pressure of current air, fuel, and carrier gas (in psi).
- 9.10.3.4.3. Ignite flame: When ignite flame is selected, the system can perform 7 attempts to light the flame; if the flame fails to light, an error message and fault alarm are displayed.
- 9.10.3.4.4. Ignite status: Indicates whether the flame is lit or not.
- 9.10.3.4.5. Clear service alarm: Selecting this menu option clears, or shuts off, all service alarms.
- 9.10.3.4.6. Speaker switch: Allows user to enable or disable the internal buzzer which is located on the mother board.
- 9.10.3.4.7. Column heater: Allows user to enable or disable the column heater.
- 9.10.3.4.8. Detector heater: Allows user to enable or disable the detector heater.

9.10.3.5. Diagnostics
- 9.10.3.5.1. Calibration: These items describe the most recent calibration, and are updated only at the end of a successful calibration cycle. Some of the calibration diagnostics are lost from memory when the instrument is turned off.
- 9.10.3.5.2. Run-time: These describe the FID operation, and present chromatographic data – such as the peak height and retention time - for the most recent analysis. Run-time diagnostics are updated at the end of each analysis, and are retained when the Model 55C is shut off.
- 9.10.3.5.3. System: System diagnostics are updated only in the event of a system failure (such as a flame out) and during the system test that occurs during power-up. System diagnostics include information such as the time of the most recent power-up and the number of flameouts that have occurred.
- 9.10.3.5.4. Set oven temperature: Allows the operator to adjust the set points for the detector and column oven heaters. The permitted range for the detector oven is 50 to 200°C, and the range for the column oven it is 50 to 150°C. These are set at the factory and should not be changed without consulting the TEI service department.
- 9.10.3.5.5. Open fuel valve: Allows user to manually open fuel valve while flame is out. This feature is useful for measuring the fuel flow rate, and for blowing the air out of the fuel system.
- 9.10.3.5.6. Calibration DACs: Allows the user to calibrate the analog outputs on the rear panel of the instrument.
- 9.10.3.5.7. Condition column: Selecting this menu option triggers a column conditioning sequence. This is useful for cleaning a new column or an old column which shows contamination.
- 9.10.3.5.8. Instrument ID: Allows user to adjust the software used by the RS-232 system. The identifier must be included in all RS232 commands, as described in Appendix B of the instrument manual.

9.10.3.6. Windows menu

9.10.3.6.1. Normally not accessed and not available. It may be activated by tuning DIP switch number 1 on the mother board on the “ON” position. When it is activated, it allows the valve actuator and data collection timing to be modified. Do not change any item listed under the Windows menu without first consulting the TEI service department (Section 13.1).

9.10.3.7. Crucial settings

9.10.3.7.1. Used this menu to modify the integration method, or to adjust the calibration of pressure sensors and/or the FID. It can be activated the same way as the Windows menu. Do not change any item listed under the Windows menu without first consulting the TEI service department (Section 13.1).

9.11. Troubleshooting

9.11.1. Troubleshooting guidelines are in Chapter 5 of the instrument manual; servicing instructions are contained in Chapter 6.

9.12. Data acquisition, calculations & data reduction requirements

9.12.1. A 4-20 mA analog output is monitored by AirDAC.

9.12.2. Report data with 3 significant digits.

9.12.3. Follow SOP B4 to correct gas concentrations for calibration and air density.

9.13. Computer hardware & software

9.13.1. AirDAC (SOP B2)

9.13.2. ARDIS (SOP B3)

9.13.3. CAPECAB (SOP B6)

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record with a bound record book designated for the method, which contains copies of the electronic record.

10.2. Manage all data according to SOPB5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. **Quality Control and Quality Assurance**

11.1. Conduct a Gas Analyzer Calibration at the frequency specified in the QAPP for the particular project.

11.1.1. The Model 55C uses a two-point calibration that incorporates a zero and a span. Zero readings are taken at times when no hydrocarbons are expected to elute form column during the span gas calibration. Calibration of the Model 55C is to be performed daily, according to the following procedure.

11.1.2. Enter the span gas concentrations for the methane and non-methane channels in the “Calibration Parameters” menu.

11.1.2.1. To avoid possible interference from oxygen, the methane span concentration must be ≥ 1.5 ppm.

11.1.2.2. To obtain good calibration repeatability, the NMHC concentration in the span gas must be > 0.05 ppm.

11.1.3. Select either the "Automatic Calibration" or "Calibration Check" option.

11.1.3.1. Set the "Auto Verification" option. For most applications, it should be set to "ON".

11.1.3.2. Return to the Main Menu and select "Calibration".

11.1.3.3. Ensure that the calibration gas cylinder is turned on. If the internal calibration solenoid is being used to control the gas flow, adjust the regulator pressure to about 15 psi.

11.1.3.3.1. If a span gas cylinder is connected directly to the instrument, an atmospheric pressure dump, or by-pass must be included to prevent pressuring the sample inlet.

11.1.3.3.2. When using a direct connection to a span cylinder, there must be an excess flow so that the span gas will not be diluted by ambient air or sample.

11.1.3.3.3. If using the internal pump, calibration gases must not be forced into the instrument at elevated pressure.

11.1.4. Select "Manual Calibration" to initiate the calibration.

11.1.5. During the initial calibration, check to be sure that the span gas flow rate is sufficient to flood the sampling line and prevent ambient air or sample air from being pulled into the instrument.

11.1.6. As a general rule, the instrument will be accurate to within 2% at sample concentrations ranging from 20% to 120% of the span concentrations.

11.2. The calibration gas should be certified using EPA protocol (1% certification).

11.3. Measure the gas analyzer inlet flow rate every six months.

11.4. Perform leak check in sample line and flow components and fittings every six months.

11.5. The instrument's guaranteed precision is 2% of reading, and its accuracy is 2% of span.

12. References

12.1. Model 55C Manual. 2002. Model 55C Direct Methane, Non-Methane Analyzer Instruction Manual. Thermo Electron Corporation, Franklin, PA

12.2. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

12.3. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.

12.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.5. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.

12.6. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.

12.7. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.
12.8. SOP G8. 2006. Multi-Point Calibration of Gas Analyzers. Standard Operating Procedure G8. Purdue Ag Air Quality Lab.
12.9. SOP G9. 2006. Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.
12.10. SOP Q1. 2006. Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturer Contact Information:
Thermo Environmental Instruments (www.thermoei.com)
8 West Forge Parkway
Franklin, MA 02038
Tel: (508) 520-0430 ext. 6812
Fax: (508) 520-1460
Sales: Souphin A. Sithideth, Inside Sales Engineer, e6812, E-Mail: SSithideth@thermoei.com
Service: Barry Pepin, Service Engineer, e6908, E-Mail: Bpepin@thermoei.com

13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

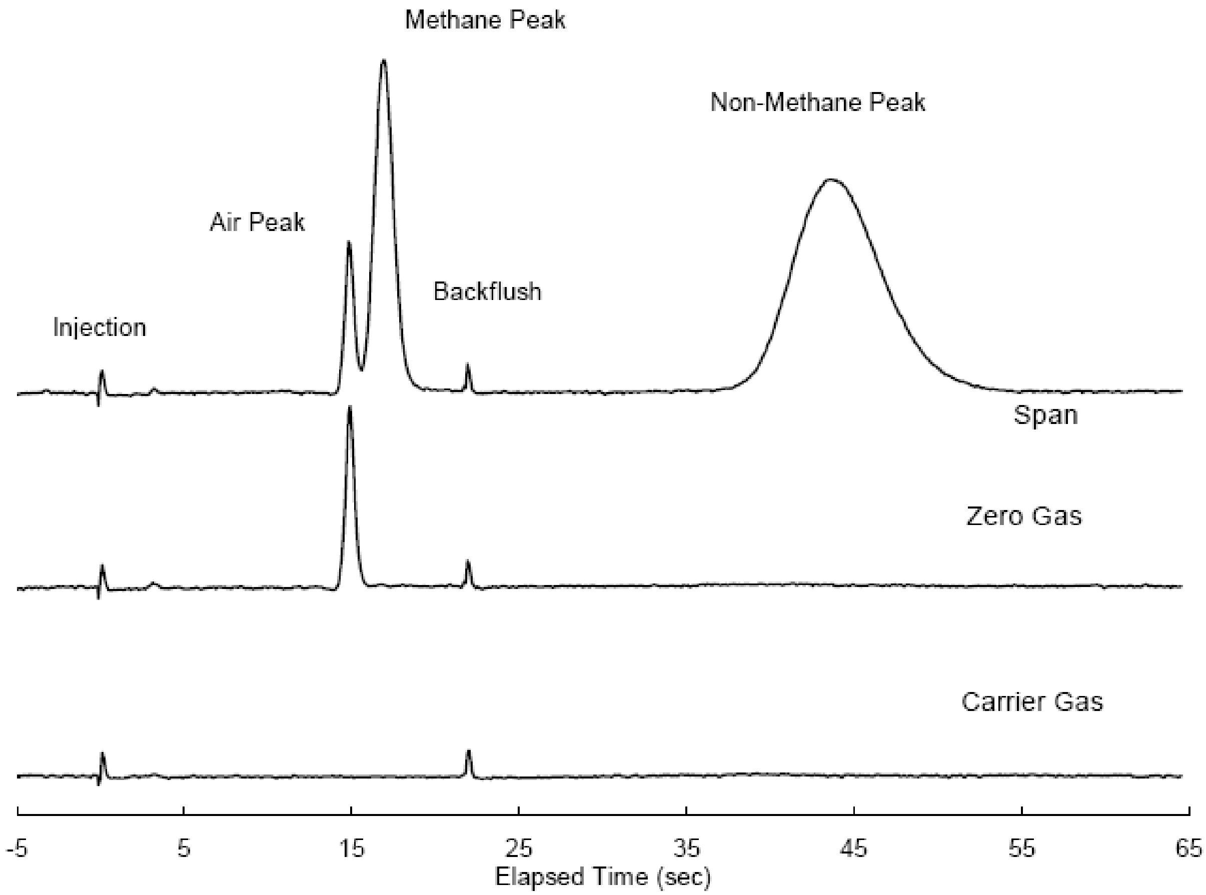

Figure 1. Appearance of normal test chromatograms obtained using the procedures detailed in Section 9.9.

USE OF THE INNOVA 1412 PHOTOACOUSTIC MULTI-GAS MONITOR

Standard Operating Procedure (SOP) G7

USE OF THE INNOVA 1412 PHOTOACOUSTIC MULTI-GAS MONITOR

Standard Operating Procedure (SOP) G7

Prepared by
Congna Li and Bill W. Bogan

Reviewed by
Claude A. Diehl, Jerry Rutherford (California Instruments),
and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The purpose of this procedure is to present the methodology and instrumentation used to automatically and sequentially measure concentrations of various gases at confined animal feeding operations (CAFO), specifically, within the barns and other buildings, and around open sources such as corrals, manure lagoons, or storage basins.

1.2. The method described in this SOP is suitable for measurement of any gas which absorbs infrared (IR) radiation. Gas selectivity is achieved through the use of optical filters. Gases which can be measured through this method, and which are relevant to CAFOs, include:

- 1.2.1. Ammonia (NH_3)
- 1.2.2. Ethanol/methanol (total alcohols)
- 1.2.3. Acetic acid
- 1.2.4. Acetaldehyde
- 1.2.5. Dimethyl sulfide
- 1.2.6. Carbon dioxide
- 1.2.7. Methane
- 1.2.8. Phenol
- 1.2.9. Total VOC

1.3. The QAPP for a particular project will specify which gases will actually be measured.

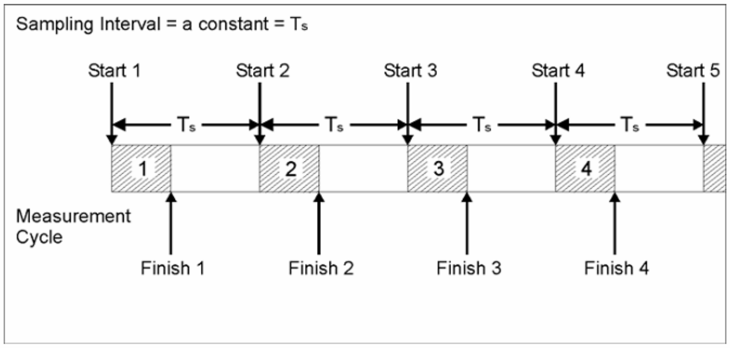
1.4. This procedure applies only to the INNOVA Model 1412 Photoacoustic Monitor.

- 1.4.1. The minimum detection limit (MDL) of this instrument is gas-dependent, but is typically in the ppb region. It is often below 100 ppb, with the exception of ammonia, which has a minimum detection limit of 200 ppb.
- 1.4.2. The range is also gas-specific. The linear range for a given gas is typically from 1 to 10,000 times the MDL.
  - 1.4.2.1. For example, the Model 1412's linear range for ammonia is from 0.2 ppm (the MDL) to 2000 ppm.
- 1.4.3. The stated precision of the Model 1412 is 1% of measured value.
- 1.4.4. The instrument's stated response time (97%) to a step change in concentration is 12 s.

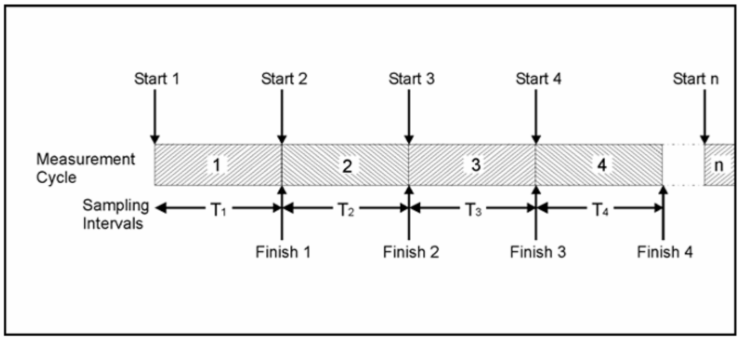
2. Summary of Method

The multi-gas monitor (INNOVA Model 1412, Innova AirTech Instruments, Ballerup, Denmark) is based on the photoacoustic infrared detection method. As shown in the schematic diagram in Fig. 1, a gas sample is drawn at a constant flow rate (in the case of the barns, from the GSS analyzer manifold), and introduced into an acoustic cell where it is exposed to pulsing infrared light of specific wavelength. If the sample contains the gas of interest, it will absorb an amount of infrared light that is proportional to the analyte gas concentration in the sample. When a gas absorbs infrared light, its temperature rises as its molecules increase in kinetic energy; this causes a pressure wave inside the photoacoustic cell. Pressure pulses, which are also proportional to the concentration of the analyte gas, thus correspond to the light pulses, and are detected by two sensitive microphones located inside the chamber. Almost any gas that absorbs infrared light can be measured by this method.

Gas analysis with the Model 1412 can be conducted either using set sampling intervals, or in continuous mode. Sampling interval is a measure of the time between the start of one measurement cycle and the start of the next measurement cycle. Therefore, if a measurement cycle (including readings of all gases being measured) takes 27 s, and the sampling interval is 1 min, then there will be 33 s before the next measurement cycle starts, as follows:



In continuous sampling mode, each measurement cycle is followed immediately by another similar measurement cycle, as below:



In either mode, a measurement cycle consists of the following steps:

- Measurement of the gas sample with each chosen individual optical filter (up to 5)
- Measurement of the gas sample with the water vapor optical filter
- Flushing the chamber & tubing and filling the chamber with the next gas sample

Gas selectivity is achieved through the use of optical filters. The Innova 1412's optical filter carousel can hold 5 optical filters for target gases, plus one for water vapor, thus allowing measurement of up to 5 gases and water vapor in a given air sample. Each individual optical filter rotates in front of the photoacoustic chamber, and pauses for the set sample integration time (SIT) before moving to the next filter. All filters rotate through once every measurement cycle. The MDL is gas-specific and filter wavelength-specific; examples include:

Acetic acid	40 ppb	Total TOC (reference propane)	20 ppb
Ammonia	200 ppb	Methane	100 ppb
Carbon dioxide	1500 ppb	Sulfur dioxide	300 ppb

Measurement accuracy is ensured by the Model 1412's ability to compensate for temperature and pressure fluctuations, water-vapor interference and interference from other IR-absorbing gases that are known to be present. Reliability of measurement results can be ensured by regular self-tests. The analysis time is dependent on the physical properties of the gas of interest, the number of gases being measured, the set-up of the instrument, the gas sampling system, and the sampling location. When a gas or a gas mixture is introduced to the analyzer, the response time can vary from approximately 13 s for one gas (or water vapor) to approximately 150 s if five gases plus water vapor are measured. The following table indicates in more detail the effect of analyzer configuration on analysis time:

Sample integration time, s	1	1	5	5	20
Water vapor measured?	no	yes	no	yes	yes
Number of gases	1	5	1	5	5
Flushing time, s	4	4	Auto (tube 1 m)	Auto (tube 1 m)	Auto (tube 1 m)
Analysis Time, s	**~13**	**~27**	**~25**	**~60**	**~150**

3. Definitions of Terms and Acronyms

AirDAC	Data Acquisition and Control software (SOP B2)
Analysis Time	The total time required to measure each gas's response to infrared light (SIT) and to flush the photoacoustic cell.
GSS	Gas sampling system (SOP G1)
IR	Infrared
LAN	Local area network
MDL	Minimum detection limit
NIST	National Institutes of Science and Technology
NMi	Netherlands Measurement Institute
PAAQL	Purdue Agricultural Air Quality Laboratory
PAML	Purdue Applied Meteorology Laboratory
PC	Personal computer
ppb	Parts per billion
ppm	Parts per million
QAPP	Quality Assurance Project Plan
SIT	Sample integration time

4. Health and Safety

4.1. Be careful when working with the analyzer's electrical power connection.

4.2. The IR source and analysis cell are very hot when the analyzer is operating. Do not attempt to service any internal components without allowing adequate cool-down time.

4.3. If used indoors (such as inside the OFIS). Properly vent the analyzer's exhaust to avoid exposure to noxious gases in the sample.

5. Interferences

5.1. Water absorbs IR light at most wavelengths, and is nearly always present in air samples. Thus, water will essentially always contribute to the total acoustic signal. The Model 1412 is permanently fitted with a special water-selective filter, which enables it to compensate for this interference.

5.2. By selecting different filters, this technique can also be used to cross-compensate for known interferents (i.e. gases which are not target analytes, but which are known to absorb IR at the wavelength(s) used to quantify one or more target compounds.

5.2.1. Possible interferent gases relevant to livestock barns, anaerobic treatment lagoons, manure storages, and related facilities (Schmidt et al, 2005; Summers, 2005) include the following (levels are based on detection limits in Innova AirTech Instruments' "Detection Limits Wall Chart" (Reference 12.3) for these gases at the same wavelength used for quantifying the given primary analyte):

5.2.1.1. **Ammonia** can be quantified at either of two wavelengths – 974 µm or 976 µm. The stated detection limit at each of these wavelengths is 200 ppb. Some of these compounds will interfere more at one wavelength (indicated in parentheses) and less (but still possibly significantly) at the other wavelength. If VOC characterization of the site indicates that any of these compounds are present above the indicated thresholds, it may be necessary to compensate for them in order to obtain accurate NH_3 data.

5.2.1.1.1. 2-butanone ≥ 500 ppb (976 µm)
5.2.1.1.2. Ethanol ≥ 60 ppb (974 µm)
5.2.1.1.3. Ethanolamine ≥ 110 ppb (974 µm)
5.2.1.1.4. Methanol ≥ 80 ppb (974 µm)
5.2.1.1.5. Phenol ≥ 400 ppb (974 µm)

5.2.1.2. **Ethanol/methanol** is optimally measured at 974 µm, with a detection limit of 80 ppb. Interferents at this wavelength include:

5.2.1.2.1. Ammonia ≥ 200 ppb
5.2.1.2.2. Ethanolamine ≥ 110 ppb
5.2.1.2.3. Phenol ≥ 400 ppb

5.2.1.3. **Acetic acid** is optimally measured at 970 µm. Its stated detection limit is 40 ppb. Interferents at this wavelength include:

5.2.1.3.1. Methanol ≥ 500 ppb

5.2.1.4. **Acetaldehyde** is optimally measured at 986 µm, with a detection limit of 80 ppb. Interferents at this wavelength include:

5.2.1.4.1. Dimethyl sulfide ≥ 400 ppb
5.2.1.4.2. Dimethylamine ≥ 40 ppb
5.2.1.4.3. Formaldehyde ≥ 40 ppb
5.2.1.4.4. Trimethylamine ≥ 20 ppb

5.2.1.5. **Dimethyl sulfide** is optimally measured at 936 µm. Its detection limit is 600 ppb at this wavelength. Interferents at this wavelength include:

5.2.1.5.1. Methanol ≥ 80 ppb

5.2.1.6. No obvious relevant interferents for **CO_2** (quantified at 983 µm) are evident. The stated diction limit for CO_2 is 3.4 ppm

5.2.1.7. **Methane** can be quantitated at 968 µm or 969 µm; however, the former of these is much more sensitive to interference from water vapor. When methane is quantified at 969 µm, it has a detection limit of 400 ppb, with the following possible interferents:

5.2.1.7.1. $H_2S \geq 14$ ppm

5.2.1.7.2. Acetone ≥ 70 ppb

5.2.1.8. **Phenol** is optimally measured at 971 µm. Its detection limit is 8 ppb. Interferents at this wavelength include:

5.2.1.8.1. m-cresol ≥ 50 ppb

5.2.1.8.2. Dimethylamine ≥ 200 ppb

5.2.1.8.3. Methyl methacrylate ≥ 20 ppb

5.2.1.8.4. $SO_2 \geq 400$ ppb

5.2.1.8.5. Trimethylamine ≥ 200 ppb

5.2.1.9. Total VOC is best measured at 987 µm, with a detection limit of 20 ppb. Since it is intended to measure all volatile organic hydrocarbons, no individual hydrocarbons can be considered interferents. Some oxygenated VOC will absorb at this wavelength; others will not. Ammonia and H_2S have negligible absorptions at 987 µm.

5.3. Certain gases require humidification in order to generate accurate calibration readings. This is needed to speed the relaxation (energy release) of the analyte molecules after they are excited by the IR light, by mediating the dispensation of energy to bulk fluid (gas). Without humidification, there will be significant downward drifting of the reading of the calibration gas, leading to inaccurate readings. An inline Nafion-based humidifier (Section 8.5) must be used (Section 9.4.3.3.1.3) with these gases.

5.3.1. Humidification is required for any calibration or span check with CO_2.

5.3.2. Humidification is required for methane if air is used as the diluent.

6. Cautions

6.1. When installing the RS-232 cable to the back of the gas analyzer monitor, ensure that both the monitor and the PC are switched off at the mains. Failure to do so may result in equipment being damaged.

6.2. Blown fuses in the monitor can indicate a serious fault in the analyzer; therefore, it is advisable to contact the Innova representative before changing the fuse.

6.3. Do not pressurize the instrument above 250 Pa (1 in. of water).

6.4. Avoid water condensation in the analyzer.

6.5. Do not allow any liquid to enter the analyzer's photoacoustic chamber.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the analyzer before initiating the procedure. Training requires about three hours.

7.2. Each analyst must read and understand the entire analyzer manual and this SOP before operating the Model 1412.

7.3. Personnel should also be trained to interpret the analyzer output signal, converted concentration data, and correction of concentrations based on calibration.

8. Equipment and Supplies

8.1. Multi-gas Photoacoustic Monitor (Model 1412, Innova AirTech Instruments, Ballerup, Denmark), with appropriate optical filters (as defined in the particular project's QAPP):
  8.1.1. UA0976 or 974 for ammonia
  8.1.2. UA0974 for ethanol/methanol
  8.1.3. UA0970 (or UA0971) for acetic acid
  8.1.4. UA0986 for acetaldehyde
  8.1.5. UA0936 for dimethyl sulfide
  8.1.6. UA0983 for carbon dioxide
  8.1.7. UA0968 for methane
  8.1.8. UA0971 for phenol
  8.1.9. UA0985 for nitrous oxide
  8.1.10. UA0984 for carbon monoxide
  8.1.11. UA0987 for total VOC (general hydrocarbon filter)
8.2. Rack and rack mounts
8.3. Data acquisition and control
  8.3.1. Barn applications: PAAQL data acquisition and control hardware (SOP B1), and AirDAC (SOP B2) and proprietary custom software to allow communication between INNOVA and AirDAC (Nexus Solutions, London, Ontario, Canada)
  8.3.2. Open-source applications: LAN Server computer in open-source trailer (SOP U5 or U7 for lagoon or corral sites, respectively), and LabVIEW software (National Instruments Corporation, Austin, TX)
8.4. Mounting post and post driver (for open-source applications – SOP U5 or U7)
8.5. Nafion humidifier (California Analytical Instruments Part # CAI-110-03-34)
8.6. Keep the following spare parts at each remote site and in central stocks at PAAQL and PAML:
  8.6.1. Threaded nuts (2x YM 0652)
  8.6.2. Swagelok stainless steel ¼" nuts and ferrules
  8.6.3. Gas Monitoring Software 7304 for Photoacoustic Multi-gas monitors 1412
  8.6.4. External filters
    8.6.4.1. (Recommended) stainless steel filter frit (10 µm, 25 mm)
    8.6.4.2. External fine air filters (CAII-F01) 100/pkg. (Millipore: Mitex Membrane Filter, PTFE, hydrophobic, 10 µm, 25 mm, white, plain; catalog number: LCW02500)
  8.6.5. Cables
    8.6.5.1. Modem cable (9 pin)
    8.6.5.2. RS-232 null modem cable (25 pin female/9 pin male)
    8.6.5.3. Power cable (cord) for the analyzer
  8.6.6. Tubing
    8.6.6.1. Teflon tubing (¼″ OD)
    8.6.6.2. UD 5037 Nafion tubing

8.6.7. Spare slow-blow (T) fuses with a rating of 2.5 A, 250 VAC, 5x20 mm, UL-approved (Innova Order Number: VF0087A)

8.6.8. Instruction manual, menu tree, and field guide for the Innova 1412 Photoacoustic Monitor

8.7. Keep the following spare parts in central stocks at PAAQL and PAML:

8.7.1. Optical filter locking springs (8x DL 3322)

9. Procedure

9.1. Installation

9.1.1. Check analyzer carefully to assure it is free of visible defects or damage.

9.1.2. Mounting options

9.1.2.1. For barn applications, securely mount the analyzer horizontally on the instrument rack in the OFIS.

9.1.2.2. For open-source applications, mount the instrument securely to a mounting post at a specified location downwind of the lagoon or other open source which is being monitored. See the Site Monitoring Plan to locate the exact location.

9.1.3. Install the gas monitoring software 7304 for the control of photoacoustic gas monitors 1412 and 1314, if it is not already installed.

9.1.4. Connect the gas analyzer monitor to the data acquisition PC.

9.1.4.1. Connect the 25-pin female cable (RS-232) to the RS-232 port on the Innova 1412. Connect the 9-pin modem cable to the RS-232 cable from the Innova 1412. Connect the null modem cable into the COM 1 port of the DAC computer.

9.1.4.2. Leave sufficient extra length to the tubing and cables such that the instrument rack can be moved a few feet to get access to the back of the analyzer.

9.1.5. Connect tubing to the Innova 1412

9.1.5.1. Connect the analyzer inlet to the gas source (e.g. the GSS analyzer manifold for barn applications) with the minimum length of ¼″ OD Teflon tube.

9.1.5.2. Connect the analyzer exhaust with a 3″ length of 4-mm tube that is connected to ¼″ ID PVC or other tubing. Connect the exhaust tube from the analyzer to the air exhaust of the OFIS.

9.1.6. Power up the analyzer, turn on its internal pump, switch to measurement mode and allow the analyzer to warm up for a minimum of 60 – 90 min before analysis. This is necessary to warm up the analysis cell, as conditions within the cell tend to stabilize more quickly (allowing stable readings) once the temperature inside the analysis cell is 15°C above the ambient room temperature.

9.2. Setting up Communication Parameters between the Model 1412 and PC

9.2.1. Using the push buttons on the front of the monitor and following the operation manual, set the communication parameters for the serial interface as follows:

Baud rate	9600
Stop bits	1
Data bits	7
Parity	Even
Hardwire mode	Leased line
Handshake type	Hardwire

9.2.2. Using the push buttons on the front of the monitor and follow the operation manual, set the text line terminator, print data log and print error log as follows to prevent communication errors:

Text line Terminator	CR-LF
Print Data Log	NO
Print Error Log	NO

9.2.3. Select the PC communication port

9.2.3.1. Start any one of the gas monitoring software 7304 options: Online, Offline, or Calibration.

9.2.3.2. Pull down the Task menu. Click on Communication. The analyzer can use COM port 1 through COM port 4.

9.2.3.3. Click on the radio push-button next to the correct port name. Refer to the PC manual if not sure which port the cable is connected to. COM Port 1 is used most of the time.

9.3. Set up and start a Monitoring Task using the gas monitor software 7304, and set the instrument parameters according to Table 1.

9.3.1. Measurement parameter set-up

9.3.1.1. Pull down the Task menu. Click on New to create a new database, or click on Open to use an existing database.

9.3.1.2. For a new database, click in the “Enter Name For” field of the database window and type in a desired name. For existing databases, click on the desired database name.

9.3.1.3. Click OK.

9.3.1.4. Pull down the Sequence menu. Click on Settings and the Setup window appears.

9.3.1.5. Click on the Sampling tab.

9.3.1.6. Click on the radio-button for the desired sampling mode. If Sampling Interval is selected, set the time to the correct value.

9.3.1.7. Click on the radio-button for the desired flushing mode.

9.3.1.7.1. If Auto is selected, set the correct tube length.

9.3.1.7.2. If Fixed Time is selected, set the desired chamber flushing time and the tube flushing time (recommended value: chamber flushing time, 8 s; tube flushing time, 3 s).

9.3.1.8. If water vapor and cross interference are required, check the appropriate box.

9.3.1.9. If average values are to be displayed on the gas monitor screen, click in the Average check box, and set the interval to the correct value.

9.3.1.10. Click on the Gas tab.

9.3.1.11. Click in the check box to the left of the desired filter.

9.3.1.12. Click in the field to the right of the selected filter and select the correct gas.

9.3.1.13. Repeat the above two steps until all the filters which are required for the measurements are selected and the correct names are displayed.

9.3.1.14. Click in the Sample Integration Time field and select the desired option.

9.3.1.15. Click on the Alarm tab and check to make sure that alarms are set to default.

9.3.1.16. Click on OK to complete the system setup.

Table 1. Appropriate settings for various instrument parameters for the INNOVA Model 1412.

Instrument Parameters	
Units	
Concentration Unit:	ppm
Length Unit:	ft
Temperature Unit:	°C
Pressure Unit:	mm Hg
Humidity Unit:	Tdew
Normalization Temperature	20.0°C
Sampling Mode	
Sample Continuously	Yes
Sampling Interval (If selected)*	1 min (barns), 200 s (open-source)
Flushing	
Auto	No
Tube Length	10 ft (barns), 0.5 ft (open-source)
Fixed Time	Yes
Chamber	8 s (barns), 13 s (open-source)
Tube	3 s
Compensation	
Water Interference	Yes
Cross Interference	Yes
Gas Monitor Display	
Average	No
Time (HH:MM)	00:10
Current Air Pressure	
Pressure	Measured by Instrument
Memory Use	
Store History	Yes
Gas Setup	
Gas	S.I.T.
Ammonia	2 s
Ethanol / Methanol	1 s
Acetic Acid	2 s
Acetaldehyde	2 s
Dimethyl Sulfide	1 s
Carbon Dioxide	1 s
Methane	1 s
Phenol	2-5 s
Total VOC	1s
Alarms	
All gases are set to “Default”	No Alarms Set

* Note: If “Sampling Interval” Mode is selected, set “Sample Continuously’ to “No”.

- 9.3.2. Start a monitoring task
  - 9.3.2.1. Pull down the Sequence menu and click on Start.
  - 9.3.2.2. In the "Enter Sequence Description" field, type in the name of the monitoring sequence. If no name is entered, the default name "Sequence 1" is used.
  - 9.3.2.3. To start the measurement immediately, click on the Now radio-button in the Start Time group.
  - 9.3.2.4. To delay the start, click on the Start At: radio-button, and define the start time in the Start Time group.
  - 9.3.2.5. To manually stop the measurement later, click on the None radio-button in the Stop Time group.
  - 9.3.2.6. To automatically stop the measurement by defining a stop time, click on the Stop at: radio-button in the Stop Time group and enter the time to stop.
  - 9.3.2.7. Press OK to start the monitoring task.
- 9.3.3. Stop a monitoring task
  - 9.3.3.1. If no pre-set monitoring period is defined, pull down the Sequence menu and click on Stop.
- 9.3.4. Displaying measurement results while monitoring
  - 9.3.4.1. Using the Online program, measurement data are displayed on screen as soon as they are available from the monitor. The data can be displayed in both a graphic window and a numeric window, simultaneously. Refer to the manual for detailed procedures for defining the graphic window and numeric window.
- 9.3.5. Displaying measurement results from a stored monitoring task
  - 9.3.5.1. Click on the Presentation program, and pull down the Task menu. Click on Open to view an existing database.
  - 9.3.5.2. In the database window, click on the desired database name.
  - 9.3.5.3. Click on OK. A window opens showing all the measurement values for the complete monitoring task. Refer to the manual for detailed procedures for defining the graphic window and numeric window.
- 9.3.6. Export measurement data as comma-delimited ASCII files
  - 9.3.6.1. Click on the Presentation program. Open the database to be exported.
  - 9.3.6.2. Pull down the Task menu and click on Export.
  - 9.3.6.3. Use the standard Windows browser, which appears on screen, to define the destination for the exported data.
  - 9.3.6.4. Type in the desired file name. All files have a .TXT extension.
  - 9.3.6.5. Click on Save.
  - 9.3.6.6. Use Microsoft Excel to open and process the saved file.

9.4. Gas Analyzer Calibration

- 9.4.1. The exact composition for each reference calibration gas is dependent upon the gases being monitored in a given project, and the concentrations expected at the site. Calibration gas compositions for a particular project will be specified in the QAPP for that project.
- 9.4.2. Calibrate Innova 1412 following SOPs G8 (multipoint calibrations) and G9 (zero/precision checks).

9.4.3. Calibrate the optical filters.

9.4.3.1. Calibrate the optical filters with the following steps: zero point calibration, humidity interference calibration, span calibration of CO_2 (if that filter is in the instrument), and span calibration of any other gases after the instrument has been dried with zero air or a clean dry source of nitrogen.

9.4.3.2. Before calibrating the optical filters:

9.4.3.2.1. Warm up the monitor for a period of 60-90 min in the measurement mode before a calibration task is started to reduce the time required for calibration.

9.4.3.2.2. Detach the air inlet tube from the existing sampling manifold. Close the gas sampling manifold with a plug.

9.4.3.2.3. Obtain a print-out of calibration data in the monitor by using the "Print Current Calibration" function. This will compare the "old" calibration factors with the "new" ones.

9.4.3.2.4. Check the calibration of each installed optical filter following the procedures described in the manual.

9.4.3.2.5. Verify that the installed optical filters have been entered correctly in the active set-up of the monitor.

9.4.3.3. Basic setup for calibration

9.4.3.3.1. Set up the calibration equipment according to Fig. 2. Connect three different lengths of Teflon tubing to a "Y"-piece.

9.4.3.3.1.1. Connect the tube attached to point 1 to the analyzer's air inlet.

9.4.3.3.1.2. Connect the tube attached to point 2 to a gas flow meter.

9.4.3.3.1.3. Connect the tube attached to point 3 to the cylinder of gas which is to be used during calibration. This connection should be direct if humidity is not to be included, or through a water bath (as shown in Fig. 3) if humidity interference calibration is being conducted. If the calibration is being done for CO_2 or methane, use a Teflon tube which has been cut into two segments, and with a Nafion humidifier inserted into it using the tubing couplers provided.

9.4.3.4. Preparation for humidity interference, zero, or span calibration

9.4.3.4.1. Verify the settings of the Model 1412's communication parameters are set to the values described in Section 9.2.1.

9.4.3.4.2. Make sure the text line terminator, print data log and print error log are set to the values described in Section 9.2.2.

9.4.3.4.3. Open the "Calibration" program and create a new calibration task.

9.4.3.5. Zero gas calibration

9.4.3.5.1. Close the regulator valve on the zero gas cylinder.

9.4.3.5.2. Open the main valve on the zero gas cylinder.

9.4.3.5.3. Open the "Calibration" program and choose "New" to create a new task.

9.4.3.5.4. Type in the desired task name and click "OK".

9.4.3.5.5. Pull down the "Sequence" menu and click "Settings".

9.4.3.5.6. Click on the "Calibration" tab, if it is not already at the front. Select the "Zero point" button.

9.4.3.5.7. Click on the "Gas" tab, click in the "Sample Integration Time" field, and make sure that SIT is set to the same as that used for monitoring (Section 9.3).

9.4.3.5.8. Click on the Sampling tab and set the flushing time. The flushing type and values should be set to the same as those used when monitoring. Click OK.

9.4.3.5.9. Insert the 1/4"-OD tubing from the zero gas cylinder into the flow meter mounted on the side of the instrument rack. Open the regulator valve to allow gas flow. Adjust regulator valve until vent airflow is about 2.5 L/min. Use the flow meter to measure the flow rate.

9.4.3.5.10. Pull down the "Sequence" menu, and click "Start". Record time and analyzer display in field notes.

9.4.3.5.11. After display has stabilized (typically 10 to 15 min), pull down the "Sequence" menu and click "Stop".

9.4.3.5.12. Close regulator and remove tubing from the zero gas cylinder.

9.4.3.6. Humidity interference calibration

9.4.3.6.1. Run the Teflon tube from the zero gas cylinder into a temperature-controlled water bath. The outlet tube from the water bath should flow into a separate, empty flask, which acts as a safety trap. The outlet line from this flask then enters the "Y" connector, and is split between the flow meter and monitor. See Fig. 3 for a diagram of this setup.

9.4.3.6.1.1. The temperature of the water bath and the safety flask should be at least 2°C below the ambient temperature of the room.

9.4.3.6.2. Pull down the "Sequence" menu and click "Settings".

9.4.3.6.3. Click on the "Calibration" tab, if it is not already at the front.

9.4.3.6.4. Click to select "Humidity Calibration" radio-button.

9.4.3.6.5. Only select Humidity Interference Calibration (All Filters). Do not select Perform Water Vapor Span Calibration.

9.4.3.6.6. Click on the "Gas" tab, click in the "Sample Integration Time" field, and select the desired time (Fast 1 s).

9.4.3.6.7. Click "OK".

9.4.3.6.8. Open the regulator valve to allow gas flow through the water bath and safety flask (Do not allow any liquid into the instrument).

9.4.3.6.9. Adjust regulator valve until vent airflow is about 2.5 L/min using a flow meter to measure the flow rate.

9.4.3.6.10. Pull down the "Sequence" menu and click "Start".

9.4.3.6.11. Allow the readout to stabilize (typically 10 to 15 min). Record time and analyzer display in field notes.

9.4.3.6.12. Pull down the "Sequence" menu; click on "Stop".

9.4.3.6.13. Close regulator and main valve and remove tubing from the zero gas cylinder.

9.4.3.7. Span gas calibration of CO_2 (if applicable)

9.4.3.7.1. Pull down the "Sequence" menu, and click "Settings".

9.4.3.7.2. Click on the "Calibration" tab, if it is not already at the front. Select the "Gas Span Calibration" button.

9.4.3.7.3. Click in the "Active Filter" field, select "Carbon Dioxide", or other gas as appropriate. Check "Perform Cross Interference Calibration". Input the concentration of the analyte in the gas which is being used.

9.4.3.7.4. Click on the "Gas" tab, click in the "Sample Integration Time" field, and select the desired time (the same as that used when monitoring). Click "OK".

9.4.3.7.5. Insert the ¼″ OD tubing from the gas cylinder into the flow meter mounted on the side of the instrument rack. Open the regulator valve to allow gas flow. Adjust regulator valve until vent airflow is about 2.5 L/min, using the flow meter to measure the flow rate.

9.4.3.7.6. Pull down the “Sequence” menu, and click “Start”**.** Record time and analyzer display in field notes.

9.4.3.7.7. After the display has stabilized (typically 10 to 15 min), pull down the “Sequence” menu and click “Stop”.

9.4.3.7.8. Close regulator and remove tubing from the gas cylinder.

9.4.3.8. Span gas calibration for other gases

9.4.3.8.1. Set the analyzer to measure water vapor only

9.4.3.8.2. Flow dry nitrogen or CEM zero air through the analyzer until the water vapor measurement is reading -58 to -60 for Tdew°C.

9.4.3.8.3. Pull down the “Sequence” menu, and click “Settings”.

9.4.3.8.4. Click on the “Calibration” tab, if it is not already at the front. Select the “Gas Span Calibration” button.

9.4.3.8.5. Click in the “Active Filter” field, select “Ammonia”, or other gas as appropriate. Check “Perform Cross Interference Calibration”. Input the concentration of the analyte in the gas which is being used.

9.4.3.8.6. Click on the “Gas” tab, click in the “Sample Integration Time” field, and select the desired time (have to be the same as those used when monitoring). Click “OK”.

9.4.3.8.7. Insert the ¼″ OD tubing from the gas cylinder into the flow meter mounted on the side of the instrument rack. Open the regulator valve to allow gas flow. Adjust regulator valve until vent airflow is about 2.5 L/min using a flow meter to measure the flow rate.

9.4.3.8.8. Pull down the “Sequence” menu, and click “Start”**.** Record time and analyzer display in field notes.

9.4.3.8.9. After display has stabilized (typically 10 to 15 min), pull down the “Sequence” menu and click “Stop”.

9.4.3.8.10. Close regulator and remove tubing from the gas cylinder (Repeat Sections 9.4.3.7.1 through 9.4.3.7.8 for the other gases).

9.4.3.9. Calculating and downloading Calibration Factors

9.4.3.9.1. While the raw measurement data are still displayed on the screen, open the “Cursor Values” dialogue box.

9.4.3.9.2. Use two cursors and the statistical data (displayed in the Cursor Values dialogue box) to locate a suitable range of data. All values in the selected interval should be very stable, and the temperature should be above 40°C.

9.4.3.9.3. When the desired region is between the cursors, pull down the “Sequence” menu, and click on “Mark Interval”.

9.4.3.9.4. Select and mark all the intervals for every calibration.

9.4.3.9.5. Pull down the “Value” menu, and click on “Calculate”. When the calculation(s) is complete, a “Calculation Finished” dialogue box is displayed.

9.4.3.9.6. Pull down the “Values” menu, and click on “Download”. The “Download” dialogue box is displayed.

- 9.4.3.9.7. Select the “Zero Point” tab, and set ticks in the appropriate check boxes, depending on which gas (and/or water vapor) calibrations were just run.
- 9.4.3.9.8. Repeat the above two steps in the “Humidity” and “Gas” tabs.
- 9.4.3.9.9. Click “OK” to download the calibration factors to the monitor.
- 9.4.3.10. After calibration is complete, reattach the Model 1412 to the GSS, and close the main valves on all gas cylinders.
- 9.4.4. Data acquisition, calculations & data reduction requirements
  - 9.4.4.1. Report data with three significant digits.
  - 9.4.4.2. Follow SOP B4 to correct gas concentrations for calibration and air density.
- 9.4.5. Computer hardware & software
  - 9.4.5.1. Barn applications:
    - 9.4.5.1.1. AirDAC (SOP B2)
    - 9.4.5.1.2. AirDAC Data Pre-Processing Software (SOP B3)
    - 9.4.5.1.3. CAPECAB (SOP B6)
  - 9.4.5.2. Open-source applications (SOPs D1, U4, and U5/U7):
    - 9.4.5.2.1. LabVIEW
    - 9.4.5.2.2. LAN Server computer

10. Data and Records Management

- 10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement his electronic record with a bound record book designated for the method, which should contain copies of the electronic record.
- 10.2. Manage all data according to SOP B5 or SOP D1 (barn or open-source applications), as appropriate.
- 10.3. Document all data and information (e.g., sample collection method used) on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.
- 10.4. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

- 11.1. Conduct gas analyzer checks according to the QAPP for the particular project. This will include zero gas and one or more reference span concentrations.
- 11.2. Conduct gas analyzer calibration when the precision check is >±10% of baseline, unless the QAPP for the particular project specifies a different value.
- 11.3. Conduct gas analyzer calibration when the zero check is >±5% of full scale different than the baseline, unless the QAPP for the particular project specifies a different value.
- 11.4. The calibration gas should be certified using EPA protocol (1% certification), if this grade is available, unless the QAPP for the particular project specifies a different value.
- 11.5. Check the response time every six months, unless the QAPP for the particular project specifies a different value.
- 11.6. Measure the gas analyzer’s inlet flow rate every six months.
- 11.7. Perform leak check in sample line and flow components and fittings every six months by measuring the inlet and exhaust flow rates with a flow meter.

11.8. Change the fine air-filter paper in the internal and external air-filtration units monthly. For analyzers that have the stainless steel 10 µm frit for the internal filter, clean the frit monthly. After cleaning or replacing filters, perform a leak check at the inlet sample port and the exhaust port by measuring the inlet and exhaust flow rates with a flow meter, to ensure that no leaks were introduced.
11.9. Clean the filter in the ventilation unit monthly.
11.10. Record any maintenance in the Instrument Performance Record File’s worksheet labeled maintenance.

12. References

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12.3. Innova AirTech Instruments. 2000. Detection Limits Wall Chart. Online at www.innova.dk/uploads/media/Wall_Chart_PW_01.pdf. Accessed 2/15/2006.
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12.6. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
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12.8. SOP B4. 2006. Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.
12.9. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.10. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
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12.12. SOP G8. 2006. General Calibration of Gas Analyzers. Standard Operating Procedure G8. Purdue Ag Air Quality Lab.
12.13. SOP G9. 2006. Zero and Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.

12.14. SOP U5. 2006. The Installation of Open-source Measurement Equipment. Standard Operating Procedure U5. Purdue Applied Meteorology Lab.
12.15. SOP U7. 2006. The Instrument Trailer and Installation of Open-source Measurement Equipment (Corrals). Standard Operating Procedure U7. Purdue Applied Meteorology Lab.

13. Contact Information

13.1. Distributor:
California Analytical Instruments
Tel: (714) 974-5560
Email: info@gasanalyzers.com

13.2. Manufacturer:
Innova AirTech Instruments (www.innova.dk)
Energivej 30, DK-2750 Ballerup, Denmark
Tel.: (+45) 44 20 0100, Fax: (+45) 44 20 0101, innova@innova.dk

13.3. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

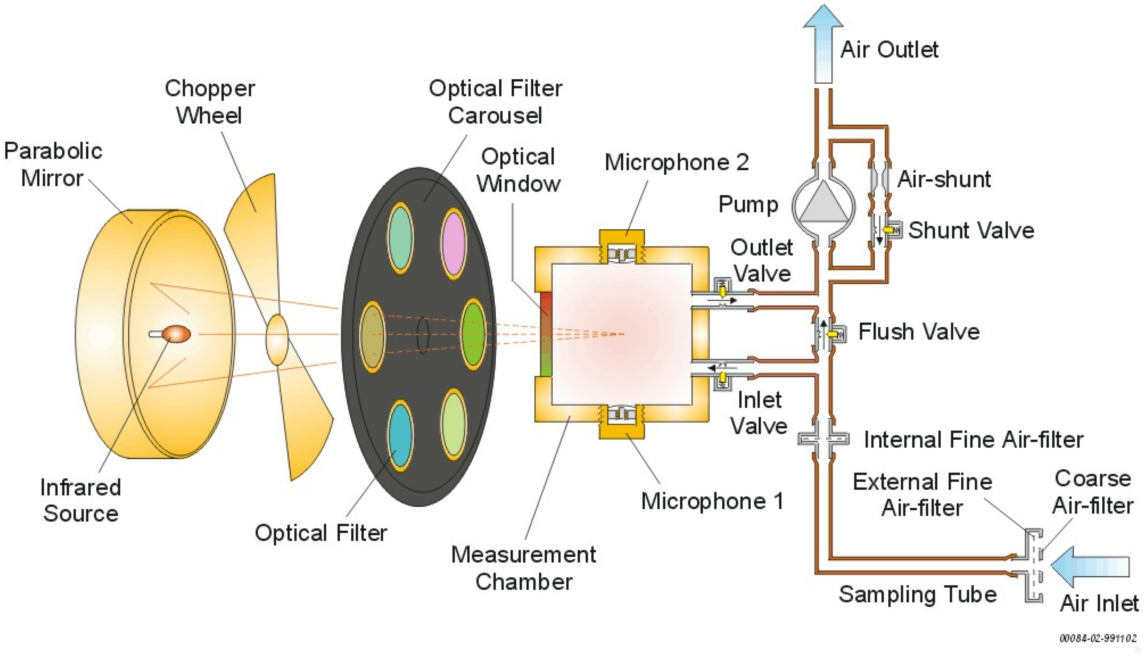

Figure 1. Schematic diagram of the major internal components of the INNOVA Model 1412 Photoacoustic Multi-gas Monitor.

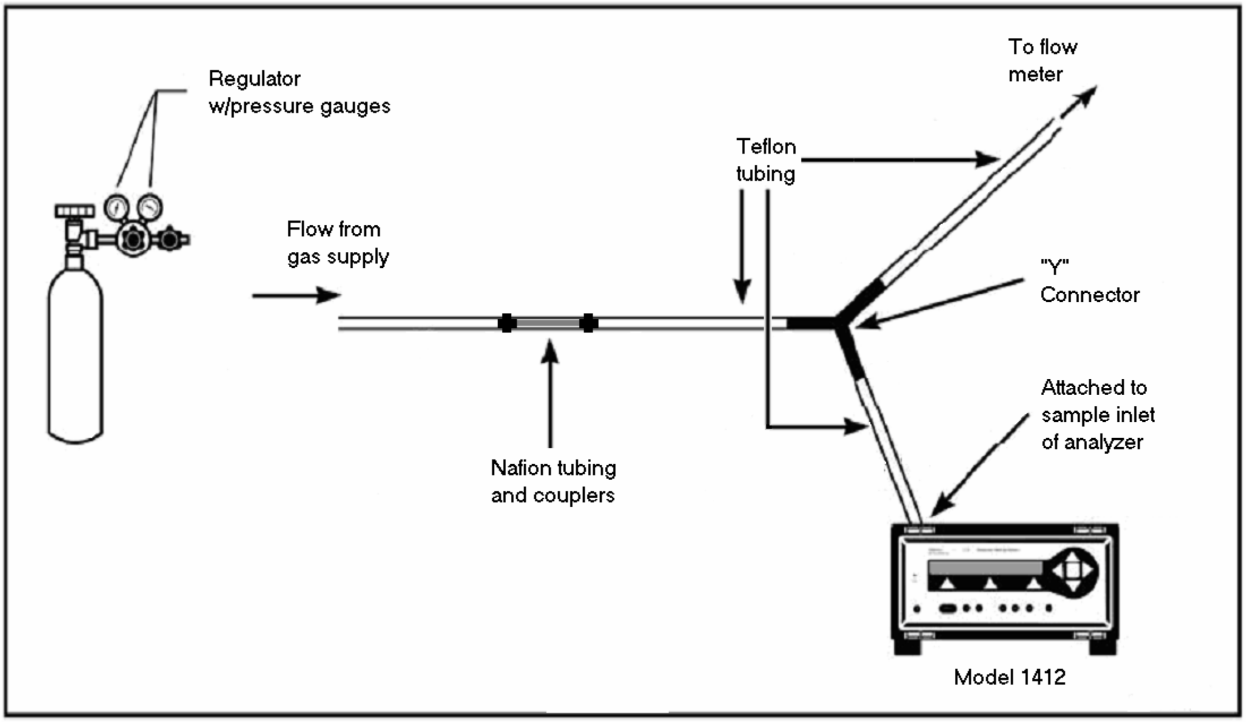

Figure 2. General equipment required for calibration of the Model 1412. Nafion tubing is coupled into the Teflon line from the cylinder during calibration of CO_2 or methane.

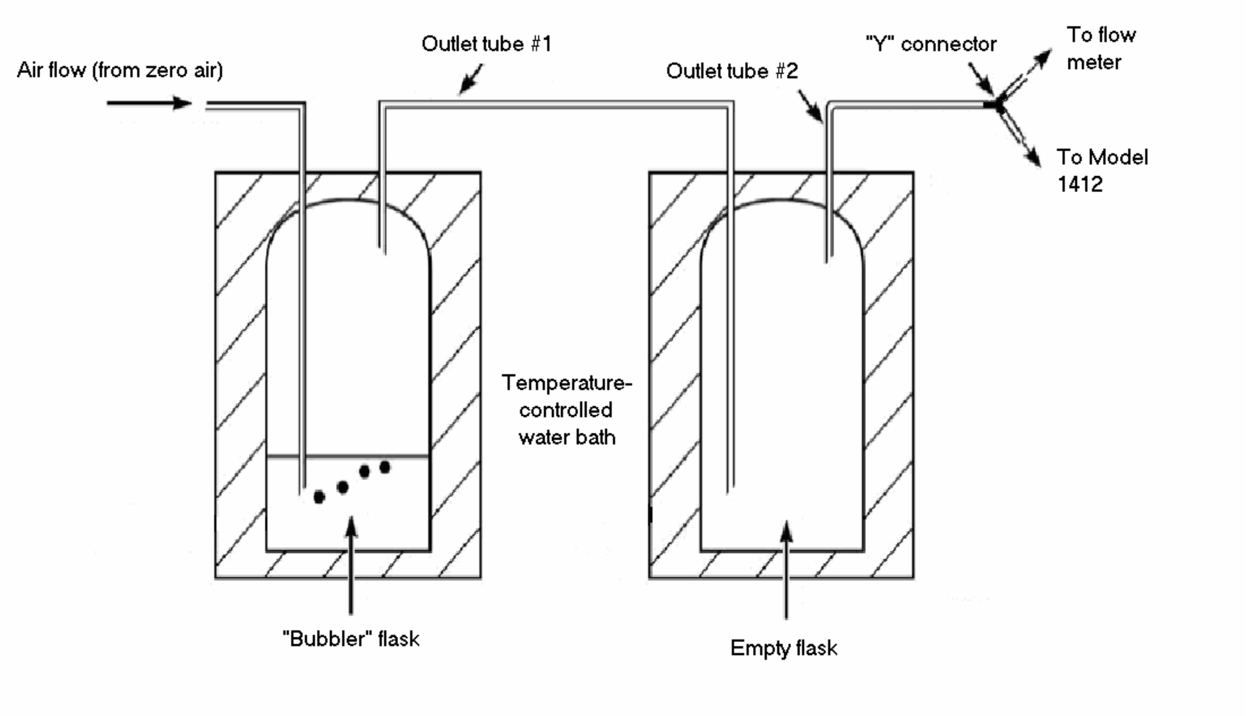

Figure 3. Schematic diagram of the equipment necessary to produce a supply of clean, wet air for humidity interference calibration.

MULTIPOINT CALIBRATION OF GAS ANALYZERS

Standard Operating Procedure (SOP) G8

MULTIPOINT CALIBRATION OF GAS ANALYZERS

Standard Operating Procedure (SOP) G8

Prepared by

Sam M. Hanni, Bill W. Bogan, and Claude A. Diehl

Reviewed by

Albert J. Heber

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. This method challenges gas analyzers with known concentrations of gases to calibrate and verifying previous calibrations of gas analyzers.

1.2. A multipoint calibration of gas analyzers has three objectives.

1.2.1. It provides a mathematical model (generally a linear function) to convert analyzer response (signal output) to gas concentration. This model is called a calibration curve.

1.2.1.1. The calibration curve is used to calculate the concentration of an unknown sample from the analyzer response.

1.2.2. Linearity can be assessed, in principle, using any number of points greater than 2.

1.2.2.1. The curve's goodness-of-fit indicates the linearity of the signal-to-concentration relationship.

1.2.3. With replications, it provides a measure of the reproducibility of the gas analysis.

1.3. Accurate multipoint calibration ensures accurate gas measurements.

1.4. This method applies to most gas analyzers, including:

1.4.1. MSA Model 3600 Photoacoustic Infrared CO_2 Monitor (SOP G3)
1.4.2. TEI Model 17C Chemiluminescence (NH_3) Analyzer (SOP G4)
1.4.3. TEI Model 450I Pulsed-Fluorescence (H_2S) Analyzer (SOP G5)
1.4.4. TEI Model 55C Methane/Non-Methane Hydrocarbon Analyzer (SOP G6)
1.4.5. INNOVA 1412 Photoacoustic Infrared Multi-Gas Monitor (SOP G7)
1.4.6. MSA Chillgard Photoacoustic Infrared (NH_3) Analyzer (SOP G10)

2. Summary of Method

Calibration curves are obtained by measuring the signals obtained with a series of standards of known concentration. A programmable diluter, such as the Environics Model S-4040 (SOP G11), can be used to generate the desired gas concentrations for the calibration curve, or gases of known concentration can be used directly. Concentration and signal data are input into the Multipoint worksheet in the Instrument Performance Record file to generate a linear regression, and the slope and intercept are entered into the AirDAC program (SOP B2) that applies the calibration curve to the collected analyzer signals.

Multipoint calibration consists of measuring an analyzer's response to known concentrations of gas over a selected range of concentrations which is appropriate for the gas analyzer. The calibration range's upper limit is chosen to be greater than the estimated actual maximum measurement to be encountered in the field, and the lower limit is set to zero. A minimum of two gas concentrations of (0 and 90% of the selected range) must be used to determine the calibration curve. If the number of gas concentrations in the calibration is greater than two, the additional points should be evenly spaced between 0 and 90%. Thus, the appropriate concentrations for a four-point calibration would be 0, 30, 60, and 90% of the selected range. If, for example, the maximum concentration of ammonia which is expected to occur in field samples is 28 ppm, an appropriate maximum for the calibration range would be 30 ppm, and the gas concentrations used for calibration would then be 0, 9, 18, and 27 ppm. The multipoint calibration requires that the series of known concentrations be measured twice.

3. Definitions

3.1.	Range	The upper and lower limits of the concentrations which a gas analyzer can accurately quantitate
3.2.	AirDAC	Air Data Acquisition and Control computer program (SOP B2)
3.3.	GSS	Gas Sampling System (SOP G1)
3.4.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.5.	QAPP	Quality Assurance Project Plan
3.6.	Zero-precision	A two-point check including zero air and one known non-zero concentration of reference gas

4. Cautions

4.1. Lack of pressure from the gas supply will cause an inaccurate reading.
4.1.1. Make sure cylinder(s) and regulator(s) are open (SOP G2).
4.1.2. Check for leakage caused by improperly connected tubing.
4.1.3. Check for blockage or kinks in the tubing.
4.1.4. If the flow of reference gas is too low, backflow from the exhaust to the instrument can occur.
4.2. If a diluter is being used, ensure that the correct reference gas concentration is entered into the diluter software (SOP G11).
4.3. Do not use any gas cylinder below 200 psi, because the certification of the reference gas is not valid below 200 psi.

5. Personnel Qualifications

5.1. Personnel must be trained in the use of each individual gas analyzer before working with it. This includes reading and understanding the manual and the relevant SOP.
5.2. Each analyst must also read and understand this SOP before conducting a multipoint calibration.

6. Equipment and Supplies

6.1. Cylinder(s) containing reference gas(es) with appropriate regulator(s) (SOP G2).
6.2. Diluter if gas dilution is required (Model S-4040, Environics, Tolland, CT) (SOP G11)
6.3. Computer and AirDAQ program (SOP B2).
6.4. Teflon tubing
6.5. Fittings
6.6. Gas analyzers: Any subset of those listed in Section 1.4.

7. Procedures

7.1. Make connections for introducing the reference gas to the analyzer.
  7.1.1. Refer to SOP G1 for descriptions of the various options for introducing a reference gas to the analyzer, and to the QAPP for the required gas introduction point. Unless the QAPP for the particular project specifies that a different point is used to introduce the gas, introduce the reference gas at the sampling inlet.
  7.1.2. If a diluter is used, connect the reference gas and zero air cylinders to the diluter, and the diluter to the gas introduction point (SOP G11).
  7.1.3. If no diluter, connect the cylinder directly to the gas introduction point.
7.2. Record all times, observations, and tasks during a multipoint calibration.
7.3. Open the valves of the gas cylinders. Use only certified gases.
7.4. Open the AirDAC program (SOP B2).
  7.4.1. Go to the DAQ tab, and change the slope to 1 and the intercept to 0 for the analyzer that is being calibrated. Press *Apply and Save* on the DAQ tab.
  7.4.2. Press the “Auto Smpl” button in the upper right hand corner of the page to switch to manual sampling.
  7.4.3. Select “Gas Cal” (Gas Calibration) from the drop-down window next to the “Manual smpl” button. This turns on the correct solenoids in the Gas Sampling System (GSS) for the calibration.
  7.4.4. Record in the field notes the time that Gas Cal is started.
7.5. Challenge the gas analyzer with reference gases.
  7.5.1. If a diluter is being used:
    7.5.1.1. The minimum number of calibration points to be performed is three (3). The concentrations will include zero concentration, approximately 90% of selected range of the analyzer, and one or more concentrations relatively evenly spaced between the zero and 90% concentrations. The flow rate of each reference gas must be at least 0.5 L/min more than the sum of flow rates of all gas analyzers drawing from the reference gas supply (when GSS is not used), or at least 0.5 L/min more than the GSS sample flow rate when using the GSS to draw from the reference gas supply.
    7.5.1.2. Analyze the different concentrations sequentially in increasing order (from zero to 90%), then repeat the sequence once more to determine repeatability.
    7.5.1.3. Open the Environics window (SOP G11) and select the Run menu.
    7.5.1.4. Select Program from the Run menu.
    7.5.1.5. Open up the drop-down window under “Name”
      7.5.1.5.1. Click the title with the desired gas and Regression (e.g.,“NH_3 Regression”).
      7.5.1.5.2. Press the “Start” button to begin gas flow (Each reference gas concentration is supplied to the analyzer for a specified duration, which is set in the Environics diluter software (SOP G11). Start with CEM Zero gas.
      7.5.1.5.3. Record the following information into a table which is located in the field notes on the worksheet titled Calibration (Table 1).
        7.5.1.5.3.1. Date
        7.5.1.5.3.2. The start and end times of the reference gas concentrations supplied to the analyzers (Use a date/time format)

7.5.1.5.3.3. Analyzer
7.5.1.5.3.4. Reference gas (i.e. NH_3, H_2S, CO_2, etc.) used
7.5.1.5.3.5. Applied reference gas concentration
7.5.1.5.3.6. Analyzer concentration reading at the end time for each reference gas
7.5.1.5.3.7. AirDAC concentration reading at the end time for each reference gas
7.5.1.5.3.8. AirDAC signal reading at the end time for each reference gas

7.5.1.6. The program will automatically stop when it has completed the calibration.

7.5.2. If no diluter is used, conduct a manual multipoint gas analyzer calibration as follows:

7.5.2.1. The minimum number of calibration points to be performed is two (2). The concentrations will include zero and span concentrations of the reference gases.

7.5.2.2. Analyze each concentration sequentially, from zero to span. Repeat once

7.5.2.3. Connect the CEM Zero cylinder to the gas introduction point (SOP G1).

7.5.2.4. Open CEM Zero gas cylinder for the appropriate sampling period at a flow rate 0.5 L/min in excess of the total (combined) flow rate required by all the gas analyzers drawing from the calibration line (if no GSS is being used), or 0.5 L/min in excess of the GSS flow rate (if a GSS is in use)..

7.5.2.4.1. Record the following information into a table, titled “Calibration”, which is located in the field notes (Table 1).

7.5.2.4.1.1. Date
7.5.2.4.1.2. The start and end times of the reference gas concentration supplied to the analyzers (Use a date/time format).
7.5.2.4.1.3. Analyzer
7.5.2.4.1.4. Reference gas (i.e. zero NH_3, H_2S, CO_2, etc.) used
7.5.2.4.1.5. Applied reference gas concentration
7.5.2.4.1.6. Analyzer concentration reading at the end time for each reference gas
7.5.2.4.1.7. AirDAC concentration reading at the end time for each reference gas
7.5.2.4.1.8. AirDAC signal reading at the end time for each reference gas

7.5.2.5. After 10 min, close the CEM Zero gas cylinder and switch the connection to the span reference gas cylinder.

7.5.2.6. Open the span reference gas for 10 min at the same flow rate as CEM Zero gas.

7.5.2.6.1. Record the information in 7.5.2.2.1 into the “Calibration” table (Table 1).

7.5.2.7. Close the span reference gas cylinder after 10 min.

7.5.2.8. Repeat Steps 7.5.2.1 – 7.4.2.5 once.

7.5.3. Return to the AirDAC window (SOP B2).

7.5.4. Press the *Manual smpl* button in the upper right hand corner to switch back to Auto Sample mode.

7.5.5. Record in the field notes the time that auto sampling is restarted.

7.6. Perform regression of the multipoint calibration data to obtain calibration curve.

7.6.1. Go to Windows Explorer and select My Computer. Select C drive

7.6.2. Select the appropriate “Project” folder (Named according to the format Project, State, Site Number; for example “NAEMS IASite4B”).

7.6.3. Select the “Calibration” folder.

7.6.4. Open the Instrument Performance Record File (Named according to the format Project, State, Sitenumber, Reference Gas, Instrument, Serial Number, Date (Year-Month-Day); for example “NAEMS IASite4B NH3 TE17C 305 2007-06-02.xls”).

- 7.6.5. Select the “Data” folder.
- 7.6.6. Paste a copy of the file containing the 15-s data, with the title of the project and the current date (for example “SEs20060320a.txt”), within the “Data” folder.
- 7.6.7. Open with Microsoft Excel.
- 7.6.8. Find the time that each gas concentration was supplied to the instrument. Each gas concentration is supplied for a set amount of time that is set in the Environics dilutor (SOP G11) or the QAPP.
- 7.6.9. Using the Calibration table, locate the start and end times in the data file for each reference gas that was supplied to the analyzers.
  - 7.6.9.1. Average the signal data for the last two minutes of the sampling period. The sampling period is the time that AirDAC samples a location (10 min). During the calibration, supply each reference gas for this same amount of time (10 min).
  - 7.6.9.2. Close the data file (without saving it).
  - 7.6.9.3. Enter the following data into the Multipoint Calibration worksheet (Fig. 1) of the Instrument Performance Record file for each reference gas and analyzer:
    - 7.6.9.3.1. Start and end times of each reference gas.
    - 7.6.9.3.2. Reference gas concentrations (Y*)
    - 7.6.9.3.3. AirDAC averaged signal data for each reference gas from the data file
    - 7.6.9.3.4. Analyst
    - 7.6.9.3.5. Any additional operating parameters (pressure, flow, etc.) required by each individual analyzer’s SOP
  - 7.6.9.4. The regression of the multipoint calibration data will be automatically updated.
  - 7.6.9.5. Save the slope, y-intercept, and date to the table in “Cal Record” worksheet.
  - 7.6.9.6. Save the table and chart in the “Multipoint Calibration” worksheet to the “Old Calibration” worksheet.
  - 7.6.9.7. Save the chart of the multipoint calibration in the “Graphs” worksheet.

7.7. Update the slope and intercept in AirDAC window (SOP B2).

- 7.7.1. Open the AirDAC window and go to the DAQ tab.
- 7.7.2. Enter the slope and intercept in rows 8 and 9 of the column in which the calibration regression was completed.
- 7.7.3. Press *Apply and Save* on the DAQ tab.
- 7.7.4. Record the slope, y-intercept, and time when settings were updated in the field notes.
- 7.7.5. Record and save the time when the slope and y-intercept is updated in AirDAC in the “Multipoint Calibration” worksheet for the Instrument Performance Record file.

8. Data and Records Management

8.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

8.2. Manage all data according to SOP B5.

8.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Initial and date all corrections.

9. Quality Control and Quality Assurance

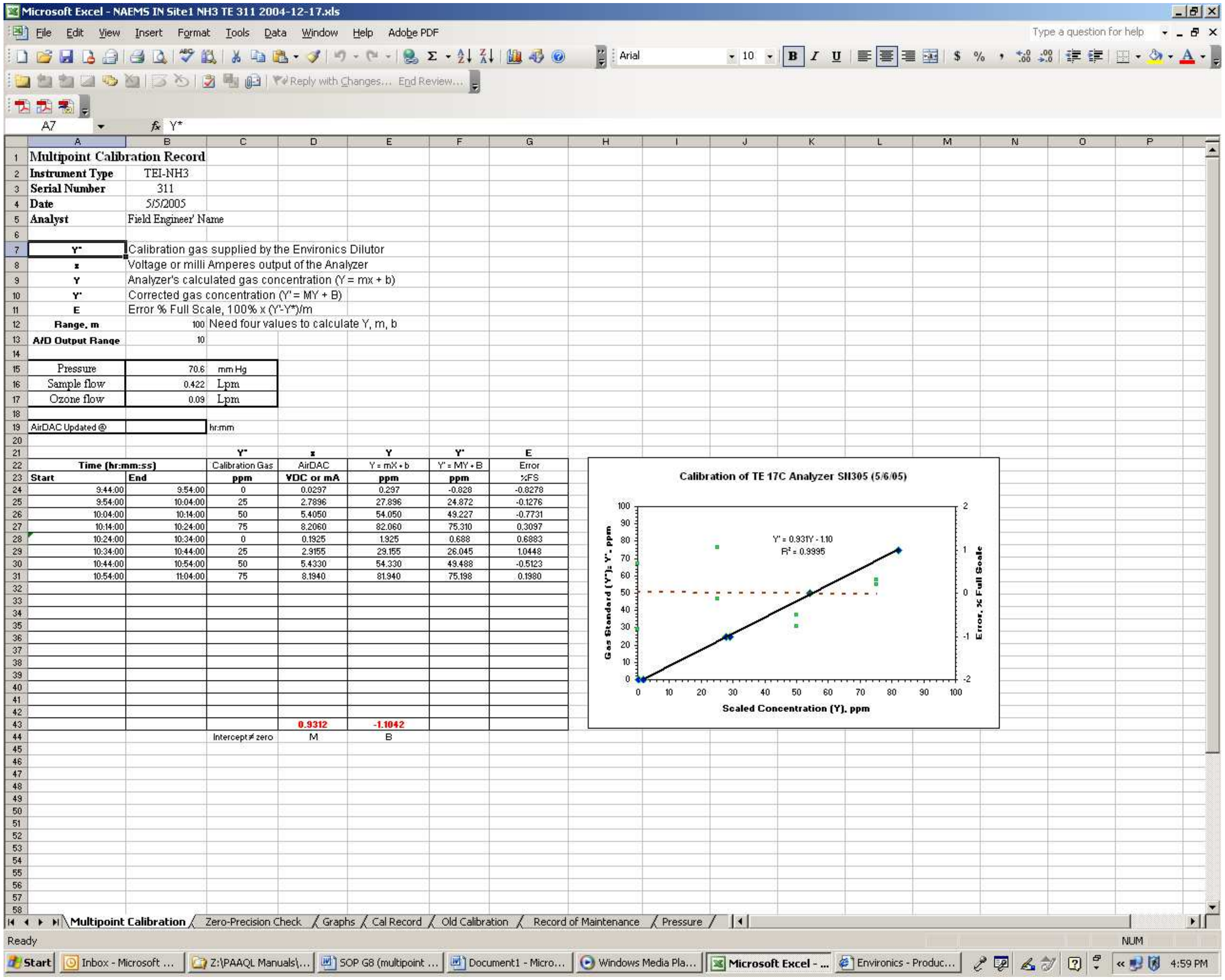
9.1. Conduct a multipoint calibration at the following times:
  9.1.1. Whenever the analyzer Control Chart (SOP Q1) indicates that a zero or precision check (SOP G9) has drifted outside the calibration limits
  9.1.2. After any repair of the gas analyzer
  9.1.3. Any time the gas analyzer has been shut down for more than 3 d
  9.1.4. After adjusting the sensitivity of a gas analyzer
  9.1.5. Any other time specified by the QAPP
9.2. Report QC data using a Control Chart in an Excel spreadsheet (SOP Q1).
9.3. Unless otherwise stated by the QAPP for the particular project, the acceptability criterion for the linear regression for a multi-point calibration (Section 7.6) is an R^2 value of 0.98.

10. References

10.1. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
10.2. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
10.3. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
10.4. SOP G3. 2006. Measurement of Carbon Dioxide (CO_2) with the MSA Model 3600 Infrared Gas Monitor. Standard Operating Procedure G3. Purdue Ag Air Quality Lab.
10.5. SOP G4. 2006. Measurement of Ammonia (NH_3) Using the TEI Model 17C Chemiluminescence Analyzer. Standard Operating Procedure G4. Purdue Ag Air Quality Lab.
10.6. SOP G5. 2006. Measurement of Hydrogen Sulfide (H_2S) with the Thermo Electron Corporation Model 450I Pulsed-Fluorescence Analyzer. Standard Operating Procedure G5. Purdue Ag Air Quality Lab.
10.7. SOP G6. 2006. Measurement of Methane and Non-Methane Hydrocarbons with the Thermo Electron Corporation Model 55C Analyzer. Standard Operating Procedure G6. Purdue Ag Air Quality Lab.
10.8. SOP G7. 2006. Use of the INNOVA 1412 Photoacoustic Multi-Gas Monitor. Standard Operating Procedure G7. Purdue Ag Air Quality Lab.
10.9. SOP G9. 2006. Zero and Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.
10.10. SOP G10. 2006. Measurement of Ammonia Using the MSA Photoacoustic Infrared Analyzer. Standard Operating Procedure G10. Purdue Ag Air Quality Lab.
10.11. SOP G11. 2006. Operation of the Environics® Computerized Gas Dilution System. Standard Operating Procedure G11. Purdue Ag Air Quality Lab.
10.12. SOP Q1. 2006. Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1. Purdue Ag Air Quality Lab.
10.13. USEPA. “Quality Assurance Handbook for Air Pollution Measurement Systems, Volume II: Part 1.” EPA-454/R-98-004. Section 12. 12.2 Multi-point Calibrations.3.

Table 1: The Multipoint Calibration Table used in the field notes.

TEI 17C Ammonia Analyzer Multipoint Calibration							
Date	10/6/2004	Analyst	Diehl		Instrument	AirDAC	
				Applied	Concentration	Corrected	
Time			Reference	Concentration	Reading	Concentration	Signal
Started	End	Instrument	Gas	ppm	ppm/ppb	ppm /ppb	vdc or mA
10/6/2004 15:44	10/6/2004 15:54	TEI 17C NH_3 Analyzer	CEM Zero	0	0.018	0.204	0.015
10/6/2004 15:54	10/6/2004 16:04	TEI 17C NH_3 Analyzer	NH3	10	9.83	9.868	3.272
10/6/2004 17:45	10/6/2004 17:55	TEI 17C NH_3 Analyzer	CEM Zero	0	0.004	0.185	0.008
10/6/2004 17:55	10/6/2004 18:05	TEI 17C NH_3 Analyzer	NH3	9	8.77	8.843	2.925
10/6/2004 18:05	10/6/2004 18:15	TEI 17C NH_3 Analyzer	NH3	16	15.97	14.608	5.207
10/6/2004 18:15	10/6/2004 18:25	TEI 17C NH_3 Analyzer	NH3	24	25.2	24.990	8.369
10/6/2004 18:25	10/6/2004 18:35	TEI 17C NH_3 Analyzer	CEM Zero	0	0.54	0.674	0.173
10/6/2004 18:35	10/6/2004 18:45	TEI 17C NH_3 Analyzer	NH3	9	9.15	9.191	3.045
10/6/2004 18:45	10/6/2004 18:55	TEI 17C NH_3 Analyzer	NH3	16	16.67	16.664	5.563
10/6/2004 18:55	10/6/2004 19:05	TEI 17C NH_3 Analyzer	NH3	24	25.4	25.265	8.461



Multipoint Calibration Record

Instrument Type	TEI-NH3
Serial Number	311
Date	5/5/2005
Analyst	Field Engineer' Name

Y*	Calibration gas supplied by the Environics Dilutor
x	Voltage or milli Amperes output of the Analyzer
Y	Analyzer's calculated gas concentration (Y = mx + b)
Y'	Corrected gas concentration (Y' = MY + B)
E	Error % Full Scale, 100% x (Y'-Y*)/m
Range, m	100 Need four values to calculate Y, m, b
A/D Output Range	10

Pressure	70.6	mm Hg
Sample flow	0.422	Lpm
Ozone flow	0.09	Lpm

AirDAC Updated @ hr:mm

		Y*	**x**	**Y**	**Y'**	**E**
Time (hr:mm:ss)		Calibration Gas	AirDAC	Y = mX + b	Y' = MY + B	Error
Start	**End**	**ppm**	**VDC or mA**	**ppm**	**ppm**	%FS
9:44:00	9:54:00	0	0.0297	0.297	-0.828	-0.8278
9:54:00	10:04:00	25	2.7896	27.896	24.872	-0.1276
10:04:00	10:14:00	50	5.4050	54.050	49.227	-0.7731
10:14:00	10:24:00	75	8.2060	82.060	75.310	0.3097
10:24:00	10:34:00	0	0.1925	1.925	0.688	0.6883
10:34:00	10:44:00	25	2.9155	29.155	26.045	1.0448
10:44:00	10:54:00	50	5.4330	54.330	49.488	-0.5123
10:54:00	11:04:00	75	8.1940	81.940	75.198	0.1980
			0.9312	**-1.1042**		
		Intercept≠ zero	M	B		

Figure 1: The Multipoint Calibration worksheet in the Instrument Performance Record File.

PRECISION CHECKS OF GAS ANALYZERS

Standard Operating Procedure (SOP) G9

PRECISION CHECKS OF GAS ANALYZERS

Standard Operating Procedure (SOP) G9

Prepared by

Bill W. Bogan and Sam M. Hanni

Reviewed by

Claude A. Diehl and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This method challenges a gas analyzer with known concentrations of gases to check the stability of the gas analyzer’s current (most recent) full calibration.

1.2. Frequent precision checks of the various gas analyzers are required to determine if the calibration curves (SOP G8) used in measuring the gases of interest are still valid. This helps guarantee accuracy and quality of data generated by the analyzers.

1.2.1. Zero checks indicate when an analyzer’s zero reading has drifted outside of the acceptable range (which is generally approximately ±2% of full scale, depending on the analyzer), at which point the analyzer needs to be recalibrated.

1.2.2. Span checks indicate when an analyzer drifts out of its calibration limit (which ranges from ±5% to ±10% of the baseline value, depending on the analyzer), at which point the analyzer needs to be recalibrated.

1.3. Zero - Span checks are used to calculate zero-offset and span factors that correct the measured gas concentrations back to the baseline measurement in the use of the CAPECAB data processing software (SOP B6).

1.4. This method applies to most gas analyzers, including:

1.4.1. MSA Model 3600 Photoacoustic Infrared CO2 Monitor (SOP G3)
1.4.2. TEI Model 17C Chemiluminescence (NH3) Analyzer (SOP G4)
1.4.3. TEI Model 450C Pulsed-Fluorescence (H2S) Analyzer (SOP G5)
1.4.4. TEI Model 55C Methane/Non-Methane Hydrocarbon Analyzer (SOP G6)
1.4.5. INNOVA 1412 Photoacoustic Infrared Multi-Gas Monitor (SOP G7)
1.4.6. MSA Chillgard Photoacoustic Infrared (NH3) Analyzer (SOP G10)

2. Summary of Method

A gas of known analyte concentration (span check) or zero air (zero check) is introduced to the appropriate gas analyzer. A diluter, such as the Environics Model S-4040 (SOP G11), can be used to generate gas concentrations required for span checks, or gases of known concentration can be used directly from the cylinder. The measured concentration at each check is entered into an analyzer-specific electronic file (the Instrument Performance Record File), which automatically updates the analyzer’s Control Chart (SOP Q1).

3. Definitions

3.1.	Range	The upper and lower limits of the concentrations which a gas analyzer can accurately quantitate
3.2.	AirDAC	Air Data Acquisition and Control computer program (SOP B2)
3.3.	CAPECAB	Calculation of Air Pollutant Emissions from Confined Animal Buildings, a custom computer program (SOP B6)
3.4.	GSS	Gas sampling system (SOP G1)
3.5.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.6.	QAPP	Quality Assurance Project Plan
3.7.	Zero-span	A two-point check including zero air and one known non-zero concentration of reference gas

4. Cautions

4.1. Lack of pressure from the gas supply will cause an inaccurate reading.
  4.1.1. Make sure cylinder(s) and regulator(s) are open (SOP G2).
  4.1.2. Check for leakage caused by improperly connected tubing.
  4.1.3. Check for blockage or kinks in the tubing.
  4.1.4. If the flow of reference gas is too low, backflow from the exhaust to the instrument can occur.
4.2. If a diluter is being used, ensure that the correct reference gas concentration is entered into the diluter software (SOP G11).
4.3. Do not use any gas cylinder below 200 psi because the certification of the reference gas is not valid below 200 psi.

5. Personnel Qualifications

5.1. Personnel must be trained in the use of each individual gas analyzer before working with it. This includes reading and understanding the manual and the relevant SOP.
5.2. Each analyst must also read and understand this SOP.

6. Equipment and Supplies

6.1. Cylinder(s) containing reference gas(es) with appropriate regulator(s) (SOP G2).
6.2. Diluter if gas dilution is required (Model S-4040, Environics, Tolland, CT) (SOP G11)
6.3. Computer and AirDAQ program (SOP B2).
6.4. Teflon tubing
6.5. Fittings
6.6. Gas analyzers: Any subset of those listed in Section 1.4.

7. Procedures

7.1. If a new baseline is being established, save the old control chart and tables in the Zero – Precision Check worksheet into the Record of Zero – Span Checks worksheet.
7.2. Make connections for introducing the reference gas to the analyzer.
  7.2.1. Refer to SOP G1 for descriptions of the various options for introducing a reference gas to the analyzer. Unless indicated otherwise by the QAPP, introduce the reference gas at a sampling tube.
  7.2.2. If a diluter is used, connect the reference gas and zero air cylinders to the diluter, and the diluter to the gas introduction point (SOP G11).
  7.2.3. If no diluter, connect the cylinder directly to the gas introduction point.
7.3. Record all times, observations, and tasks during the zero – span check.
7.4. Open the valves of the gas cylinders. Use only certified gases.
7.5. Open the AirDAC program (SOP B2).
  7.5.1. Press the "*Auto Smpl*" button in the upper right hand corner of the AirDAC window to switch to manual sampling.
  7.5.2. 7.5.2. Select "*Gas Cal*" (Gas Calibration) from the drop down window next to the

Manual smpl button. This turns on the correct solenoids in the Gas Sampling System (GSS, See SOP G1) for a zero-span check.

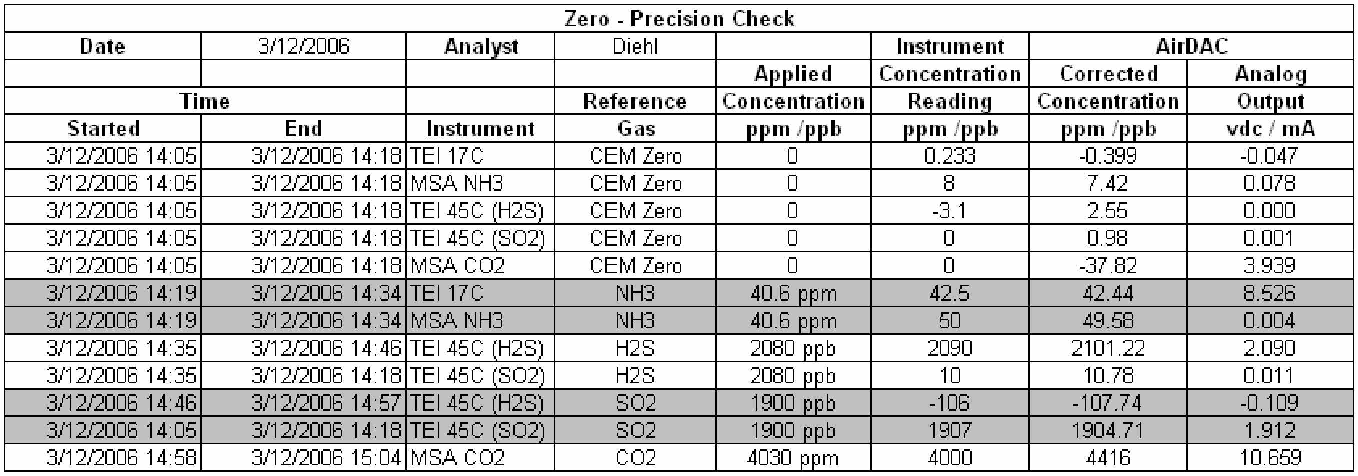
7.5.3. Record in the field notes the time that Gas Cal was started.

7.6. Challenge the gas analyzer with reference gases.

- 7.6.1. If a diluter is being used:
  - 7.6.1.1. Open the Environics window (SOP G11) and select the Run menu.
  - 7.6.1.2. Select “Program” from the Run menu.
  - 7.6.1.3. Open up the drop-down window under “Name”.
    - 7.6.1.3.1. Open the program titled “Zero – Span Check”.
    - 7.6.1.3.2. Press the “Start” button to begin gas flow (Each reference gas concentration is supplied to the analyzer for a specified duration, which is set in the Environics diluter software, as described in SOP G11). Start with CEM Zero gas.
    - 7.6.1.3.3. While the program is running, record the following information into a table, titled” Zero – Span Check”, which is located in the field notes (Fig. 1).
      - 7.6.1.3.3.1. Date
      - 7.6.1.3.3.2. The start and end times of the reference gas concentrations supplied to the analyzers (Use a date/time format)
      - 7.6.1.3.3.3. Analyzer
      - 7.6.1.3.3.4. Reference gas (i.e. NH_3, H_2S, CO_2, etc.) used
      - 7.6.1.3.3.5. Applied reference gas concentration
      - 7.6.1.3.3.6. Analyzer concentration reading at the end time for each reference gas
      - 7.6.1.3.3.7. AirDAC concentration reading at the end time for each reference gas
      - 7.6.1.3.3.8. AirDAC signal reading at the end time for each reference gas
  - 7.6.1.4. The program will automatically stop when it has completed the check.
  - 7.6.1.5. Repeat Steps 7.4.5.3.2 through 7.4.5.4 for each analyzer.
- 7.6.2. If a diluter is not used, conduct a manual zero - span check as follows:
  - 7.6.2.1. Connect the CEM Zero cylinder to the gas introduction point (SOP G1).
  - 7.6.2.2. Open CEM Zero gas cylinder for 10 min (or duration of the ambient gas sampling period) to a flow rate of 0.5 L/min in excess of total (combined) flow rate that is required by all of the gas analyzers that are being checked.
    - 7.6.2.2.1. Record the following information into a table, titled “Zero-Span Check”, which is located in the field notes (Fig. 1).
      - 7.6.2.2.1.1. Date
      - 7.6.2.2.1.2. The start and end times of the reference gas concentrations supplied to the analyzers (Use a date/time format)
      - 7.6.2.2.1.3. Analyzer
      - 7.6.2.2.1.4. Applied reference gas (i.e. zero gas, NH_3, H_2S, CO_2, etc.)
      - 7.6.2.2.1.5. Applied reference gas concentration
      - 7.6.2.2.1.6. Analyzer concentration reading at the end time for each reference gas
      - 7.6.2.2.1.7. AirDAC concentration reading at the end time for each reference gas
      - 7.6.2.2.1.8. AirDAC signal reading at the end time for each reference gas

7.6.2.3. Close the CEM Zero gas cylinder

7.6.2.4. Repeat steps 7.5.6.2 to 7.5.6.4 for each reference gas required by the gas analyzers using the sampling period of gas measurement.



Zero - Precision Check							
Date	3/12/2006	Analyst	Diehl		Instrument	AirDAC	
				Applied	Concentration	Corrected	Analog
Time			Reference	Concentration	Reading	Concentration	Output
Started	End	Instrument	Gas	ppm /ppb	ppm /ppb	ppm /ppb	vdc / mA
3/12/2006 14:05	3/12/2006 14:18	TEI 17C	CEM Zero	0	0.233	-0.399	-0.047
3/12/2006 14:05	3/12/2006 14:18	MSA NH3	CEM Zero	0	8	7.42	0.078
3/12/2006 14:05	3/12/2006 14:18	TEI 45C (H2S)	CEM Zero	0	-3.1	2.55	0.000
3/12/2006 14:05	3/12/2006 14:18	TEI 45C (SO2)	CEM Zero	0	0	0.98	0.001
3/12/2006 14:05	3/12/2006 14:18	MSA CO2	CEM Zero	0	0	-37.82	3.939
3/12/2006 14:19	3/12/2006 14:34	TEI 17C	NH3	40.6 ppm	42.5	42.44	8.526
3/12/2006 14:19	3/12/2006 14:34	MSA NH3	NH3	40.6 ppm	50	49.58	0.004
3/12/2006 14:35	3/12/2006 14:46	TEI 45C (H2S)	H2S	2080 ppb	2090	2101.22	2.090
3/12/2006 14:35	3/12/2006 14:18	TEI 45C (SO2)	H2S	2080 ppb	10	10.78	0.011
3/12/2006 14:46	3/12/2006 14:57	TEI 45C (H2S)	SO2	1900 ppb	-106	-107.74	-0.109
3/12/2006 14:05	3/12/2006 14:18	TEI 45C (SO2)	SO2	1900 ppb	1907	1904.71	1.912
3/12/2006 14:58	3/12/2006 15:04	MSA CO2	CO2	4030 ppm	4000	4416	10.659

Figure 1. A Zero-Span Check table as it should be entered in the field notes.

7.6.3. Return to the AirDAC window (SOP B2).

7.6.4. Press the *Manual smpl* button in the upper right hand corner to switch back to Auto Sample mode.

7.6.5. Record in the field notes the time that auto sampling is restarted.

7.7. Record the data from the zero-span check(s) for each reference gas in the zero-span check worksheet in the pertinent Instrument Performance Record File.

7.7.1. Go to Windows Explorer and select My Computer.

7.7.2. Select C drive.

7.7.3. Select the appropriate “Project” folder (Named according to the format Project, State, Site Number; for example “NAEMS IASite4B”).

7.7.4. Select the “Calibration” folder.

7.7.5. Open the appropriate Instrument Performance Record File (Named according to the format Project, State, Site, Reference Gas, Instrument, Serial Number, Date (Year-Month-Day); for example “NAEMS IASite4B NH3 TE17C 305 2007-06-02.xls”).

7.7.6. Select the “Data” folder.

7.7.7. Paste a copy of the file containing the 15-s data, with the title of the project and the current date (for example “SEs20060320a.txt”), within the “Data” folder.

7.7.8. Open with Microsoft Excel.

7.7.9. Using the zero-span table (See the table in the field notes – Fig. 1), locate the start and end times in the data file for each reference gas supplied to the analyzers.

7.7.10. Average all valid measured concentration and signal data for each reference gas that is supplied during the zero – span check. Each reference gas is supplied to the GSS, either via a diluter or manually, for the same amount of time as AirDAC samples each location (i.e., 10 min).

7.7.11. Close the data file (without saving it).

7.7.12. Open the Instrument Performance Record file for each gas analyzer.

7.7.13. Enter the following data into the zero-span check worksheet (Fig. 2) in the Instrument Performance Record File for each instrument and reference gas:

- 7.7.13.1. Start and end times of each reference gas supplied to the gas analyzers.
- 7.7.13.2. Reference gas concentrations
- 7.7.13.3. Analyzer concentration reading
- 7.7.13.4. AirDAC averaged concentration for each reference gas from the data file
- 7.7.13.5. Analyst
- 7.7.13.6. Any other parameters required by each individual gas analyzer's SOP

7.8. The Control Chart (SOP Q1) for the individual gas analyzer will automatically update as this data is entered into the zero-span check worksheet.

7.9. Inspect the instrument's Control Chart in the zero-span check worksheet in the Instrument Performance Record File.

- 7.9.1. If the zero-span check is within calibration limits, the calibration curve is valid.
- 7.9.2. If the zero-span check is outside the calibration limits of the baseline measurement, the calibration curve is invalid. Recalibrate the analyzer (See SOP G8 and the SOP for the individual analyzer).

7.10. Repeat Steps 7.7.9 to 7.9.2 for each instrument, and each for reference gas.

7.11. Close the copy of the data file, and do not save the copy.

7.12. Save changes to the Instrument Performance Record File and close.

8. Data and Records Management

8.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

8.2. Manage all data according to SOP B5.

8.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Strike out all errors in writing with a single line. Initial and date all such corrections.

9. Quality Control and Quality Assurance

9.1. Conduct zero and span checks at the following times:

- 9.1.1. Before a calibration adjustment of any gas analyzer
- 9.1.2. Following a multipoint calibration
- 9.1.3. Before and after any repair of the gas analyzer
- 9.1.4. Before shutting down a gas analyzer
- 9.1.5. After turning on a gas analyzer and warming it up
- 9.1.6. Before the cylinder pressure drops below 200 psi, requiring its replacement.
- 9.1.7. Upon the introduction of a new gas cylinder
- 9.1.8. Before and after adjusting the sensitivity of a gas analyzer
- 9.1.9. Any other time specified by the QAPP

9.2. Enter beginning and end times of all zero-span checks (both regularly scheduled and otherwise) immediately after completion, so the Control Chart is kept up-to-date.

10. References

10.1. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
10.2. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
10.3. SOP B6. 2006. Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
10.4. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
10.5. SOP G3. 2006. Measurement of Carbon Dioxide (CO_2) with the MSA Model 3600 Infrared Gas Monitor. Standard Operating Procedure G3. Purdue Ag Air Quality Lab.
10.6. SOP G4. 2006. Measurement of Ammonia (NH_3) Using the TEI Model 17C Chemiluminescence Analyzer. Standard Operating Procedure G4. Purdue Ag Air Quality Lab.
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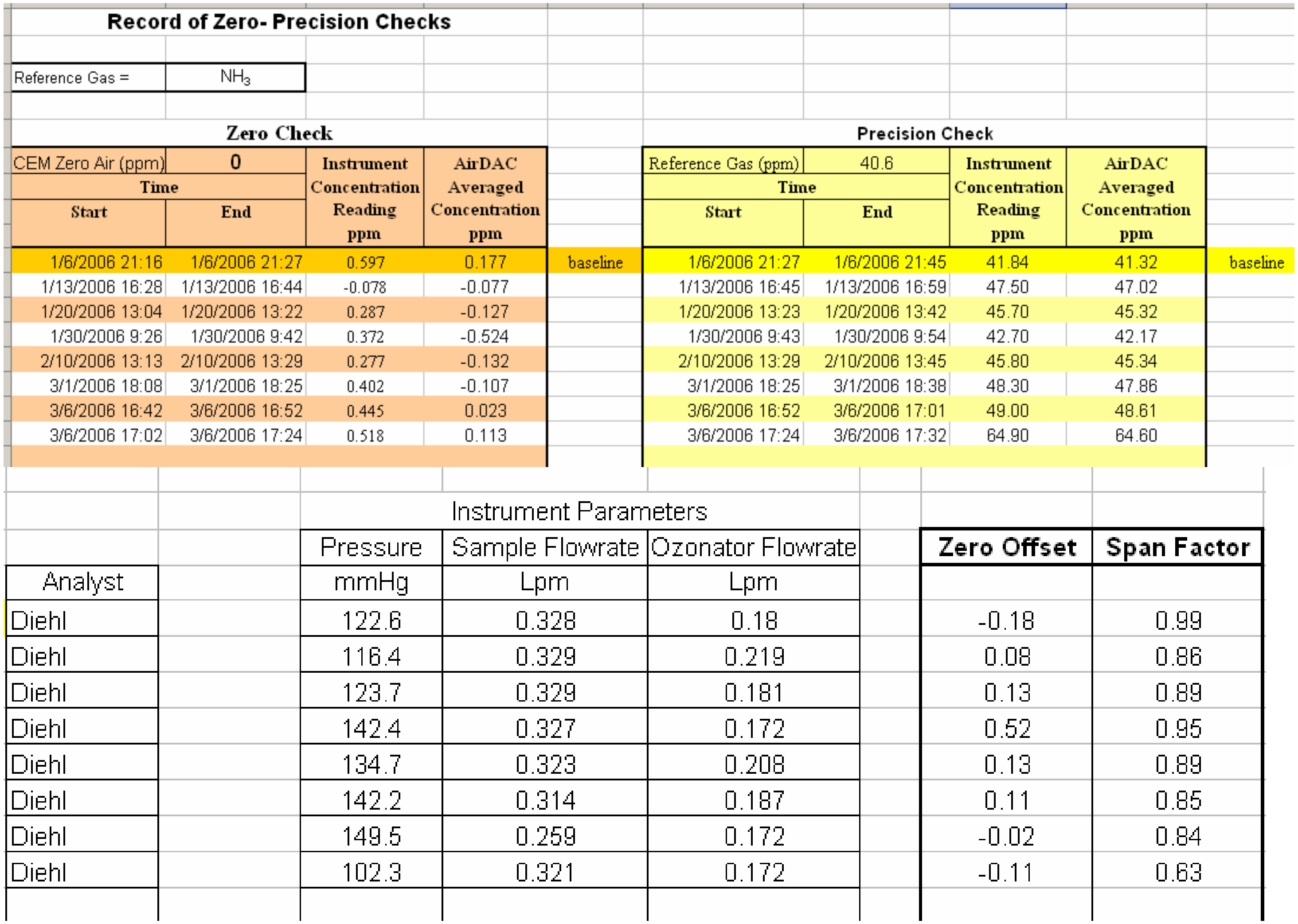
10.9. SOP G7. 2006. Use of the INNOVA 1412 Photoacoustic Multi-Gas Monitor. Standard Operating Procedure G7. Purdue Ag Air Quality Lab.
10.10. SOP G8. 2006. Multi-Point Calibration of Gas Analyzers. Standard Operating Procedure G8. Purdue Ag Air Quality Lab.
10.11. SOP G10. 2006. Measurement of Ammonia Using the MSA Photoacoustic Infrared Analyzer. Standard Operating Procedure G10. Purdue Ag Air Quality Lab.
10.12. SOP G11. 2006. Operation of the Environics® Computerized Gas Dilution System. Standard Operating Procedure G11. Purdue Ag Air Quality Lab.
10.13. SOP Q1. 2006. Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1. Purdue Ag Air Quality Lab.



Record of Zero- Precision Checks

Reference Gas = NH_3

Zero Check

CEM Zero Air (ppm)	0	Instrument Concentration Reading ppm	AirDAC Averaged Concentration ppm	
Time				
Start	End			
1/6/2006 21:16	1/6/2006 21:27	0.597	0.177	baseline
1/13/2006 16:28	1/13/2006 16:44	-0.078	-0.077	
1/20/2006 13:04	1/20/2006 13:22	0.287	-0.127	
1/30/2006 9:26	1/30/2006 9:42	0.372	-0.524	
2/10/2006 13:13	2/10/2006 13:29	0.277	-0.132	
3/1/2006 18:08	3/1/2006 18:25	0.402	-0.107	
3/6/2006 16:42	3/6/2006 16:52	0.445	0.023	
3/6/2006 17:02	3/6/2006 17:24	0.518	0.113	

Precision Check

Reference Gas (ppm)	40.6	Instrument Concentration Reading ppm	AirDAC Averaged Concentration ppm	
Time				
Start	End			
1/6/2006 21:27	1/6/2006 21:45	41.84	41.32	baseline
1/13/2006 16:45	1/13/2006 16:59	47.50	47.02	
1/20/2006 13:23	1/20/2006 13:42	45.70	45.32	
1/30/2006 9:43	1/30/2006 9:54	42.70	42.17	
2/10/2006 13:29	2/10/2006 13:45	45.80	45.34	
3/1/2006 18:25	3/1/2006 18:38	48.30	47.86	
3/6/2006 16:52	3/6/2006 17:01	49.00	48.61	
3/6/2006 17:24	3/6/2006 17:32	64.90	64.60	

Instrument Parameters

		Pressure	Sample Flowrate	Ozonator Flowrate		Zero Offset	Span Factor
Analyst		mmHg	Lpm	Lpm			
Diehl		122.6	0.328	0.18		-0.18	0.99
Diehl		116.4	0.329	0.219		0.08	0.86
Diehl		123.7	0.329	0.181		0.13	0.89
Diehl		142.4	0.327	0.172		0.52	0.95
Diehl		134.7	0.323	0.208		0.13	0.89
Diehl		142.2	0.314	0.187		0.11	0.85
Diehl		149.5	0.259	0.172		-0.02	0.84
Diehl		102.3	0.321	0.172		-0.11	0.63

Figure 2. Example of the Zero-Span Worksheet in the Instrument Performance Record File.

MEASUREMENT OF AMMONIA USING THE MSA PHOTOACOUSTIC INFRARED ANALYZER

Standard Operating Procedure (SOP) G10

MEASUREMENT OF AMMONIA USING THE MSA PHOTOACOUSTIC INFRARED ANALYZER

Standard Operating Procedure (SOP) G10

Prepared by

Juan Carlos Ramirez and Claude A. Diehl

Reviewed by

Ji-Qin Ni, Bill W. Bogan, and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The purpose of this procedure is to present the methodology and instrumentation used to measure automatically and sequentially concentrations of ammonia (NH_3) emissions at animal feeding operations (AFO), specifically at the barns.

1.2. NH_3 concentrations encountered at livestock facilities range from normal atmospheric concentrations (which can be as low as 1.3 ppb) to over 300 ppm (inside the barns).

1.3. The photoacoustic method is useful for measuring NH_3 in confined animal buildings because of the low interference of water vapor, its wide measurement range, and low maintenance required even when measuring barn concentrations.

1.4. The procedures described in this SOP apply only to the MSA Chillgard RT Photoacoustic Infrared Gas Monitor. The manufacturer's specifications are as follows:

  1.4.1. The minimum detection limit of this method is 3 ppm

  1.4.2. The short-term stability of the method is ±1% and its long-term stability, including linearity, is ±5% in 18 mos.

  1.4.3. The 90% response time to a step change in NH3 concentration is 70 s.

  1.4.4. The analyzer is not degraded in the presence of silicon or sulfur compounds, including H2S, which is emitted from livestock barns.

  1.4.5. The selectable ranges are 0 to 1000 ppm.

  1.4.6. The sampling flow rate is 0.75 L/min.

2. Summary of Method

Ammonia concentration in air is measured using photo-acoustic infrared detection with a commercial analyzer (Model Chillgard RT Photoacoustic Infrared Gas Monitor, Mine Safety Appliances, Pittsburgh, PA). With this method, a gas sample is drawn continuously from the gas sampling system's analyzer manifold, and introduced into an acoustic cell, where it is exposed to pulsing infrared light of a specific wavelength. If the sample contains NH_3, it will absorb an amount of infrared light proportional to the concentration of NH_3 in the sample. When gas molecules absorb this infrared light, their temperature rises, and a pressure wave occurs inside the acoustic cell. The audible pressure pulses corresponding to the light pulses are detected by a very sensitive microphone located inside the chamber (MSA, 2001) and are proportional to the concentration of NH_3 molecules (Fig. 1).

3. Definitions of Terms and Acronyms

3.1.	AirDAC	Air Data Acquisition and Control program
3.2.	MSA	Mine Safety Appliances, Inc.
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	QAPP	Quality Assurance Project Plan

4. Health and Safety

4.1. Be careful when working with electrical power connections.

4.2. Properly vent analyzer exhaust to avoid exposure to noxious gases in the sample.

5. Cautions

5.1. Do not mount the unit to any structure that is subject to vibration.
5.2. Do not locate the unit near an excessive heat source, and allow at least 3 in of clearance around the unit for proper cooling.
5.3. Ensure the radii of all tubing are wide enough to prevent kinking or bending. Otherwise, an obstruction in the flow path may occur.
5.4. Thoroughly inspect contents of the packing box to avoid discarding important parts.

6. Interferences

6.1. Compounds or parameters that interfere with the NH_3 readings are as follows:

6.1.1.	Temperature	±0.3% change in reading per °C temperature change above or below that at which the analyzer was last calibrated
6.1.2.	Humidity	<1 ppm change in reading at any humidity level (Humidity effect is compensated using an internal humidity sensor).
6.1.3.	Other gases	See Table 1.

Table 1. Typical cross-sensitivities of various interferants with NH_3 determination using the MSA Chillgard. Values given are averages, as actual sensitivities vary among analyzers.

Interferant gas	Concentration (ppm, %)	Equivalent NH_3 concentration (ppm)
Acetone	1000	45
Isopropanol	1000	725
Methane	2.5%	5
Methyl Ethyl Ketone	100	25
Methylene Chloride	1000	12
o-Xylene	100	7
Pentane	0.75%	100
Propane	0.6%	50
R11	500	50
R12	100	65
R123	100	20
R134a	100	130
R22	550	15

Test conditions: Calibrated 0-1000 ppm NH_3 in N_2. Temperature: 25°C

7. Personnel Qualifications

7.1. Personnel must be trained in the use of the analyzer before initiating the procedure. Training requires about 3 h.
7.2. Read and understand the analyzer manual and this SOP before operating this analyzer.
7.3. Personnel should also be trained to interpret the analyzer output signal, converted concentration data, and correction of concentrations based on calibration.

8. Equipment and Supplies

8.1. Ammonia analyzer (Model Chillgard RT, Mine Safety Appliances, Pittsburgh, PA)
8.2. Rack and rack mounts
8.3. 3/8″ OD x 1/4″ ID x 5′ Teflon tubing
8.4. 3/8″ OD x 1/4″ ID x 5′ PVC tubing
8.5. NIST-traceable gravimetric formulated gas cylinders (specific composition will be defined in the project QAPP and/or the Site Monitoring Plan)
  8.5.1. Gas cylinder with Span gas
  8.5.2. Gas cylinder with zero air
8.6. Spare parts that should be on hand at each monitoring site include:
  8.6.1. Internal Filter, Single Point, MSA Part No. 711561
  8.6.2. Internal Filters, all Multipoint and Single-Point Ammonia, MSA Part No. 655533
  8.6.3. 2.0-A, 250-V Fuse, MSA Part No. 638091
  8.6.4. Low Flow Switch, MSA Part No. 637824

9. Procedure

9.1. Unpacking the system (See Section 2 of the Instruction Manual)
  9.1.1. Check the shipping box for damage. Report any damage to the carrier and note it on the delivery receipt or packing slip.
  9.1.2. Carefully remove the analyzer from the box.
  9.1.3. Check that there are no parts remaining in the box.
  9.1.4. Do not discard the shipping box.
  9.1.5. Do not install or operate the analyzer if damage is suspected.
9.2. Initial inspection
  9.2.1. Inspect the interior for damaged components or missing parts. Fig. 2 shows the front and right side view of the analyzer. Fig. 3 shows a bottom view with some components identified.
9.3. Gas analyzer setup
  9.3.1. Do not mount the unit onto any structure that is subject to vibration.
  9.3.2. Do not locate the unit near an excessive heat source.
  9.3.3. Allow at least 3 in. (7.5 cm) clearance around the unit for proper cooling.
  9.3.4. Securely mount the analyzer vertically on the instrument rack.
  9.3.5. Power connection
    9.3.5.1. Verify the analyzer voltage requirements match the available supply voltage. It accepts either 110 VAC or 220 VAC (Fig. 4).
      9.3.5.1.1. Wire the analyzer for 120 V with the following connections.
        9.3.5.1.1.1. Power wire (Black) to L1
        9.3.5.1.1.2. Neutral wire (White) to can.
        9.3.5.1.1.3. Ground wire (Green) to ground.
    9.3.5.2. Power wires should enter through a different opening than for signal wires.

- 9.3.6. Signal connection
  - 9.3.6.1. Connect the analog signal (4-20 mA) output of the analyzer, at output terminals 2 (I+) and 3 (RTN) on terminal strip J17 (Fig. 5), to the data acquisition system.
  - 9.3.6.2. If a 0-10 VDC output is preferred, connect instead to terminals 4 (V+) and 5 (COM) on terminal strip J17 (Fig. 5).
  - 9.3.6.3. Signal wiring should exit through an opening at the bottom of the analyzer. Do not use the same opening as that used for power wiring.
- 9.3.7. Sample tubing connection
  - 9.3.7.1. Remove all caps and plugs at sample line inlets and exhaust.
  - 9.3.7.2. Connect the gas sampling system’s analyzer manifold to the analyzer inlet with ¼″ OD Teflon tubing, and connect the analyzer outlet to the air exhaust of the on-farm instrument shelter with ¼″ ID PVC or other tubing.
- 9.3.8. Power up the analyzer, and allow it to warm up for at least 60 min before checking the concentration readings.
- 9.3.9. Enter the analyzer’s analog signal and measurement ranges into the AirDAC software (SOP B2) so that concentrations can be displayed, converted and recorded.

9.4. Gas analyzer calibration

- 9.4.1. Calibrate the Chillgard RT following SOP G8 (multipoint calibrations) and SOP G9 (precision checks).
  - 9.4.1.1. Use QAPP-specified numbers of points and gas concentrations for the multipoint calibrations and precision checks.
  - 9.4.1.2. Become familiar with the calibration screens by stepping the monitor through the whole sequence shown in Table 2.

Table 2. Calibration Sequence Screens of the Chillgard RT.

#	Press	Result
1	ANY KEY	BRINGS UP MENU
2	CAL	BRINGS UP CAL MENU
3	USER	ALLOWS ADJUSTMENTS
4	ZERO	ALLOWS ZERO CALIBRATION
5	NEXT	PROMPT: ALARMS ARE NOW OFF
6	NEXT	PROMPT: SAMPLE POINT 1 TO BE USED
7	NEXT	PROMPT: APPLY ZERO GAS
8	NEXT	PROMPT: ADJUST OR OK READING
9	OK	PROMPT: REMOVE ZERO GAS
10	SPAN	PROMPT: GO INTO SPAN CALIBRATION
11	NEXT	PROMPT: ALARMS ARE NOW OFF
12	NEXT	PROMPT: SAMPLE POINT 1 TO BE USED
13	NEXT	PROMPT: APPLY SPAN GAS
14	NEXT	PROMPT: ADJUST OR OK READING
15	OK	PROMPT: REMOVE SPAN GAS
16	NEXT	PROMPT: ALARMS ARE NOW ACTIVE
17	NEXT	RETURNS TO NORMAL OPERATION

- 9.4.1.3. Precision checks
  - 9.4.1.3.1. Precision checks documents responses to zero and one or more span gases.
  - 9.4.1.3.2. No analyzer adjustments are made or maintenance conducted during a check.
- 9.4.1.4. The calibration involves analyzer adjustment only when:
  - 9.4.1.4.1. For reference zero gas, stabilized reading is more than 1% of the full scale (current full scale range of the analyzer) different than zero.
  - 9.4.1.4.2. For reference span gas, stabilized reading is more than 10% different than the certified concentration of the reference gas.
  - 9.4.1.4.3. If analyzer is adjusted, then record the analyzer's responses to both zero and span gases in an as-found precision check (SOP G8) immediately prior to adjusting the analyzer, even before the analyzer's first use. The as-found responses are used to validate data since the previous calibration or previous precision check.

- 9.4.2. The calibration procedure for each reference gas (zero or span) is as follows:
  - 9.4.2.1. Record calibration date and time in the electronic field notes according to SOP B2.
  - 9.4.2.2. On the analyzer's front panel, follow the screen's prompts for zero or span calibration.
  - 9.4.2.3. Press "NEXT" three times. Analyzer prompts for gas (line 7 or 13 in Table 2).
  - 9.4.2.4. Introduce reference gas to the analyzer. See SOP G1 for delivery options.
  - 9.4.2.5. The following gas delivery parameters should be recorded in the fieldnotes: pressure, flow, temperature, relative humidity (SOP G1).
  - 9.4.2.6. Wait until the display values has stabilized.
  - 9.4.2.7. Record the time and concentrations shown on the Chillgard display, and by AirDAC, in the field notebook.
  - 9.4.2.8. Press "NEXT". Chillgard will prompt: ADJUST OR OK READING (Table 2).
    - 9.4.2.8.1. Press "OK" to accept reading if the analyzer does not need to be adjusted.
    - 9.4.2.8.2. If analyzer adjustment is needed (See Section 9.2.2.3), press "ADJ":
      - 9.4.2.8.2.1. Press the "↑" or "↓" buttons to adjust the reading.
      - 9.4.2.8.2.2. Press "OK" to accept reading.
  - 9.4.2.9. Stop flow of reference gas.
  - 9.4.2.10. Press "NEXT" twice to return to Normal Operation.
  - 9.4.2.11. Record calibration end time in the lab notebook.
- 9.4.3. Repeat the steps in Sections 9.4.3 for each reference gas.
- 9.4.4. Return AirDAC to automatic sampling.

9.5. Precision checks

- 9.5.1. Repeat steps in Section 9.2.2, but skip adjustment (Section 9.4.3.8.2).
- 9.5.2. Check soon after any repair or maintenance to verify solution to problem.
- 9.5.3. Use QAPP-specified frequency, replications and reference gas concentrations.

9.6. Troubleshooting (see Table 5-2 of the Analyzer Manual)

- 9.6.1. Check wiring and power connections if there is no signal or power.
- 9.6.2. Check pump if there is no flow or displayed concentrations are too low.
- 9.6.3. Check filter and replace if the filter is dirty.
- 9.6.4. Check flow path integrity if span gas concentration is under-reported, or if sample flow rate warning is displayed.

9.6.5. Clean or replace leaking solenoids. Solenoids (Fig. 5) that cannot close properly will cause a leakage into the acoustic cell, resulting in slow response and under-reporting of the span gas concentration.

9.7. Data acquisition, calculations & data reduction requirements

9.7.1. Monitor a 4-20 mA analog output using AirDAC.

9.7.2. Report the data to three significant digits.

9.7.3. Follow SOP B4 to correct gas concentrations for calibration and air density.

9.8. Computer software

9.8.1. AirDAC (SOP B2) for data acquisition

9.8.2. CAPECAB (SOP B6) for data processing

10. Data and Records Management

10.1. Maintain all laboratory records in an electronic field notes spreadsheet designated for this method. Supplement this electronic record with a record book designated for the method, and include copies of the electronic record.

10.2. Manage data according to SOP B5 “Management of Barn Data”.

10.3. Document all data and information (e.g., sample collection method used) in the field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Conduct gas analyzer checks (zero gas and one or more reference span concentrations) at a frequency specified by the QAPP.

11.2. Report QC data using a control chart in a Microsoft Excel spreadsheet (SOP Q1).

11.3. Conduct a multipoint calibration whenever the precision check of the gas analyzer drifts more than 10%.

11.4. Conduct a multipoint calibration when the zero check reading drifts more than 1% of full scale (or 10 ppm).

11.5. Gas cylinder concentrations will be verified by FTIR (SOP G12), or will be checked against cylinders which have been FTIR-verified.

11.6. Check the response time at a frequency specified by the QAPP.

11.7. Measure the gas analyzer inlet flow rate at a frequency specified by the QAPP.

12. References

12.1. Chillgard RT Manual. 1993. Chillgard RT Refrigerant Monitor Instruction Manual. (L) Rev. 13. Mine Safety Appliances. Pittsburgh, PA. Online at http://www.msa northamerica.com/gasdetection_literature.html. Accessed 3/28/2006

12.2. Roczko, A. 2001. MSA Photoacoustic Infrared Technology for Detection of Refrigerant Gases. Mine Safety Appliances. Pittsburgh, PA. Online at http://media.msanet.com/NA/USA/PermanentInstruments/HVACMonitors/ChillgardLERefrigerantMonitor/PhotoacousticRefrigerantWhitePaper.pdf. Accessed 11/7/05.

12.3. SOP B2. 2005. Standard Operating Procedure for Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.4. SOP B3. 2005. Standard Operating Procedure for Air Data Pre-Processing Software (ADPP). Standard Operating Procedure B3. Purdue Ag Air Quality Lab.
12.5. SOP B4. 2005. Standard Operating Procedure for Calculation and Reporting of Air Emissions from Barns. Standard Operating Procedure B4. Purdue Ag Air Quality Lab.
12.6. SOP B5. 2005. Standard Operating Procedure for Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.7. SOP B6. 2005. Standard Operating Procedure for Data Processing Software (CAPECAB). Standard Operating Procedure B6. Purdue Ag Air Quality Lab.
12.8. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
12.9. SOP G2. 2005. Standard Operating Procedure for Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.
12.10. SOP G8. 2005. Standard Operating Procedure for Multi-Point Calibration of Gas Analyzers. Standard Operating Procedure G8. Purdue Ag Air Quality Lab.
12.11. SOP G9. 2005. Zero and Precision Checks of Gas Analyzers. Standard Operating Procedure GP. Purdue Ag Air Quality Lab.
12.12. SOP Q1. 2005. Standard Operating Procedure for Use of Control Charts for Performance Monitoring of Gas Analyzers and Analytical Instruments. Standard Operating Procedure Q1. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. To obtain replacement parts, address the order or inquiry to:
Mine Safety Appliances Company
Instrument Division
P.O. Box 427, Pittsburgh, PA 15230
Phone: 1-800-MSA-INST

13.2. Manufacturer Technical Support: 1-888-672-4678
http://www.msanorthamerica.com/customerservice.html.

13.3. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com

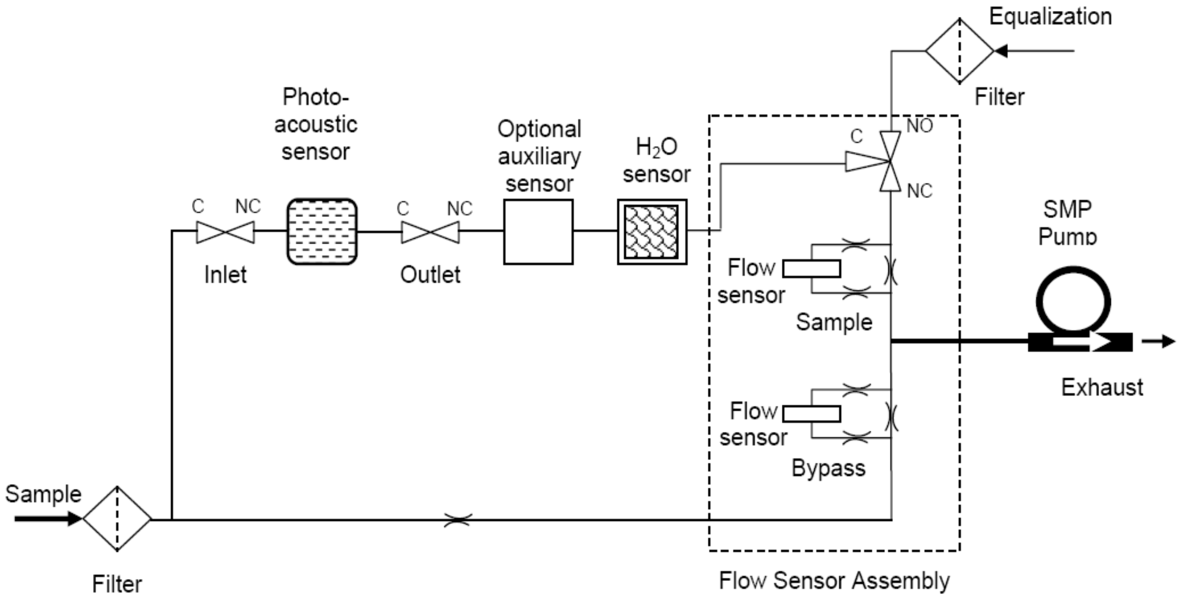


Figure 1. Analyzer flow diagram (Chillgard RT Manual, 1993).

Figure 2. Chillgard RT analyzer front view (a) and right side view (b).

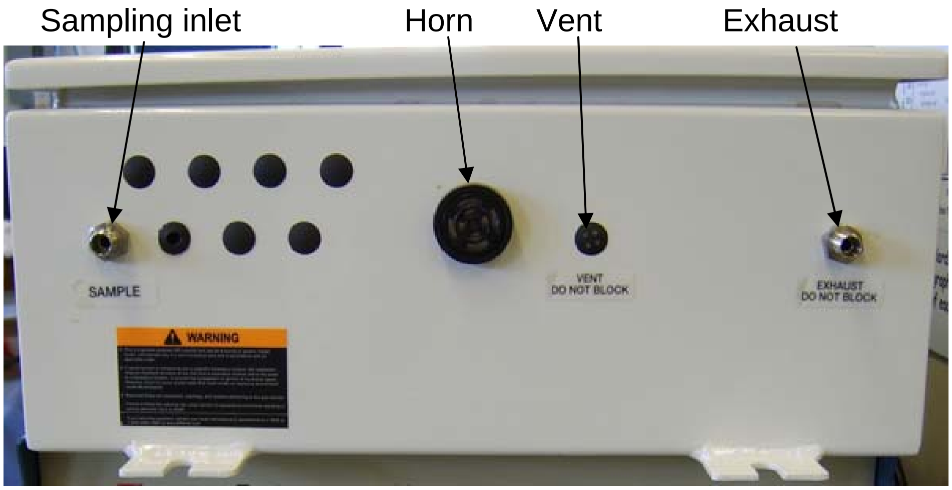


Figure 3. Chillgard RT analyzer bottom view.

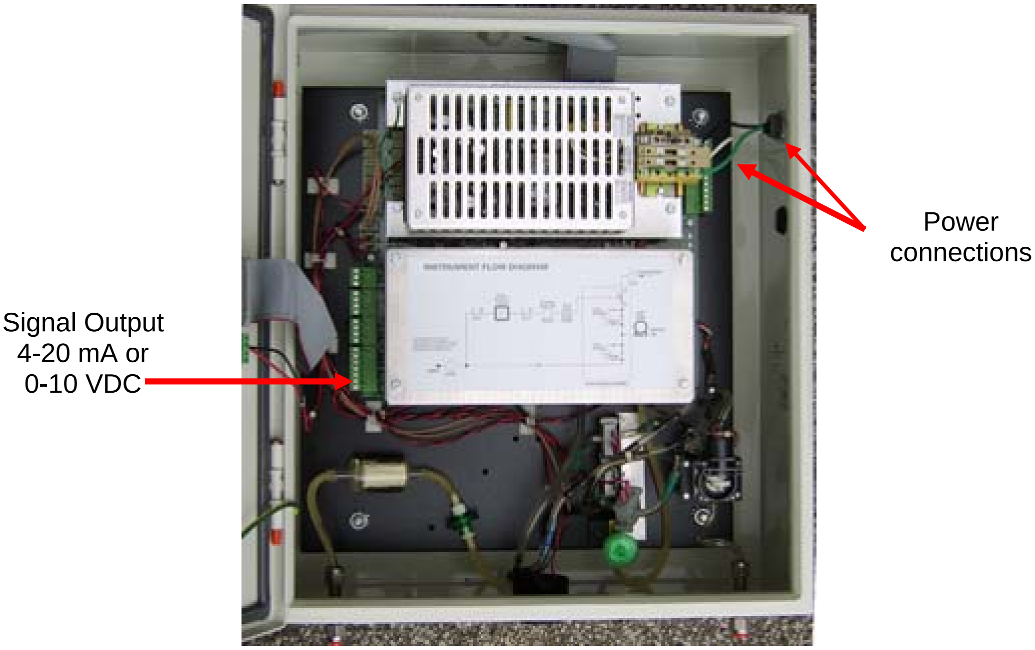


Figure 4. Chillgard RT NH_3 analyzer power connections and signal outputs.

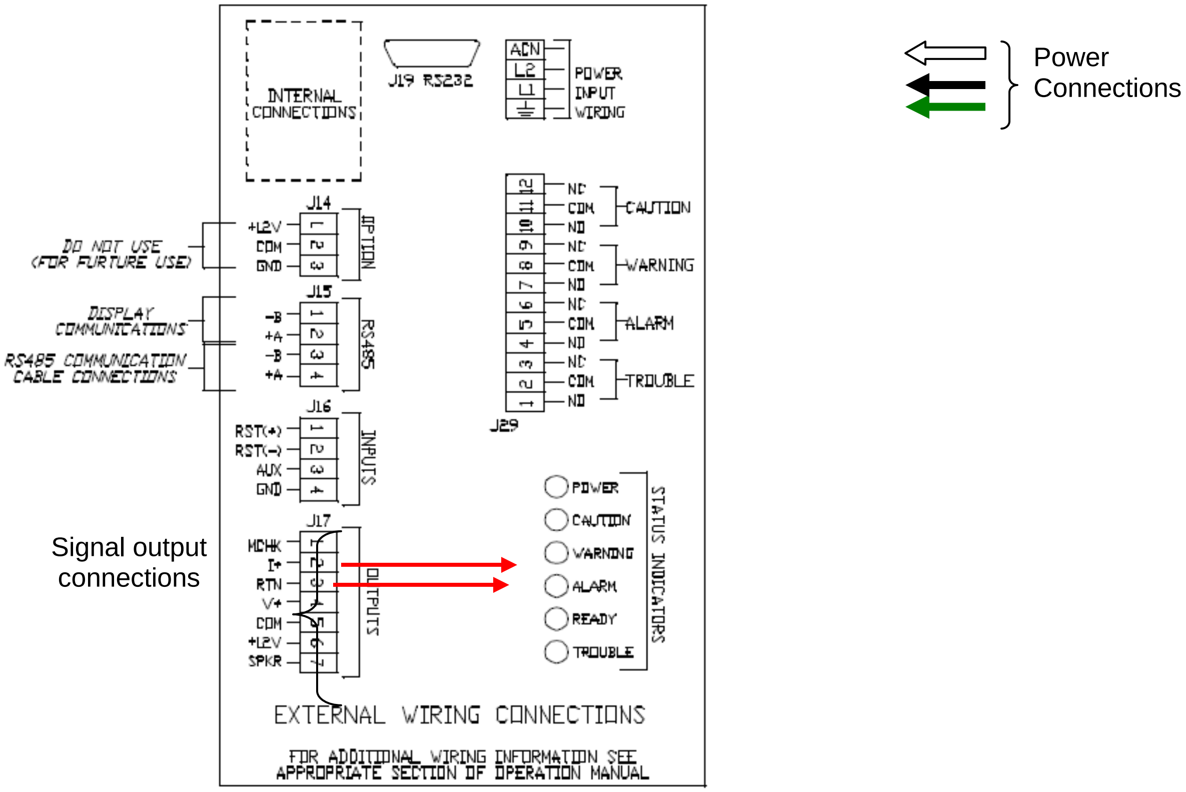


Figure 5. Wiring connections for the MSA Chillgard RT.

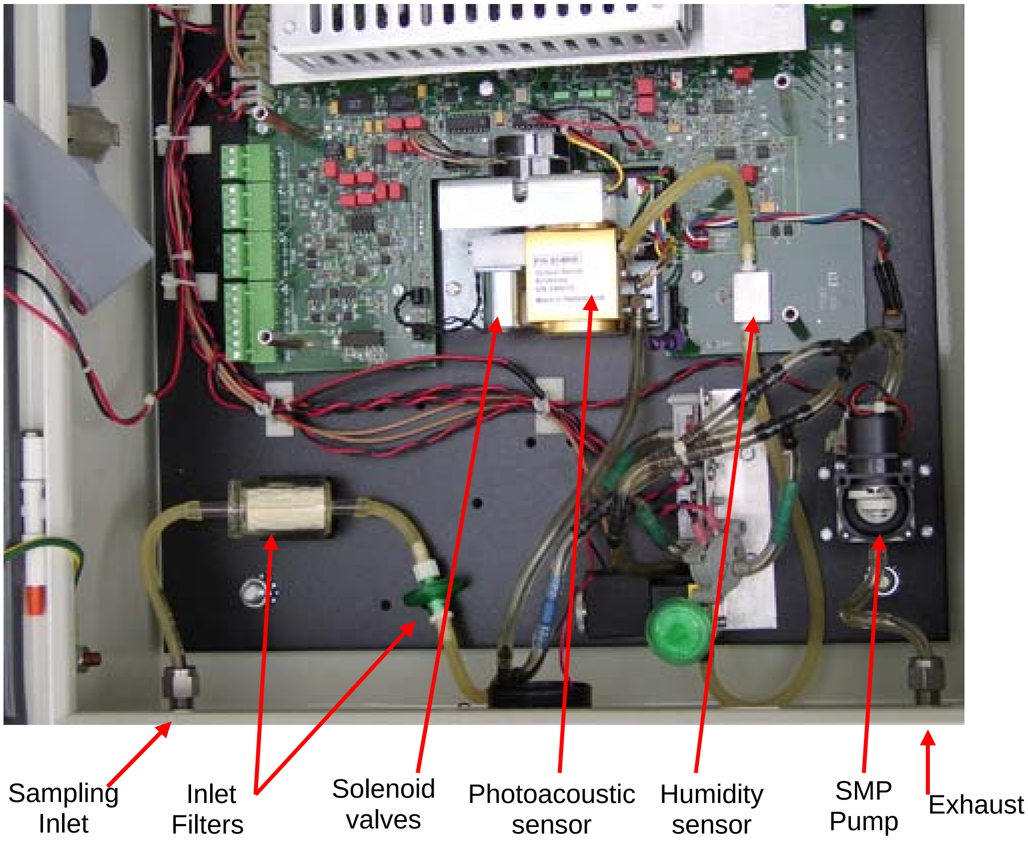


Figure 6. Chillgard RT NH_3 analyzer main components and sensors.

OPERATION OF THE ENVIRONICS® COMPUTERIZED

GAS DILUTION SYSTEM

Standard Operating Procedure (SOP) G11

OPERATION OF THE ENVIRONICS® COMPUTERIZED GAS DILUTION SYSTEM

Standard Operating Procedure (SOP) G11

Prepared by
Sam M. Hanni and Juan Carlos Ramirez

Reviewed by
Congna Li, Bill W. Bogan, and Albert J. Heber

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This method dilutes a compressed gas standard with a balance gas, allowing the resulting mixture to be used for calibrating the continuous gas analyzers which are used in monitoring barn emissions.

1.2. This method applies only to the Environics Series 4040 Computerized Gas Dilution System and its accompanying computer software.

  1.2.1. The maximum flow rate of the gas mixture is 5 L/min.

  1.2.2. The gas standard is diluted to concentrations that range from 10 to 99% of its original concentration.

  1.2.3. The minimum concentration can be reduced to 1% of the original with the addition of one mass flow controller (MFC).

  1.2.4. The minimum concentration can be reduced to 0.1% of the original with the addition of two MFCs.

  1.2.5. The accuracy of each MFC is ±1% of its set flow rate.

  1.2.6. The accuracy of the overall dilution ratio is an additive function of the errors of all MFCs involved in the dilution. For example, if two MFCs are used, the maximal error (if the individual errors of the two MFCs are in the same direction) is ±2%. If the errors of the individual MFCs are in the opposite directions, the overall dilution ratio error will be considerably lower than this.

  1.2.7. The dilutor can be programmed to automatically deliver diluted standards on a schedule.

  1.2.8. The diluter described and used in this SOP has all its gas-accessible internal surfaces passivated with a non-reactive (RESTEK) coating, which makes it suitable for use with reactive gases.

2. Summary of Method

The Environics® Series 4040 is a computerized gas dilution system that automatically generates precise gas calibration standards for single or multi-point calibration of analyzers. The system consists of two components: the Series 4040 Diluter and the user's PC. The user interface is a Microsoft® Windows application that communicates with the Environics system via a RS232 serial interface connected to any available COM port of the personal computer. The Series 4040 instrument has a single chassis supporting up to four mass flow controllers (MFC) having ranges of 5, 5, 0.5, and 0.05 L/min, respectively. This set of flow controllers allows accurate dilution of gas standards over a very wide range of dilution ratios, by selection of the appropriate flow controllers. The MFCs are factory-calibrated using a primary flow standard traceable to the National Institute of Standards and Technology (NIST). Each flow controller utilizes an 11-point calibration table with linear interpolation, to increase accuracy and reduce flow controller nonlinearity. During operation, the protocol gas concentration, inlet port, desired output concentration, and desired output flow rate are entered by means of the keypad of the personal computer used to operate the 4040 diluter, and the diluter then sets the required standard and diluents flow rates to produce the desired mixture. The 4040 diluter indicates on the computer’s display the actual concentration being produced, which in some cases differs very slightly from the nominal concentration requested. In all cases the actual concentration produced is recorded as the concentration provided to the analyzers undergoing testing. To calibrate this instrument, it is necessary to choose a pre-calibrated gas analyzer to test the concentrations produced by the diluter.

3. Definitions

3.1.	FTIR	Fourier transform infrared spectroscopy
3.2.	GC/MS	Gas chromatography/mass spectrometry
3.3.	GSS	Gas sampling system
3.4.	K-factor	Gas correction factor
3.5.	MFC	Mass flow controller
3.6.	NIST	National Institute of Standards and Technology
3.7.	OGC	Output gas concentration
3.8.	PC	Personal computer
3.9.	QAPP	Quality Assurance Project Plan

4. Health and Safety

4.1. Avoid mixing gases that may produce an explosion or other hazardous reaction. Follow all other health and safety precautions related to gas cylinders (SOP G2).
4.2. Disconnect power before servicing the unit.
4.3. Make sure that replacement fuses are the correct size and rating (115 V).
4.4. Use only grounded outlet electrical outlets.

5. Cautions

5.1. Verify that scheduled calibration date is prior to the expiration date of the standard gas.
5.2. Verify that the instrument ambient temperature conditions are in the manufacturer's recommended range of 0°C to 50°C.
5.3. If the Environics software is not connected to the LabView (AirDAC) data acquisition software (SOP B2), adjust its time to agree with the time of the LabView computer.
5.4. Note all other cautions related to gas cylinders (SOP G2).
5.5. In any case where the Model 4040 is not under the control of the AirDAC program, make sure that the computer clock (used by the Environics system) is synchronized with the time in AirDAC. If the times are not synchronized, any task programmed on the Environics dilutor could be out of phase with other tasks controlled by the AirDAC program.
5.6. Use of any USB adapter other than the one described in Section 8.3 may cause communications problems between the PC and diluter. If such problems are suspected with a different adapter, replace with this one as a first measure.

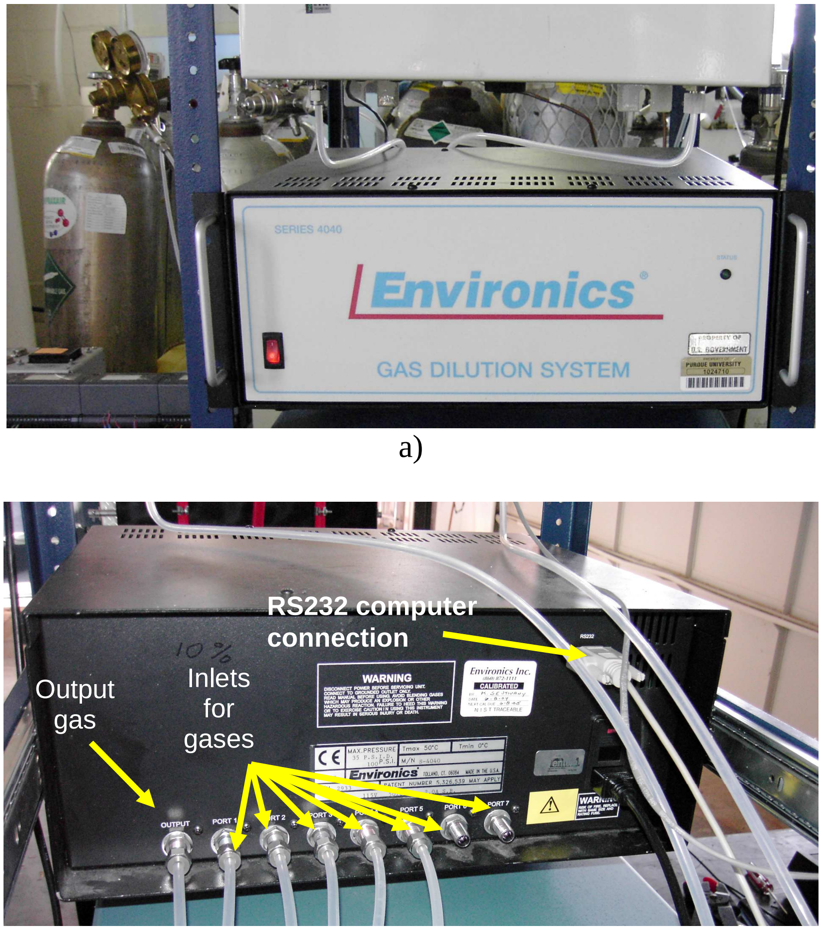
6. Interferences

6.1. Do not operate the diluter at a flow lower than 10% of the working range of the flow controller selected (this instrument has four flow controllers for different working ranges), which is a flow region where flow control errors might be enhanced. The 4040 diluter provide warnings if a flow controller is being operated at this low range. Switching to another flow controller, if available, will minimize these uncertainties.

7. Personnel Qualifications

7.1. Each operator must read and understand this SOP, SOP G2, and the instrument manual before working with the instrument.

8. Equipment and Supplies



a)

b)

Figure 1. Front (a) and back (b) of the Environics Model 4040 Gas Diluter.

8.1. Environics Series 4040 Gas Dilution System

8.2. PC. Minimum recommended: 66-MHz 486 PC with 8 MB of RAM.

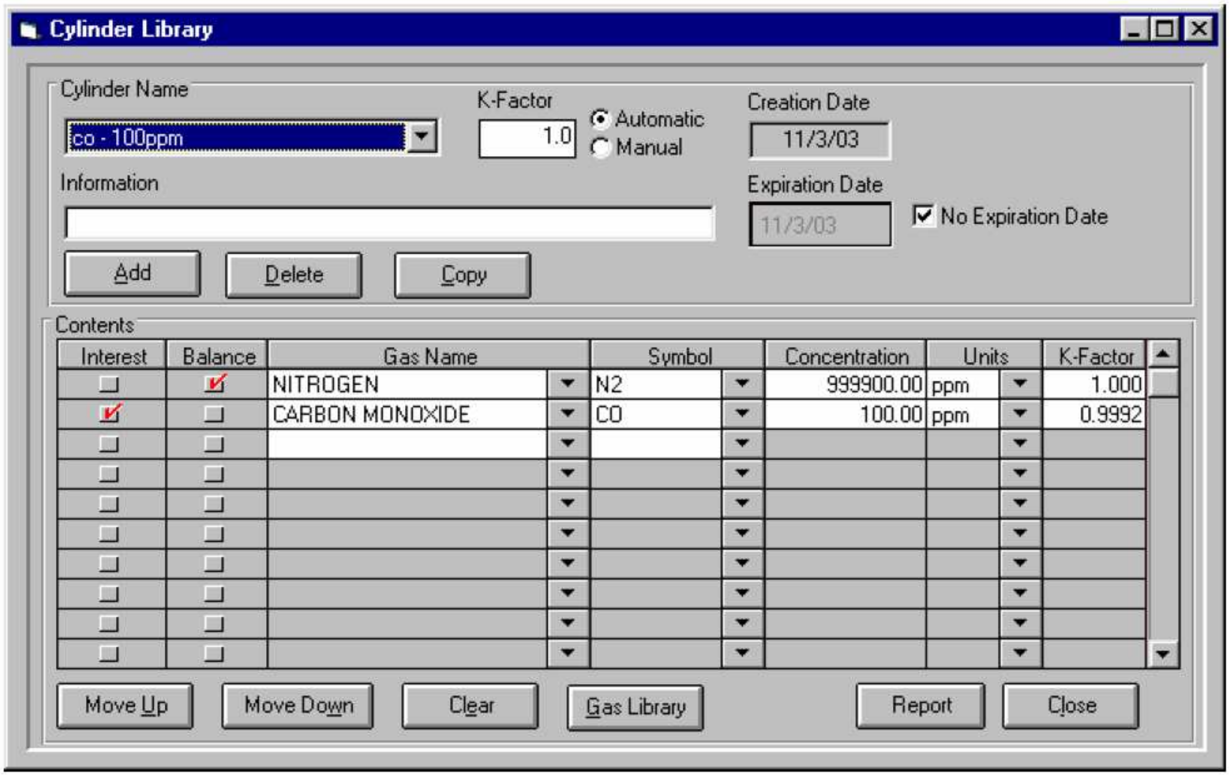
8.2.1. Operating system: Windows 3.1 or newer (including Windows 95/98/Me and Windows NT/2000/XP).

8.3. Communications cable/adapter: USB to Serial adapter DB9m, G-uc232a, Cyberguys.com.
8.4. Mass flow meter
8.5. Teflon tubing
8.6. 9/16″ box wrench

9. Procedure

9.1. Instrument setup
  9.1.1. Hardware setup
    9.1.1.1. Connect the diluter to the computer via an RS232 cable. Connect the cable to one of the COM ports (1-4) on the computer. COM 1 is the system's default port.
  9.1.2. Software installation
    9.1.2.1. Close all running window applications.
    9.1.2.2. Install the Environics Series 4000 Software from the CD included with the instrument.
    9.1.2.3. To start the software, double-click the Environics Series 4000 icon or select Environics Series 4000 from the START menu.
  9.1.3. Data disk installation
    9.1.3.1. Instrument Data Disk Installation installs instrument specific information into the Environics Instrument Data base.
    9.1.3.2. Start the Environics Series 4000 Software.
    9.1.3.3. From the Main Menu, select Configure – Instrument – Install.
    9.1.3.4. Insert the Instrument Data Disk in the appropriate floppy disk drive.
    9.1.3.5. When the Install Instrument box appears, select the appropriate Drive Icon (A or B) from the pull down box and click OK.
    9.1.3.6. The instrument is now ready to use.
  9.1.4. Creating desktop
    9.1.4.1. From the Environics Series 4000 main window select File and then New.
    9.1.4.2. In the DESKTOP box, enter a name for the Desktop.
    9.1.4.3. In the INSTRUMENT box, click the drop down arrow to display the list of available instruments and select the serial number of the instrument you are using.
    9.1.4.4. Click OK to save the new file.
  9.1.5. Cylinder Configuration
    9.1.5.1. Open Series 4000 main window click on Configure and then Cylinder to open the cylinder library. This will bring up the Cylinder Library form (Fig. 2).
    9.1.5.2. Click Add and enter a name for the new cylinder at the prompt. The name of the cylinder will usually be the name of the gas of interest in the cylinder.
    9.1.5.3. Click the OK button. This name will appear in the Name box.
    9.1.5.4. K-Factor should be set to automatic.
    9.1.5.5. Creation Date should be the current date.
    9.1.5.6. If there is no expiration date on the cylinder then click on the box next to No Expiration Date. If there is an expiration date then unclick the box next to No Expiration Date and enter in the expiration date on the cylinder.
    9.1.5.7. Type the cylinder serial number in the Information box.

9.1.5.8. Enter contents of the cylinder beginning with the balance gas. Using the pull-down box under Gas Name or Symbol in the Contents section, select the desired balance gas. The concentration will be automatically set at 1 million ppm.



Cylinder Name: co - 100ppm
K-Factor: 1.0 ● Automatic ○ Manual
Creation Date: 11/3/03
Information:
Expiration Date: 11/3/03
☑ No Expiration Date

Contents

Interest	Balance	Gas Name	Symbol	Concentration	Units	K-Factor
☐	☑	NITROGEN	N2	999900.00	ppm	1.000
☑	☐	CARBON MONOXIDE	CO	100.00	ppm	0.9992
☐	☐					
☐	☐					
☐	☐					
☐	☐					
☐	☐					
☐	☐					
☐	☐					
☐	☐					

Figure 2. The Cylinder Library Screen.

9.1.5.9. Continue adding the remaining component gases by selecting them from the Gas Name or Symbol pull down box.

9.1.5.10. Select default gas of interest by clicking the Interest box next to the desired gas.

9.1.5.11. Once all gases have been added, enter the concentration of each component gas under the concentration box. The units can be changed from ppm to % using the pull down box under units. The concentration of each gas and the unit of gas will be identified on the side of the cylinder. If the gas is read in ppb then will need to be converted to ppm. The balance gas concentration will automatically be filled in as the difference so that all gases add up to 1 million ppm (100%).

9.1.5.12. As data is entered, the cylinder K-factor will automatically be computed based on the concentration of the individual gases in the cylinder.

9.1.5.13. When done, click Close to save the cylinder information and exit the Cylinder Library. The Program will display a prompt to allow the new cylinder to be saved. Click the Yes button to save.

9.1.5.14. Alternately, click Add to add a new cylinder without exiting the Cylinder Library.

9.1.6. Editing cylinder gas information

9.1.6.1. To move or delete a gas, click the name of the gas. The name box will turn red.

9.1.6.2. To move a gas, click on the Move Up or Move Down button to move the gas down one position on the list. Continue to click on the Move Down button until the gas is in the desired location on the list.

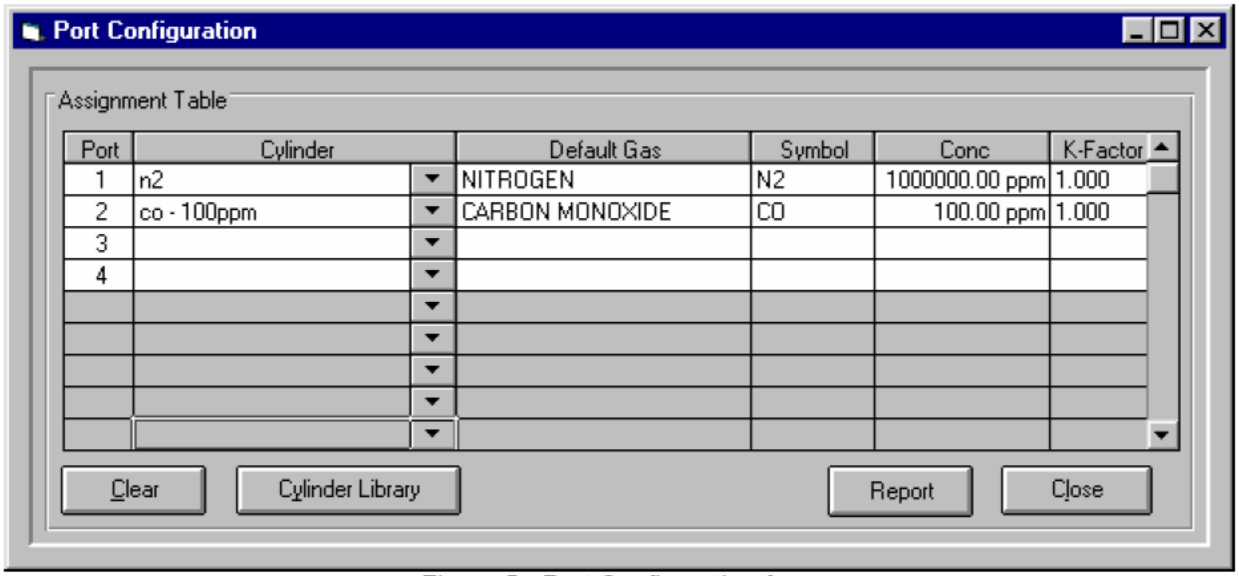
9.1.6.3. To delete the selected gas from the cylinder, click the Clear button.

9.1.7. Port configuration

9.1.7.1. To open the Port Configuration screen, select Configure – Port from the main menu. The desktop must be open to change the port configuration. If a desktop is not open, then Configure – Port will not be accessible.

9.1.7.2. The current cylinder assignments for the port configuration are displayed in the port configuration assignment table (Fig. 3). To assign a different cylinder to the port, uses the pull down box under cylinder, and select the desired cylinder from those listed in the cylinder library.

9.1.7.3. Once the cylinder is assigned, the default gas, symbol, concentration, and K-factor are automatically placed in the table from the cylinder library. It cannot be edited within the port configuration table. To edit this information, click on Cylinder Library and edit from within the library.



Port	Cylinder	Default Gas	Symbol	Conc	K-Factor
1	n2	NITROGEN	N2	1000000.00 ppm	1.000
2	co - 100ppm	CARBON MONOXIDE	CO	100.00 ppm	1.000
3					
4					

Figure 3. The Port Configuration Table.

9.1.7.4. 9.1.7.4. To save the cylinder/port assignments, click on Close, then click YES.

9.1.7.5. Using ¼″ Teflon tubing with a Gyrolok fittings provided with the instrument connect one end of the tubing to the Environics configured port and, with a Swagelok fitting connect the other end of the Teflon tubing to the regulator on the desired cylinder.

9.1.7.6. To remove cylinders from a port, select the cylinder by clicking on the cylinder name in the assignment table, and click the Clear button to remove the cylinder from the port configuration table.

9.2. Operating the instrument

9.2.1. Concentration Mode

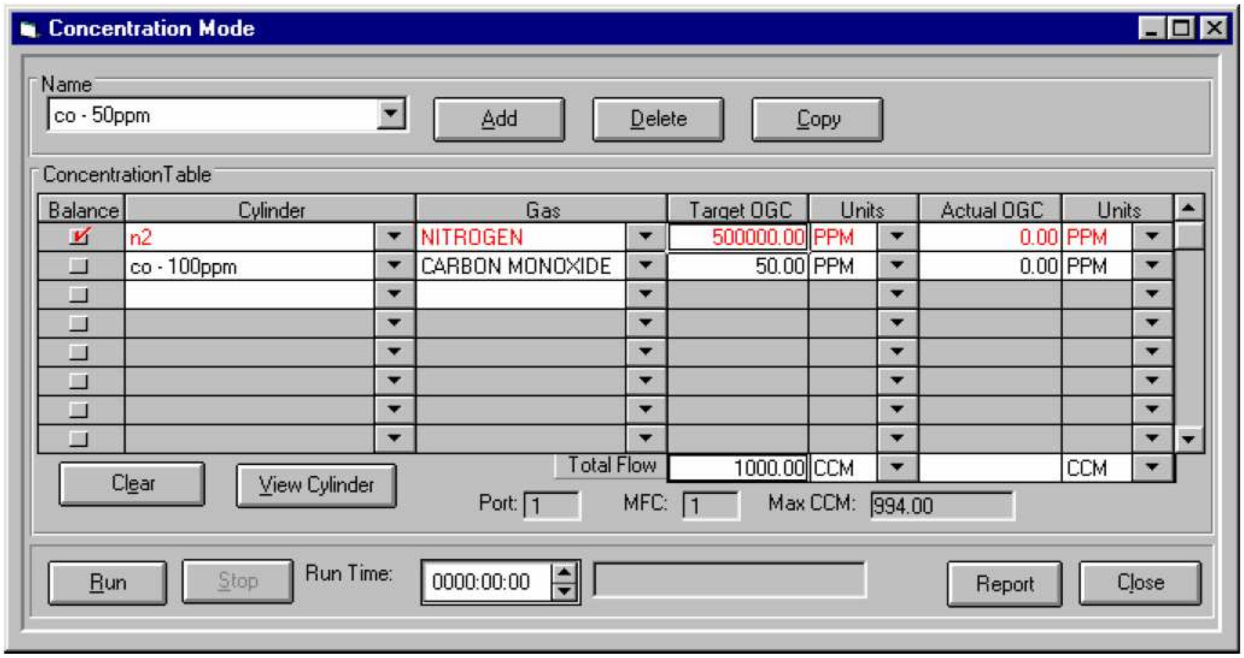
9.2.1.1. To open the Concentration Mode (Fig. 4) screen, select Run – Concentration from the Series 4000 main window.

9.2.1.2. To add a Concentration Mode file click on Add.

9.2.1.3. Enter the file name and click OK.

9.2.1.4. A blank Concentration Mode table will appear.

9.2.1.5. Specify each desired source cylinder by using the pull down box in the concentration table under Cylinder. Select the cylinder by clicking on it. The port is automatically selected based on the current cylinder/port assignments. The port number is displayed in the Port box.



Name: co - 50ppm

Balance	Cylinder	Gas	Target OGC	Units	Actual OGC	Units
☑	n2	NITROGEN	500000.00	PPM	0.00	PPM
☐	co - 100ppm	CARBON MONOXIDE	50.00	PPM	0.00	PPM
☐						
☐						
☐						
☐						
☐						
☐						
		Total Flow	1000.00	CCM		CCM

Port: 1
MFC: 1
Max CCM: 994.00
Run Time: 0000:00:00

Figure 4. The Concentration Mode Screen.

9.2.1.6. Next, specify the gas of interest by using the pull down box under Gas next to the cylinder name. Select the component gas of interest by clicking on it. To see the contents of the cylinder, click on View Cylinder.

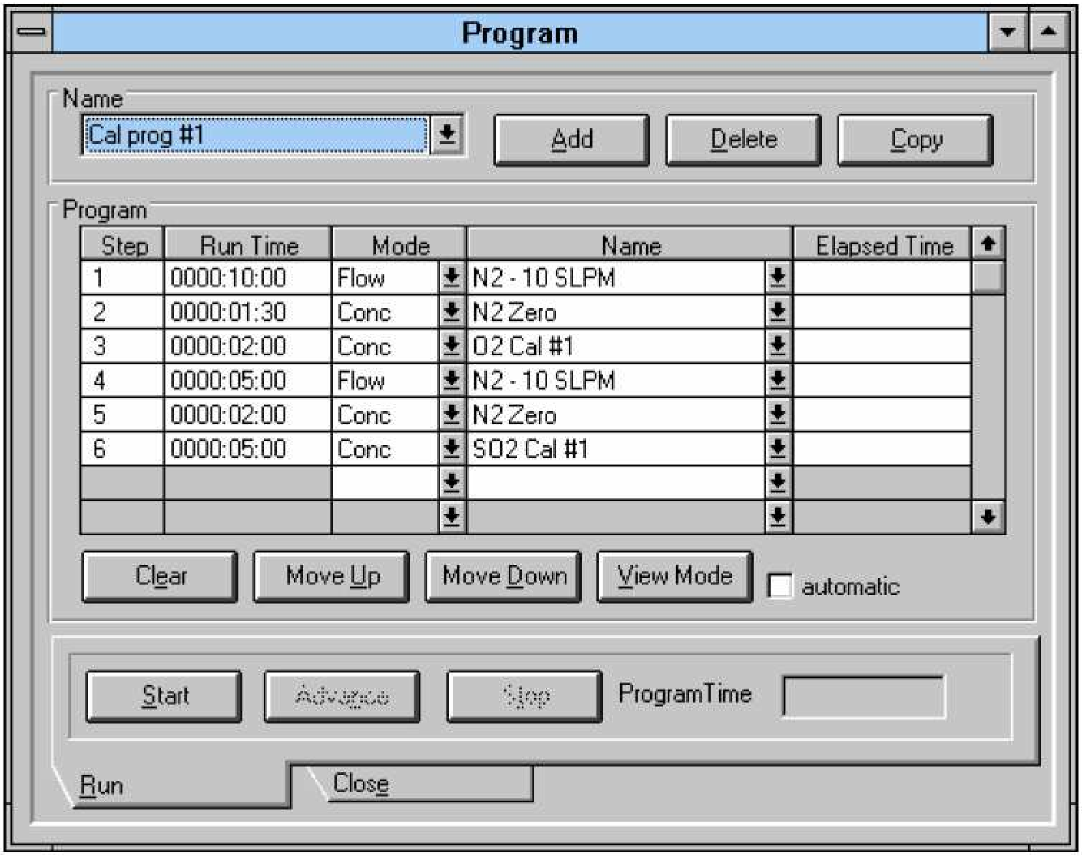
9.2.1.7. Once all of the cylinders are entered, select the balance gas by clicking the balance box beside the cylinder name.

9.2.1.8. Specify the desired output concentration for each cylinder. Type the value in the Target Output Gas Concentration (OGC) box. If desired, the units can be changed between ppm and % by using the pull down box under units.

9.2.1.9. Finally, enter the total flow by typing in its value. The units can be changed from ccm to L/min by using the pull down menu under units. The value entered is used by the system to compute the target concentration of the balance gas and the required flow of each controller.

9.2.2. Program Mode

9.2.2.1. To open the Program Mode screen (Fig. 5), select Run – Program from the Series 4000 main window.
9.2.2.2. To add a Program Mode file click on Add.
9.2.2.3. Click the Mode pull down box in the row of the desired step. Select the desired run mode which will be Conc.



Name: Cal prog #1

Program

Step	Run Time	Mode	Name	Elapsed Time
1	0000:10:00	Flow	N2 - 10 SLPM	
2	0000:01:30	Conc	N2 Zero	
3	0000:02:00	Conc	O2 Cal #1	
4	0000:05:00	Flow	N2 - 10 SLPM	
5	0000:02:00	Conc	N2 Zero	
6	0000:05:00	Conc	SO2 Cal #1	

ProgramTime

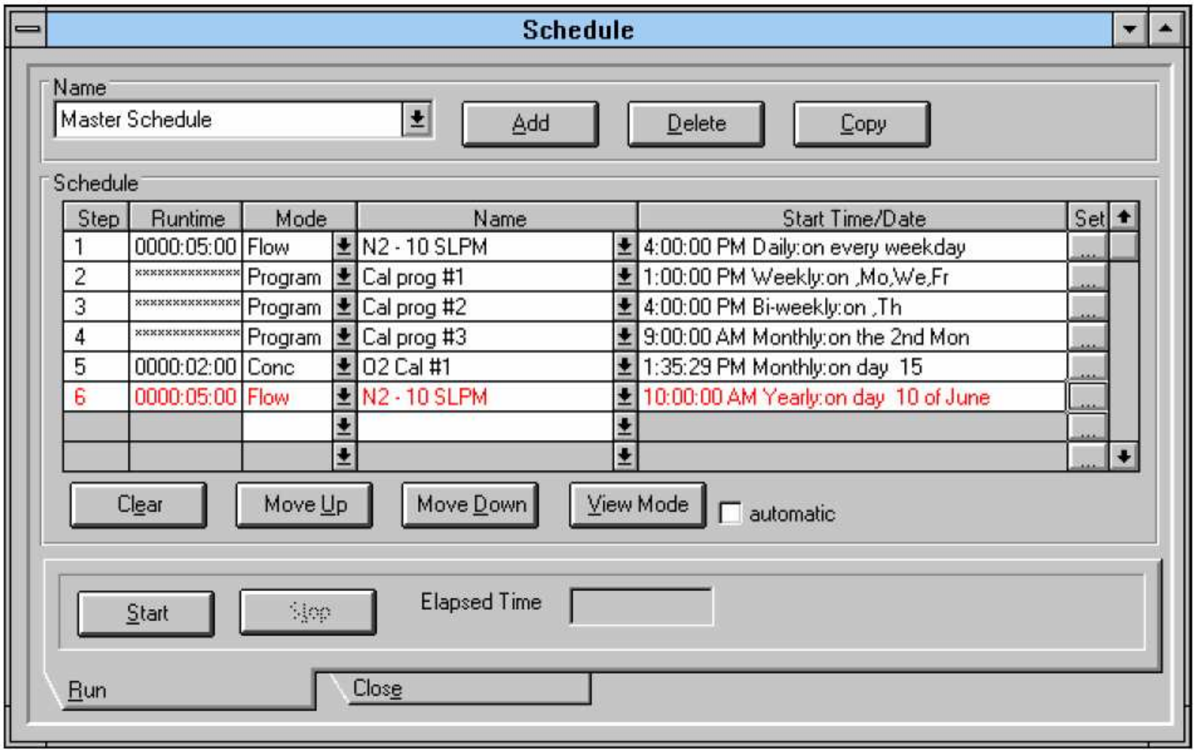
Figure 5. The Program Mode Screen.

9.2.2.4. The available saved mode names will appear in the Name box. Open the pull down box under Name; select the desired run mode file.
9.2.2.5. Click in the Run Time box to set the run time for the mode (HH:MM:SS).
9.2.2.6. Repeat until all desired steps have been entered.
9.2.2.7. Press the Start button to begin the current program. While the program is running, the Elapsed Time box indicates the elapsed time for the current step. In addition, the Program Time box indicates the total elapsed time.
9.2.2.8. To abort the current step and proceed to the next, press the Advance button.
9.2.2.9. To stop the program before completion, click the Stop button.

9.2.3. Schedule Mode

9.2.3.1. To open the Schedule Mode screen (Fig. 6), select Run – Schedule from the Series 4000 main window.
9.2.3.2. Click Add, enter a name for the file and click OK.

9.2.3.3. A blank Schedule Mode table will appear. Fill in the table with the desired values.



Name: Master Schedule

Step	Runtime	Mode	Name	Start Time/Date	Set
1	0000:05:00	Flow	N2 - 10 SLPM	4:00:00 PM Daily:on every weekday	...
2	**************	Program	Cal prog #1	1:00:00 PM Weekly:on ,Mo,We,Fr	...
3	**************	Program	Cal prog #2	4:00:00 PM Bi-weekly:on ,Th	...
4	**************	Program	Cal prog #3	9:00:00 AM Monthly:on the 2nd Mon	...
5	0000:02:00	Conc	O2 Cal #1	1:35:29 PM Monthly:on day 15	...
6	0000:05:00	Flow	N2 - 10 SLPM	10:00:00 AM Yearly:on day 10 of June	...
					...
					...

Figure 6. The Schedule Mode Screen.

9.2.3.4. Click the Mode pull down box in the row of the desired step. Select the desired run mode which will be Conc.

9.2.3.5. The available saved mode names will appear in the Name box. Open the pull down box under Name; select the desired run mode file.

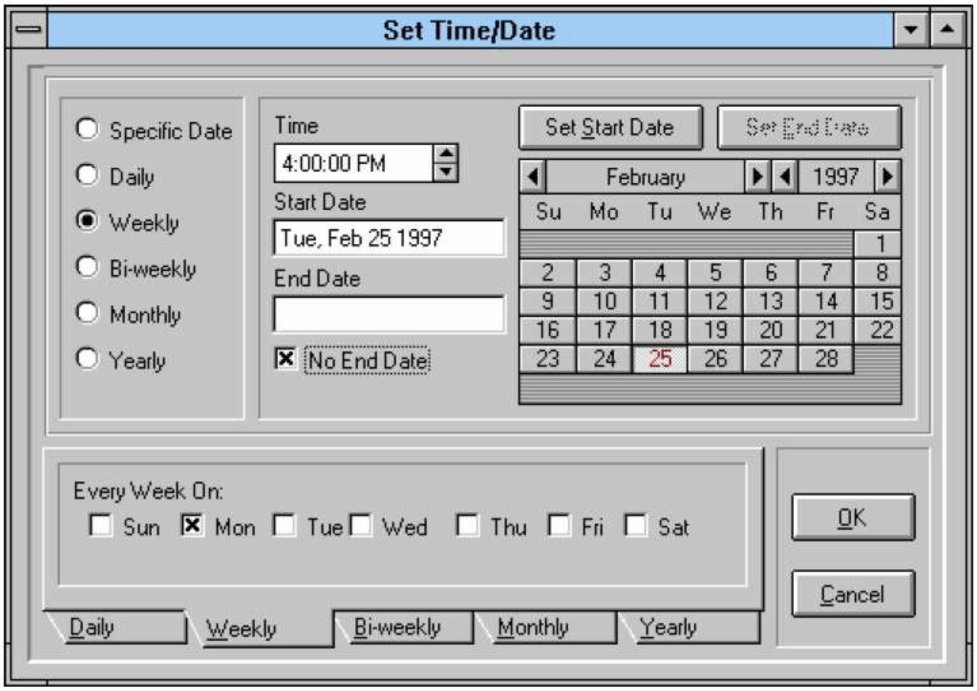
9.2.3.6. Click in the Run Time box to set the run time for the mode (HH:MM:SS).

9.2.3.7. Click the SET button to set the time/date for this item. This will bring up the Time/Date editor (Fig. 7).

9.2.3.7.1. Select the type of event using the buttons on the left side of the screen. For an item that occurs only once, click the Specific Date button. For a repeating (Daily, Weekly, etc.) event, click the button for the desired frequency.

9.2.3.7.2. For a repeating event, fill out the appropriate options at the bottom of the screen. The options displayed will vary, depending on the type of repeat chosen. If an item is repeated weekly or biweekly, select the day(s) of the week that it is to be run by clicking in the appropriate square(s). For items repeated monthly, select the day of the month on which to repeat the item (such as every first of the month or every third Monday). For items repeated yearly, select the day and month on which to repeat the item (such as every January 1 or every third Monday in May).

9.2.3.7.3. Enter the desired start time, by clicking on the Start Time box and typing in the time, or by clicking the up/down arrows.



○ Specific Date
○ Daily
● Weekly
○ Bi-weekly
○ Monthly
○ Yearly

Time: 4:00:00 PM
Start Date: Tue, Feb 25 1997
End Date:
☒ No End Date

February 1997

Su	Mo	Tu	We	Th	Fr	Sa
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	

Every Week On:
☐ Sun ☒ Mon ☐ Tue ☐ Wed ☐ Thu ☐ Fri ☐ Sat

Figure 7. The Time/Date Editor within Schedule Mode.

9.2.3.7.4. Select the desired start date from the calendar by clicking on the day and then clicking the SET START DATE button. Use the left/right buttons to change the month or year. For a Specific Date event, this is the date the item will be run. For repeating events, it is the date the event will start to repeat.

9.2.3.7.5. For repeating events, select the desired end date from the calendar by clicking on the day and then clicking the SET END DATE button. This allows the repeating event to occur within a specific range of dates. Alternately, if this item is to be repeated indefinitely, click the NO END DATE box. End Date is not used for a Specific Date event.

9.3. 9.3. Generating reports

9.3.1. From the Main Menu, select Report and then the desired report type, or click the Report button directly from the Configure/Run Mode that is currently in use.

9.3.2. In the Reports dialog box (Fig. 8), click the Select Report dropdown box to select the desired report type. The types of available reports are given in Table 1.

9.3.3. Select the desired "Create Report For" and "Selection" options desired.

9.3.3.1. To limit the report to a specific item, click the "Current desktop, selection only" option, and select the desired item in the "Selection" box.

9.3.3.2. To limit the report to all items in the current desktop, click the "Current desktop, all items" option. The item shown in the "Selection" box is ignored.

9.3.3.3. To report on all items in all desktops, click the "All items" option. The item shown in the "Selection" box is ignored.

Select Report: Divider Modes

Create Report For
● All items
○ Current desktop, all items
○ Current desktop, selection only

Selection: co divider

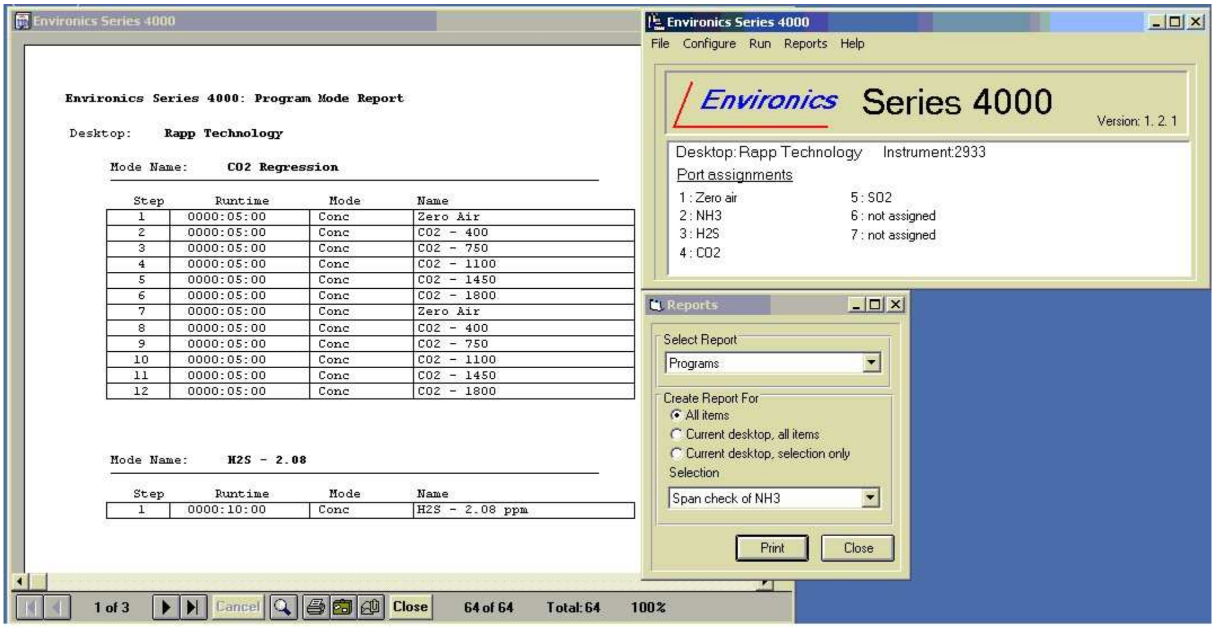
Figure 8. The Reports dialog box.

Table 1. Available report formats in the Environics software.

Gas Library	Lists all gases in the gas library
Cylinder Library	Shows cylinder name(s) and parameters (compositions and concentrations), for one or all cylinders
Cylinder Audit	Gives names, creation and expiration dates, and days until expiration for all cylinders
Physical Configuration	Gives configuration details for the MFCs, ports, and solenoids in the instrument
Instrument Calibration	Gives calibration tables for the MFC
Port Configuration	Gives cylinder assignments (name, gas and concentration) currently made to each port
Concentration Mode	Details one or more Concentration Mode files (cylinders, gas concentrations, total flow rate)
Programs	Details one or more Program Mode files
Schedules	Details one or more Schedule Mode files

9.3.4. Click Print to view the report on the screen. A sample Program Mode report is shown in Fig. 9.
9.3.5. Print the report and store it according to SOP B5.
9.3.6. Click the arrow buttons to move between pages. Click the Magnifying Glass Icon to change the view size.
9.3.7. Click the Printer icon to send the report to the printer.

9.3.8. When finished, click the Close button to return to the Reports menu.
9.3.9. Repeat Sections 9.6.2 through 9.6.8 to generate additional reports.
9.3.10. When done, click Close to return to the Main Menu.



Environics Series 4000: Program Mode Report

Desktop: Rapp Technology

Mode Name: CO2 Regression

Step	Runtime	Mode	Name
1	0000:05:00	Conc	Zero Air
2	0000:05:00	Conc	CO2 - 400
3	0000:05:00	Conc	CO2 - 750
4	0000:05:00	Conc	CO2 - 1100
5	0000:05:00	Conc	CO2 - 1450
6	0000:05:00	Conc	CO2 - 1800
7	0000:05:00	Conc	Zero Air
8	0000:05:00	Conc	CO2 - 400
9	0000:05:00	Conc	CO2 - 750
10	0000:05:00	Conc	CO2 - 1100
11	0000:05:00	Conc	CO2 - 1450
12	0000:05:00	Conc	CO2 - 1800

Mode Name: H2S - 2.08

Step	Runtime	Mode	Name
1	0000:10:00	Conc	H2S - 2.08 ppm

Desktop: Rapp Technology Instrument:2933

Port assignments

1 : Zero air
2 : NH3
3 : H2S
4 : CO2
5 : SO2
6 : not assigned
7 : not assigned

Select Report: Programs

Create Report For
● All items
○ Current desktop, all items
○ Current desktop, selection only

Selection: Span check of NH3

Figure 9. Screen capture showing a sample Program Mode report.

9.4. Troubleshooting

9.4.1. Perform the steps in Section 9.1.3 if a "no instruments registered" warning appears.
9.4.2. When opening a desktop, the software will try to communicate with the assigned instrument. If it is unable to communicate, a warning message will be displayed. There are two possible reasons for this:
9.4.2.1. The desktop's assigned serial number does not match the instrument being used.
9.4.2.2. The selected PC serial port on the Environics software might be configured to a COM different from the actual COM that is connected to the PC.
9.4.3. The only available cylinders listed are those assigned to ports. If the desired cylinder is not listed, modify the port settings.
9.4.4. The Program Mode cannot be set up unless either the Concentration, Flow, or Divider mode is set up.

9.5. Computer hardware & software

9.5.1. Store all applicable software in the data acquisition computer.
9.5.2. The dilutor can be controlled by, and input data to, the AirDAC program (SOP B2).

10. Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.
10.3. Document all data and information (e.g., sample collection method used) on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.
10.4. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Flow Calibration (Initial)
  11.1.1. Mass flow controller zero check
    11.1.1.1. Some MFCs require the cover to be removed to make adjustments
    11.1.1.2. Connect the (-) lead from a voltmeter to PC402 GROUND (TP2).
    11.1.1.3. Connect the (+) lead to each MFC Response Test Point: MFC1 (TP9), MFC2 (TP11), MFC3 (TP13), and MFC4 (TP15).
    11.1.1.4. Verify that the voltage at each test point is 0 V ±.025 V for a Tylan MFC and 0.01 V ±0.005 V for a Hastings MFC. If the "zero" is out of spec, adjust the MFC “zero” pot to bring it within these specified ranges.
    11.1.1.5. After adjusting the “zero” pot, replace system cover.
    11.1.1.6. After "zero" adjustment, wait at least one hour (1 h) for temperature to stabilize before proceeding to MFC calibration (Section 11.1.2).
  11.1.2. Mass flow controller calibration
    11.1.2.1. Connect calibration gas to the appropriate input ports for the MFCs being calibrated. The input pressure should be approximately 25 psig.
    11.1.2.2. Connect a primary standard flow calibration device to the output of the system.
    11.1.2.3. Be sure the instrument is connected to the PC and powered up.
    11.1.2.4. Run the Environics Series 4000 software.
    11.1.2.5. From the menu screen, select Configure.
    11.1.2.6. Select Instrument.
    11.1.2.7. Select Calibrate.
    11.1.2.8. In the Reference Gas box, click the down arrow button and set this to match the calibration gas for that MFC.
    11.1.2.9. In the Controller Instrument box, click the down arrow button, and select the serial number of the instrument to be calibrated.
    11.1.2.10. In the MFC box, click the down arrow button, and select the desired Mass Flow Controller to enter data (start with MFC 1).
      11.1.2.10.1. If the MFC has been changed, select Init Points, enter appropriate size in Max Flow, Table will initialize.
    11.1.2.11. Click on the 100% calibration point and press Start. Wait at least 10 min for flow to stabilize before continuing.
    11.1.2.12. Using a mass flow meter, take a flow measurement. Measured flow value must be between 100% and 110% of the MFCs rated full-scale flow. If flow value is out of this range, adjust the MFC “span” pot.
      11.1.2.12.1. Some MFCs require the cover to be removed to make adjustments. In this case, after performing “span” adjustment, replace MFC cover. After adjusting “span” pot, replace system cover and wait at least 1 h for temperature to stabilize before continuing.

11.1.2.13. If measured flow value is acceptable, enter the measured value in the True Flow column. If not, repeat Step 9.3.11.

11.1.2.14. Click on the next calibration point, and press the Start button. Wait at least 2 min for flow to stabilize before continuing.

11.1.2.15. Take a flow measurement, and enter the value in the True Flow column.

11.1.2.16. Repeat Steps 9.3.14 to 9.3.15 until all calibration points have been completed.

11.1.2.17. Press Stop, then press Save to save the MFC calibration data. This will download the new calibration files to the instrument.

11.1.2.17.1. If a warning appears “CAL TABLE ERROR -3”, click OK, then save again before exiting.

11.1.2.18. Repeat steps 9.3.10-9.3.17 until all MFCs have been calibrated.

11.1.2.19. Click Close to return to the main menu screen.

11.2. Flow Calibration (Periodic)

11.2.1. The FRM 205 recommends that the gas dilution system shall be recalibrated once per calendar year using NIST-traceable primary flow standards with an uncertainty of ≤ 0.25%. The QAPP may specify a more frequent calibration schedule. The manufacturer will conduct this recalibration.

11.2.2. Keep a label (Fig. 10) affixed at all times to the gas dilution system listing the date of the most recent calibration, and the due date for the next calibration.

Calibration date:________________
Next calibration due date:_________

Figure 10. Sample calibration label.

11.2.3. Before sending a unit to the manufacturer for re-calibration, record the existing (as-found) flow rate (if this is not automatically recorded by AirDAC), and the resultant dilution ratio based on that flow rate.

11.3. At each use of the Model 4040, document its delivered flow rate to ensure that it is at least 0.5 L/min higher than the GSS flow rate (SOP G1).

11.4. In any case where the Model 4040 is not under the control of the AirDAC program, make sure that the computer clock (used by the Environics system) is synchronized with the time in AirDAC.

12. References

12.1. Environics Model 4040 Manual. 2003. Series 4000/4040 Gas Mixing System/Gas Dilution System. Environics, Inc, Tolland, CT.

12.2. Environics Inc. 2003. Computerized Gas Dilution System Series 4040, Online at http://www.environics.com/4040.html. Accessed 10 January 2006.

12.3. SOP B2. 2006. Data Acquisition and Control Software (AirDAC) Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

12.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue

Ag Air Quality Lab.
12.5. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
12.6. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.
12.7. SOP G12. 2006. FTIR Verification of Gas Cylinder Concentration. Standard Operating Procedure G12. Purdue Ag Air Quality Lab.
12.8. SOP V6. 2006. GC/MS Analysis of VOCs Collected in Sampling Canisters. Standard Operating Procedure V6. Purdue Ag Air Quality Lab.
12.9. SOP V7. 2006. Cleaning, Certification and Pre-sampling Preparation of Sampling Canisters. Standard Operating Procedure V7. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturer:
Environics, Inc.
69 Industrial Park Road East
Tolland, CT 06084-2805
Phone: (860) 872-1111
Fax: (860) 870-9333
E-mail: info@environics.com
Web Page: http://www.environics.com

FTIR VERIFICATION OF GAS CYLINDER CONCENTRATION

Standard Operating Procedure (SOP) G12

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Standard Operating Procedure (SOP) G12

Prepared by

Congna Li

Reviewed by

Bill W. Bogan, Jacek A. Koziel (Iowa State Univ.), and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. A method is needed which will accurately analyze the concentrations of certified standard gases in cylinders purchased from outside vendors. Such a method is needed to ensure that the gas cylinders which are used for calibrations and/or performance checks of gas analyzers and other analytical instruments do, in fact, contain gases at their stated concentrations.

1.2. Fourier Transform Infrared (FTIR) Spectroscopy provides a reliable method for verifying gas cylinder concentrations for vapor-phase organic or inorganic compounds that absorb energy in the mid-infrared spectral region, about 800-4000 cm-1. Compounds that can be checked using this method include ammonia, carbon dioxide, methane, hexane, n-butanol, acetone, ethylene, carbon monoxide, propane, and nitrous oxide.

1.3. Typically, the FTIR minimum detection limit is as low as 2-10 ppb. Analytical range and sensitivity depend on the frequency-dependent component absorptivity, instrument configuration, data collection parameters, and gas stream concentration.

  1.3.1. Instrument factors that affect performance (range, sensitivity, etc.) include:
    1.3.1.1. Spectral resolution
    1.3.1.2. Interferometer signal averaging time
    1.3.1.3. Detector sensitivity and response
    1.3.1.4. Absorption path length

1.4. This procedure applies only to the Nexus 670 FTIR gas spectrometer (Thermo Electron Corporation, Palatine, IL).

2. Summary of Method

The FTIR gas spectrometer (Nexus 670, Thermo Electron Corporation, Palatine, IL) allows accurate analysis of concentrations of compounds that are delivered from gas cylinders. The FTIR analyzer consists of a KBr beamsplitter, a mercury cadmium telluride High D* (MCT-High D*) detector (cooled with liquid nitrogen), an IR source, a heated stainless steel gas absorption cell, an electronic package, and a computer. The sample gas can be delivered to the gas absorption cell either directly from the gas cylinder (continuous purge mode), or from a sample bag to the vacuumed gas cell (batch mode). The latter is used if the gas cylinder is not available onsite with the FTIR. The optical bench measures the intensity of a specially encoded infrared beam after it has been passed through a sample. The resulting signal, called an “interferogram”, contains information about all frequencies present in the beam. The computer reads the interferogram, uses Fourier transformation to decode the intensity information for each frequency, and presents the spectrum. Absorbance band intensities in the spectrum are related to sample concentrations by what is commonly referred to as Beer’s Law. The frequency-dependent relationship between absorptivity and concentration can be determined by taking standard spectra of samples of compounds at known concentrations. Unknown compounds can be detected by matching sample absorbance bands with bands in standard spectra, and their concentrations can be calculated by comparing sample band intensities with standard band intensities. Using OMNIC QuantPad software (Thermo Nicolet Instrument Corporation, Madison, WI), quantitative analysis methods can be created which allow analysis of spectra from gas- or condensed-phase samples using the Classical Least-Squares (CLS) quantitative analysis algorithms.

3. Definitions of Terms and Acronyms

3.1.	FTIR	Fourier Transform Infrared (FTIR) spectrometer
3.2.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.3.	Analyte	A compound that the method is required to measure.

4. Health and Safety

4.1. When filling the detector's Dewar flask, be careful not to contact the liquid nitrogen with your skin. Wear protective gloves and goggles, and follow standard laboratory safety practices.

4.2. Do not touch the infrared source housing; it may be very hot. It stays hot for up to 15 min after the spectrometer is turned off.

4.3. Always follow the safety information that is displayed on the spectrometer itself. Do not operate a spectrometer, or any accessory, without following the safety precautions described in the manual and the documentation that came with the spectrometer.

4.4. Laser light exposure is possible when a beam-deflecting accessory (for example, a diffuse reflectance accessory) is installed. Never stare into the sample compartment when a beam-deflecting accessory is installed.

4.5. Avoid exposure to hazardous compounds when delivered from gas cylinders. Ensure that the gases are properly vented and that the gas delivery system is leak-free.

5. Interferences

5.1. Background interference. This results from a change in throughput relative to single beam background. In routine sampling, throughput may degrade over several hours. Periodically a new background spectrum must be collected.

5.2. Interference occurs when other compounds in the sample have spectral features that overlap with those of the analyte(s). Water vapor and CO2 are common spectral interferents. The extent of interference depends on the interferent concentration, analyte concentration, and the degree of band overlap. Spectral interference can be minimized or avoided by choosing an alternate spectral region for analysis.

5.3. If the temperature in the gas cell is too low, condensation of the analytes and/or water vapor can occur. Set the temperature of the gas cell at 50°C to minimize condensation.

5.4. In addition to being a spectral interferent, condensed moisture removes soluble compounds from the gas phase by allowing them to dissolve into the separate liquid phase.

5.5. Ambient air can mix with the sample if the gas absorption cell valves are not leak-free when delivering the sample in batch mode from a sample bag.

5.5.1. When introducing sample from a sample bag, minimize the length of inlet tubing to reduce errors in gas concentrations.

5.6. Samples stored in sample bags should be analyzed as soon as possible (preferably within 24-48 hrs) to avoid potential contamination of chemicals released from the sample bag itself and the loss/uptake of gases via diffusion though walls.

5.6.1. If possible, controlled tests with sample bags should be performed prior to their use to collect samples, to establish that the analyte(s) of interest are not lost from the bags. See Section 11.9.

6. Cautions

6.1. Always ensure that the detector is cooled by liquid nitrogen before taking a spectrum.

6.2. The manufacturer recommends that the spectrometer power remain on, even when not in operation. Allow the spectrometer to warm up for one hour if the power has just been turned on, then align it before collecting spectra.

6.3. Collect a new background spectrum regularly, preferably once every 4 h during the operation of the FTIR.

6.4. Collect a new background spectrum if the software parameters have been changed.

6.5. Align the spectrometer daily for optimum performance. The spectrometer should also be aligned if the ambient temperature has changed by at least 5°C, or in such situations such as when a laser has been replaced, a beamsplitter has been installed, the spectrometer has just been moved, or the detector signal intensity has dropped significantly from its usual level.

6.6. Never use a flammable gas to purge a spectrometer bench. The purge gas must be free of moisture, oil and other reactive materials. Use dried air or nitrogen to purge the instrument. Other gases, even inert gases such as argon (Ar), can damage the spectrometer laser.

6.7. The FTIR operates reliably at ambient temperatures between 16°C and 27°C. Temperature changes may result in drift in the system response.

6.8. The sample spectra to be analyzed using a particular method must have the same data point spacing and the same spectral range (frequency limits) as the spectra used to calibrate the method.

6.9. The calibration spectra must be of pure components or pure components diluted with a solvent or gas that either doesn’t absorb infrared energy or absorbs in a different region of the infrared spectrum.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument before initiating the procedure. Training requires about three days.
7.2. Each analyst must read and understand the entire instrument manual and this SOP before operating it.
7.3. Personnel should also be trained in verifying the instrument is functioning properly, performing routine maintenance, making a calibration method for analyzing a specific component, and interpreting the analyzer output signal.

8. Equipment and Supplies

8.1. FTIR gas spectrometer (Model Nexus 670, Thermo Electron Corp., Palatine, IL).
8.2. Stainless steel gas absorption cell (Mars Model 8L/40V, Gemini Scientific Instruments, Buena Park, CA)
8.3. Purge gas generator (Model PCDA1112-122, MTI-Puregas, Westminster, CO).
8.4. Absolute pressure gauge (Automation Products Group, Logan, UT)
8.5. Temperature controller (Model 689-0005, Barnant Co., Barrington, IL).
8.6. Heat Jacket and Thermo Controller
8.7. Vacuum pump
8.8. Nitrogen gas
8.9. Liquid nitrogen, Dewar flask, and funnel
8.10. Teflon tubing
8.11. Calibration standard gas
8.12. Sample bags (if gas cylinder is offsite)
8.13. Diluter

9. Procedures

9.1. Take triplicate bag (#1, 2, and 3) samples from a gas cylinder, if the gas cylinder is offsite.
  9.1.1. Flush each bag thoroughly at least 3 times with ultra-high purity (UHP) grade nitrogen and vacuum completely before use. Bag volume should be ≥ 40 L.
  9.1.2. Turn on the gas cylinder following SOP G2.
  9.1.3. Connect Teflon tubing that is connected to the gas cylinder regulator to the hose connection of bag (#1) fitting (stem protruding from the side of the bag fitting).
  9.1.4. Open the shut-off valve of the bag (#1) by holding the side stem and turning the entire upper portion of the fitting counterclockwise one revolution. Gas from cylinder begins to fill the bag. Fill the bag to no more than 80% of its maximum volume.
  9.1.5. Turn the gas cylinder off and close the shut-off valve of the sampling bag (#1) by holding the side stem and turning the entire upper portion of the fitting clockwise until it is snug.
  9.1.6. Detach the Teflon tubing from the sample bag (#1).

- 9.1.7. Finish sampling for bags #2, and 3 by repeating the Sections 9.1.1 to 9.1.6.
- 9.1.8. Pack the filled sample bags in a rigid carton to prevent damage or discharge during shipping. Ship the samples to the laboratory by overnight delivery, but do not ship sample bags by air unless the cargo cabin of the aircraft is pressurized. Time shipping dates so that samples are received by the laboratory when someone is there to accept them.

9.2. Turning on the system components

- 9.2.1. Connect external power supply.
- 9.2.2. Turn on accessories such as the temperature controller.
- 9.2.3. Turn on the spectrometer by pressing the power switch (I/O).
- 9.2.4. Turn on the printer (if available).
- 9.2.5. Turn on the computer.
- 9.2.6. Allow at least 1 h after turn on of the spectrometer and wait until the temperature inside the gas cell stabilized at 50°C before collecting spectrum.
- 9.2.7. Keep spectrometer on at all times for stable operation.
- 9.2.8. If the system components are to be turned off, do so in the following order:
  - 9.2.8.1. Turn off computer.
  - 9.2.8.2. Turn off printer.
  - 9.2.8.3. Turn off spectrometer.
  - 9.2.8.4. Turn off accessories.

9.3. Checking the purge gas generator

- 9.3.1. Set the pressure regulator of the purge gas generator between 20 and 40 psi.
- 9.3.2. Set the flow meter to deliver around 30 scfh.
- 9.3.3. Use only nitrogen or compressed air to purge the system.

9.4. Starting OMNIC software

- 9.4.1. Double-click the OMNIC shortcut on the windows desktop.

9.5. Cooling the detector with liquid nitrogen

- 9.5.1. Before running any samples, check whether liquid nitrogen needs to be added.
  - 9.5.1.1. Open OMNIC.
  - 9.5.1.2. Select “Experiment Setup” from the “Collect” Menu.
  - 9.5.1.3. Go to the tab labeled “Diagnostic”.
  - 9.5.1.4. If the detector signal is a flat line, liquid nitrogen must be added to the system before spectra are collected.
  - 9.5.1.5. Wait 15 min, or until the signal intensity is satisfactory before collection (the magnitude of signal changes as a function of resolution being used). A minimum signal intensity of 30% of maximum voltage is required if resolution is set at 1.
  - 9.5.1.6. Liquid nitrogen will evaporate over time, even if the FTIR does not scan. As a rule of thumb, it should be replenished after 8-10 h, even if the system has been idle during that time.
- 9.5.2. Add liquid nitrogen
  - 9.5.2.1. ALWAYS wear protective eye wear and gloves.
  - 9.5.2.2. Fill the small liquid nitrogen Dewar cylinder 2/3 full from a large Dewar.
  - 9.5.2.3. Open the lid on the left hand side of FTIR, and pour liquid nitrogen from the small Dewar into the top hole using the special funnel provided.

9.5.2.4. Close the lid and return gloves/goggles to the drawer.

9.6. Quant Pad set up prior to collecting spectrum

9.6.1. Open Quant Pad.

9.6.2. Click “Method” button on the Quant Pad button panel.

9.6.2.1. Click the “Select Method” button.

9.6.2.2. Select the file of the quant method you want to use for the gas cylinder concentration check and then choose “OK”. An analysis method can be made following the procedures described in Section 9.11. If the gas concentration being checked is outside the analysis range, dilute the gas (SOP G11).

9.6.3. Click “Collect” button on the Quant Pad button panel.

9.6.3.1. Set the number of scans for both background and sample at 64.

9.6.3.2. Click the “More” button at the bottom of the above dialog box to check the settings of the data collection parameters.

9.6.3.2.1. Make sure that Resolution, Apodization, Zero Filling, Final Format, and File Handling parameters are set properly according to Table 1.

9.6.3.2.2. If a new background is needed before taking the sample spectra (e.g., when the sample is going to be taken more than 4 h after the last background spectrum is taken), make sure the background setting is placed at the third option (“collect background after x minutes”).

9.6.3.2.3. Otherwise, make sure the background setting is placed at the fourth option (“use specified background file”), and that the latest background file is loaded.

9.6.3.2.4. Click “OK” when finished setting the collection parameters.

9.6.4. Align the optical bench by clicking “Align” in the Quant Pad button panel.

9.7. Perform FTIR gas absorption cell leak-check. Follow the procedures described in Section 11.8.

9.8. Collecting a background spectrum

9.8.1. Check the settings of the data collection parameters by clicking the “Collection” button on the Quant Pad button panel. Make sure the background setting is placed at “collect background after xx minutes”.

9.8.2. Flush the FTIR chamber with pure nitrogen, delivered directly from gas cylinders, for at least 10 min. Control delivery rate at 5-10 L/min. Continue to deliver nitrogen while the background spectrum is being collected.

9.8.3. Click the “Background” button on the Quant Pad button panel.

9.8.4. Click “OK”.

9.8.5. Wait until the specified number of scans has been collected. A typical background spectrum is depicted in Fig. 1.

9.8.6. Click “Yes” to add the background spectrum to the indicated spectral window.

9.8.7. Use the “Save As” command in the OMNIC File menu to save the background spectrum on the hard disk.

9.8.8. A new background should be taken at least once at the beginning of the day’s work, or preferably every 4 h during continuous scanning.

9.9. Collecting and analyzing a sample spectrum

- 9.9.1. Check the settings of the data collection parameters by clicking the “Collection” button on the on the Quant Pad button panel. Change the background setting to “use specified background file” option, and load the file where the most recent background spectrum is saved. When collecting sample spectra, use the same parameter settings that were used to collect the standard spectra (Table 1). Collect the sample and standard spectra at the same pressure and approximately the same temperature.
- 9.9.2. Introduce sample
  - 9.9.2.1. Batch Sampling (offsite cylinder): Load bag sample into FTIR chamber using vacuum/fill step.
    - 9.9.2.1.1. Purge the FTIR gas cell with nitrogen at 5-10 L/min for at least 10 min.
    - 9.9.2.1.2. Close inlet valve on FTIR.
    - 9.9.2.1.3. Attach vacuum pump to the outlet tubing connected to the FTIR.
    - 9.9.2.1.4. Turn on the vacuum pump, open outlet valve on FTIR, and wait until the pressure drops to stable level (usually around 80-200 torr).
    - 9.9.2.1.5. Close the outlet valve. Turn off vacuum pump.
    - 9.9.2.1.6. Attach sample bag to the inlet tubing. Open the bag valve. Minimize the length of inlet tubing to reduce errors in gas concentrations.
    - 9.9.2.1.7. Open the FTIR inlet valve partially and let the bag sample deliver to the FTIR gas cell, close the inlet valve until the pressure reading stabilizes to ambient pressure. Close the bag valve.
    - 9.9.2.1.8. Repeat Steps 9.9.2.1.3 to 9.9.2.1.7 to deliver and purge the sample 3 times. Use the third-time sample as the representative sample delivered from the bag. Wait for at least 2 min for stabilization of gas delivered to the FTIR gas cell before taking the sample spectrum.
    - 9.9.2.1.9. If the gas concentration from the gas cylinder is greater than the maximum analytical range of the current method, then a new method has to be established by incorporating a standard spectrum with a certified gas concentration greater than the gas cylinder concentration.
  - 9.9.2.2. Continuous Sampling (onsite cylinder): Load sample directly from cylinder into FTIR.
    - 9.9.2.2.1. Follow the procedures described in SOP G2 (Standard Operating Procedure for Compressed Gas Cylinders) to deliver gas directly from the gas cylinder.
    - 9.9.2.2.2. If the gas concentration from the gas cylinder is greater than the maximum analytical range of the method, use Environics (See SOP G11) or TEI 146 diluter (See SOP C3) to dilute the gas concentration to below the maximum concentration level that the method can analyze accurately before taking the spectrum.
    - 9.9.2.2.3. Flush the FTIR gas cell with nitrogen beforehand. Vacuum the FTIR gas cell before delivering standard gas to reduce the time before a stable concentration can be reached. Deliver the sample gas at a flow

rate of 5 L/min for at least 10 min to ensure delivery of a representative sample of the gas to be checked.

9.9.3. Click "Sample" button on the Quant Pad button panel. Scanning of the sample will begin immediately. The final spectrum displays when the specified number of scans have been collected.

9.9.4. Click "Save As" in the OMNIC File menu to save the displayed sample spectrum.

9.9.5. Click the "Quantify" button on the Quant Pad button panel. The Quantify window shows the title of the selected quantitative analysis method and the path length, temperature and pressure values it used to calculate the results, followed by the concentration value and confidence range for each component.

9.9.6. To analyze a spectrum already saved on the disk, click the "Open" button on the Quant Pad button panel. Click the "Quantify" button on the Quant Pad button panel to automatically display the gas sample concentration.

9.9.7. To save the concentration data in a file on the disk, click the "Save" button in the "Quantify" window. The concentration data will be saved in a file named with the current base name and the extension "CNC".

9.10. Calculating the gas cylinder concentration analyzed by the FTIR

9.10.1. Following procedures described in Section 9.9, collect spectra for samples from at least three sample bags filled with the specified gas to be checked, if the gas cylinder is offsite. If the sample is continuously delivered directly from a gas cylinder, collect at least three spectra, at an interval of every 2-3 min.

9.10.2. Average the concentration data. Apply dilution factor if diluted sample is used. Compare the averaged value with the specified span gas concentration. The accuracy of the gas cylinder is confirmed if the average measured concentration is within 5% of the specified span gas concentration.

9.11. To make a Single Gas Method:

9.11.1. Collect calibration standard, a known concentration sample spectrum, using Quant Pad (select any method file) following the procedures described in Steps 9.2 to 9.9. Examples of standard spectra for representative compounds are displayed in Fig. 2.

9.11.2. Click the "Save as Standard" button on the Quant Pad button panel. Click "OK" after entering the spectrum information displayed on the window.

9.11.3. Enter a file name for this standard in the "File Name" box and select the drive and directory where the standards should be stored.

9.11.4. Open Quant Setup.

9.11.5. Choose "New Method" from the "File" menu

9.11.5.1. Select your sample phase as gas and concentration units as ppm.

9.11.5.2. Click "OK".

9.11.6. Choose "Components" from the "Edit" Menu

9.11.6.1. Type in the component name.

9.11.6.2. Type an abbreviated name in the component code box.

9.11.6.3. Click "OK".

- 9.11.7. Choose “Standards” from the Edit Menu
  - 9.11.7.1. Click “Browse”.
  - 9.11.7.2. Find the file of the standard spectrum and click “OK”.
  - 9.11.7.3. Once the file is specified to be used in a method, it can not be moved out of its specified directory or the method will fail. If you choose to move the file, the method must be modified to match.
  - 9.11.7.4. Check that the concentration, temperature, and pressure are correct for your standard.
  - 9.11.7.5. Click “OK”.
- 9.11.8. Choose “Regions/Windows” from the Edit Menu
  - 9.11.8.1. Carefully study the calibration spectra and choose frequency ranges in which the component peak are clearly identifiable and can be used to quantify the component in a method. Avoid using regions which show high absorption for water vapor or CO_2. Do not choose a frequency range in which the absorbance units are greater than 1 for the component to be quantified. The recommended regions for certain representative compounds are listed in Table 2.
  - 9.11.8.2. Click the “Region Add” button to add regions.
  - 9.11.8.3. If you want Quant Setup to use only certain windows in this analysis region to calculate component concentrations, click in the “Window” box and then click the “Window Add” button to add windows.
  - 9.11.8.4. Repeat the above two steps until all regions and windows have been specified.
- 9.11.9. Choose “Calculations” from the Edit menu
  - 9.11.9.1. Type an “S” for the region of the spectrum that you wish to use to calculate the concentration of this component. For the other regions, type “I”.
  - 9.11.9.2. Click “OK”.
- 9.11.10. Choose “Save Method As” from the File Menu
  - 9.11.10.1. Enter a title for the method.
  - 9.11.10.2. Click “OK”.

9.12. Validating the Method:

- 9.12.1. Once Quant Pad is running, select any method and collect at least one sample spectrum from a sample containing a known concentration of the component, using Quant Pad and the method described above. The concentration should be about one-tenth of the concentration of the corresponding standard used to make the above method.
- 9.12.2. Save spectrum as a standard with Quant Pad.
- 9.12.3. Create a validation sample set
  - 9.12.3.1. From Quant Setup, choose “Sample Sets” from the Analyze menu.
  - 9.12.3.2. Click “New”.
  - 9.12.3.3. Click “Add” button.
  - 9.12.3.4. Select file names of spectra you wish to add.
    - 9.12.3.4.1. To change the information associated with the file, click the file name, then click in the appropriate text box and enter the correct value.

        - 9.12.3.4.2. To display a spectrum, click “View Spectra” in the Samples dialog box.
    - 9.12.3.5. Click “OK”.
    - 9.12.3.6. Click “Save Set”.
    - 9.12.3.7. Enter a unique title for the sample set.
    - 9.12.3.8. Click “New” to add this sample set to the list of sample sets.
    - 9.12.3.9. Click “OK” to close the Samples dialog box.
- 9.12.4. Quantify the validation sample set
    - 9.12.4.1. Be sure the correct method is open.
    - 9.12.4.2. Choose “Quantify” from the Analyze menu.
        - 9.12.4.2.1. This will open a dialog box containing information about the sample set based on the method selected.
        - 9.12.4.2.2. The calculated component concentrations will be displayed.
        - 9.12.4.2.3. Click the next button to see results for the next sample in the set.
    - 9.12.4.3. When finished click “OK”.
    - 9.12.4.4. If the calculated component concentrations differ from the actual concentrations by more than an acceptable amount (usually 1 to 5%, depending on the application), and if the errors tend to change regularly as a function of concentration, the absorbance vs. concentration plot for that component may be curved instead of linear. In this case, follow the instructions below to calculate a correction curve for that component.
- 9.12.5. Calculate a correction curve:
    - 9.12.5.1. Use Quant Pad Application to collect spectra from different known concentrations (preferably 4 to 6 different concentration levels) and save as standards using Quant Pad.
    - 9.12.5.2. Open “Quant Setup” and click “Open Method” from the File menu.
    - 9.12.5.3. Select the title of the method to be corrected in the drop down list box and choose “OK”.
    - 9.12.5.4. Create the calibration sample set:
        - 9.12.5.4.1. Choose “Sample Sets” from the analyze menu.
        - 9.12.5.4.2. Click “New”.
        - 9.12.5.4.3. Click the “Add” button.
        - 9.12.5.4.4. Select file names of the spectra you want to add.
        - 9.12.5.4.5. Check to be sure information for each spectrum is correct.
        - 9.12.5.4.6. Click “OK”.
        - 9.12.5.4.7. Click “Save Set”.
        - 9.12.5.4.8. Enter a unique title for your new sample set.
        - 9.12.5.4.9. Click “New” to add this sample set to the list of sample sets.
        - 9.12.5.4.10. Click “OK” to close the Sample dialog box. This set automatically becomes the active sample set.
- 9.12.6. Calculate the correction curve coefficients and save the calibration sample set.
    - 9.12.6.1. Click “Calibration” from analyze menu.
    - 9.12.6.2. Select the component you want to correct by clicking its name in the “Component” list.

- 9.12.6.3. Press the correction button in the calibration dialog box to analyze the calibration sample set using the primary standard for the selected component.
  - 9.12.6.3.1. To force the curve through zero, turn on the “Force Zero Intercept” Option. The accuracy of the method can be improved by forcing the correction curve through zero if the concentration of the analyte in the samples may approach zero. Do not force the curve through zero if the lowest expected concentration in the samples is higher than the lowest standard in the calibration set, especially when all of the spectra in the calibration set are taken at high concentration range.
- 9.12.6.4. Calculate the correction curve coefficient.
  - 9.12.6.4.1. Click on the “Calculate” button in the calibration dialog box to calculate the correction curve coefficients.
  - 9.12.6.4.2. To exclude a selected calibration spectrum from the curve calculation (in case the spectrum is suspected to be an outlier or out of the desired calibration concentration range), select its file name and then turn off the “Include This Sample” option. If necessary, re-run a standard spectrum at such concentration to guarantee the accuracy of the standard spectrum concentration, and reintroduce the new spectrum into the calibration sample set.
  - 9.12.6.4.3. Click “Display” in the Correction Curve Selection dialog to see a graph of the actual vs. measured values.
  - 9.12.6.4.4. Click “Results” in the Correction Curve Selection dialog to see detailed information about the fit of the selected polynomial function to the spectral data.
  - 9.12.6.4.5. Click the up or down arrow button next to the selected order to examine a higher- or lower-order function.
  - 9.12.6.4.6. Select the lowest curve order that fits the actual concentration to the calculated concentrations with the required degree of accuracy specified in the QAPP.
- 9.12.6.5. Transfer curve coefficients to the current method.
  - 9.12.6.5.1. Display the Correction Curve Selection dialog box and make sure the correct polynomial order is selected.
  - 9.12.6.5.2. Click the “Use” button. This transfers the current set of coefficients into the current method for use in correcting the concentrations of the selected component.
- 9.12.6.6. Save the Calibration sample set.
  - 9.12.6.6.1. Press the “Return” button in the Correction Curve Selection dialog box. Calibration Data dialog box appears on screen.
  - 9.12.6.6.2. Press “Save Set”, then either click “Replace” or enter new title and click “New”.
  - 9.12.6.6.3. Press “Return” to get to Quant Setup menu.

9.12.7. Save the corrected method by clicking “Save Method” from File menu, or clicking “Save Method As” and enter a title for the method, and then choose “OK”.

9.12.8. To run the corrected method, open Quant Pad and select the method. Then either open, quantify, or collect and quantify a spectrum.

9.13. Troubleshooting

9.13.1. Troubleshooting measures for software, hardware, and application problems are listed in the last three chapters of the ThermoNicolet Nexus 670 User's Guide.

9.13.2. If the above action does not solve the problem, call Thermo Nicolet Service office at 1-800-642-6538, 608-276-6100, or email them at techinfo@thermonicolet.com.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information (e.g., sample collection method used) on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

10.4. Maintain gas certification records.

10.5. Store the quantitative analysis method and spectra (standard, background, and sample spectra) on a computer disk. Store a second backup copy on a separate disk.

11. Quality Control and Quality Assurance

11.1. The accuracy of any FTIR quantitative analysis is limited by the accuracy of the concentrations of the gas standards used in establishing the calibration method. Preferably the calibration gas should be certified using EPA protocol (1% certification).

11.2. The calibration spectra must be of pure components, or pure components diluted with a solvent or gas that either doesn't absorb infrared energy or absorbs in a different region of the infrared spectrum.

11.3. Check the FTIR calibration on a monthly basis by comparing the concentrations of the spectra taken from a reference span gas cylinder with its specified gas cylinder concentration that is guaranteed of accuracy. Recalibrate the instrument if the average measured concentration deviates more than 5% from the specified span gas concentration.

11.4. New background spectra should be collected regularly, preferably once every 4 h during the operation of the FTIR.

11.5. Align the spectrometer daily for optimum performance.

11.6. Keep the room temperature where the FTIR is installed at temperatures between 16°C and 27°C.

11.7. Verify that the detector is cooled by liquid nitrogen before taking any spectrum.

11.8. Perform FTIR gas absorption cell leak-check before taking sample spectra. Leak check the FTIR cell under both vacuum and pressurized (greater than ambient) conditions.

11.8.1. For the batch sampling technique, close the inlet valve to the FTIR cell, open the outlet valve and connect to a vacuum pump. Evacuate the absorption cell to the minimum absolute pressure P_{min}. Close the outlet valve, and determine the change in pressure P_v after 2 min.

11.8.2. For both the batch sampling and continuous purging techniques, pressurize the system to about 100 mmHg above atmospheric pressure. Determine the change in pressure P_p after 2 min.

11.8.3. Determine the percent leak volume $\%V_L$, calculated as P_{max} divided by atmospheric pressure and then multiplied by 100%, where P_{max} is the larger of P_v or P_p.

11.8.4. Leak volumes in excess of 4% of the FTIR system volume are unacceptable, and the tubing connection should be re-checked.

11.9. Prior to use of sample bags for storage of gas samples for subsequent FTIR analysis, perform tests to evaluate sample recoveries and/or contamination from sample bags under controlled conditions. This could be accomplished by comparing FTIR responses to gases in the purge mode and in the batch mode simulating bag materials (walls and fittings), storage times and storage temperatures. Choose the type of sample bag that has the least amount of gas loss and contamination.

12. References

12.1. EPA Test Method 320. Measurement of Vapor Phase Organic and Inorganic Emissions by Extractive Fourier Transform Infrared (FTIR) Spectroscopy. www.midac.com/apnotes/Ap-139.PDF

12.2. Thermo Electron Corporation. 2001. Thermo Nicolet Nexus 670 User’s Guide. Madison, WI.

12.3. Thermo Electron Corporation. 2002. Thermo Nicolet Spectrometer Safety Guide. Madison, WI.

12.4. Thermo Electron Corporation. 2002. Thermo Nicolet OMNIC User’s Guide. Madison, WI.

12.5. Nicolet Instrument Corporation. 1995.QuantPad User’s Guide. Madison, WI.

12.6. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.7. SOP G11. 2006. Operation of the Environics® Computerized Gas Dilution System. Standard Operating Procedure G11. Purdue Ag Air Quality Lab.

12.8. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Technical Support: 1-800-Nicolet (1-800-642-6538), 1-608-276-6373.

13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

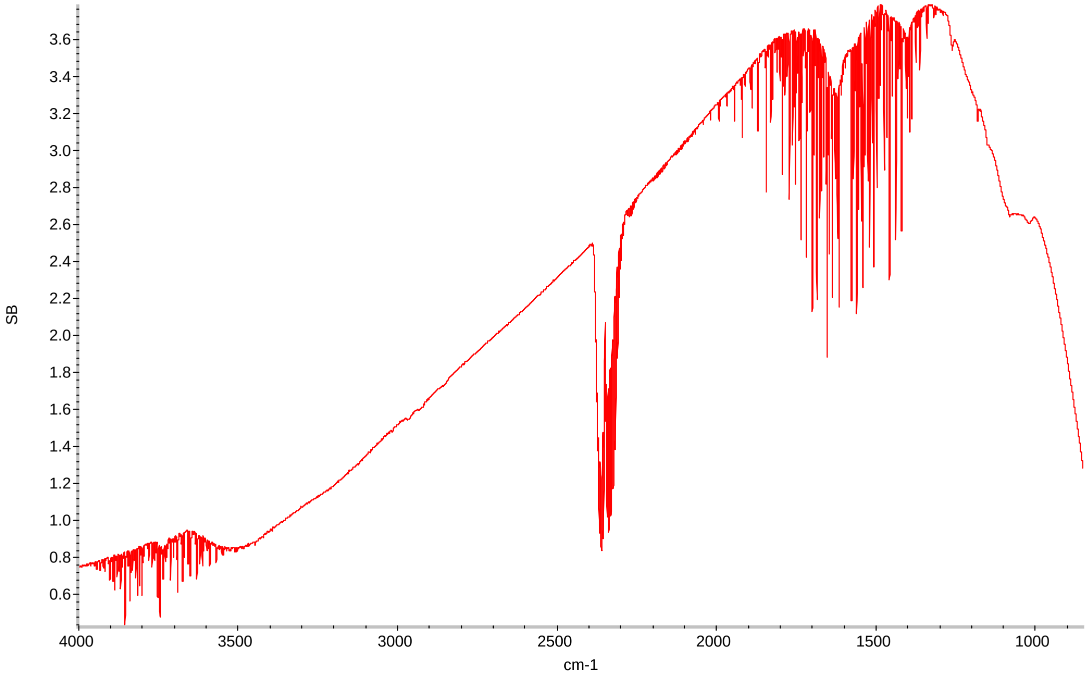

Figure 1. Example of a background spectrum.

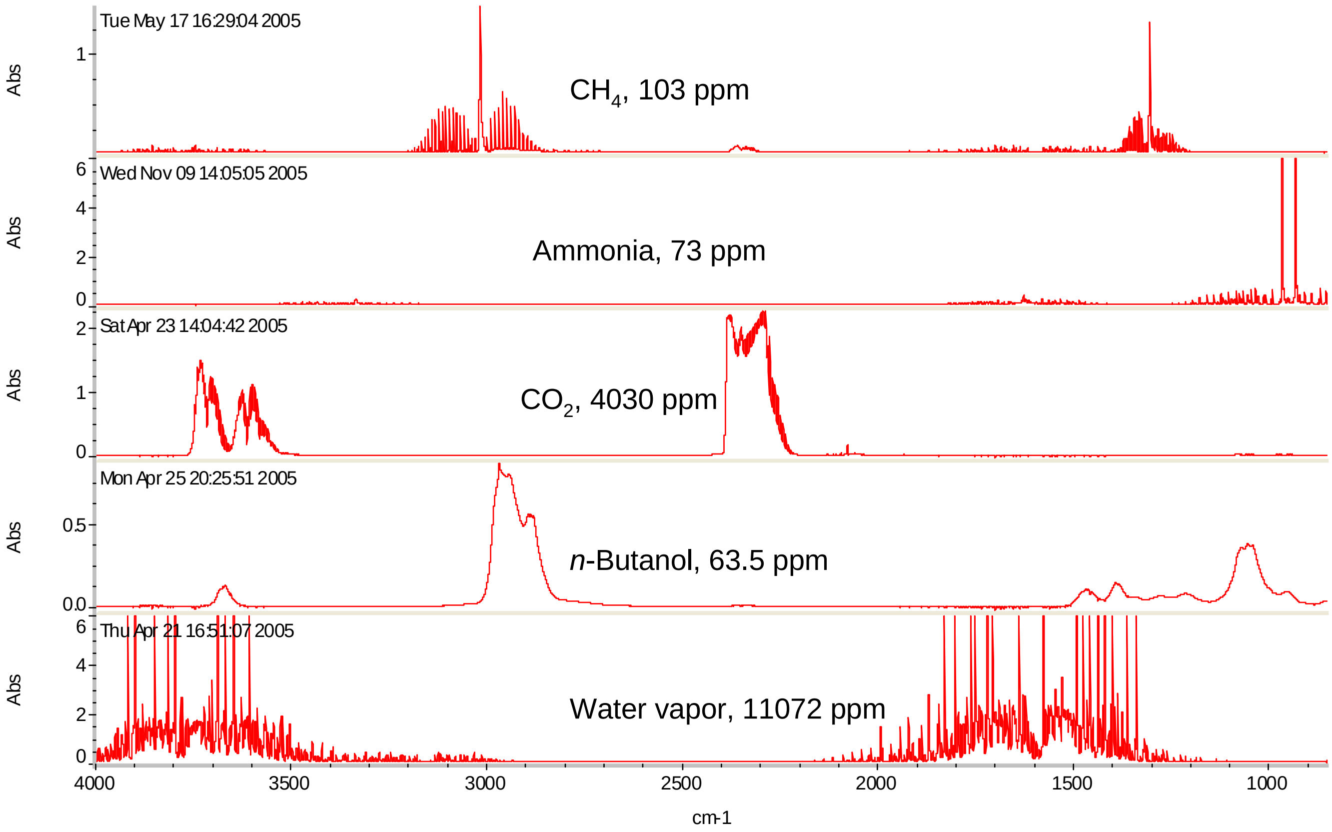

Figure 2. Standard spectra for representative compounds.

Table 1. Data collection and optical bench setup parameter for standard and sample spectra collection.

Parameter	**Setting**
Number of sample scans	64
Number of background scans	64
Resolution	1
Data spacing	0.482 cm-1
Spectral range	4000-850 cm-1
Mirror velocity	1.8988
Gain	1
Aperture	34
Level of zero filling	0
Apodization	Happ-Genzel
Phase correction	Mertz

Table 2. Preferred frequency ranges to be used as calculation regions for making the analysis methods for each compound.

Compound Name	Frequency Ranges (cm^{-1})
Carbon dioxide	2075.7-2080
Water vapor	3372.7-3405
Methane	3008.2-3019.6
n-Butanol	2809-3019
Ammonia	961.3-969

MEASUREMENT OF LAGOON SLUDGE DEPTH WITH MARKLAND MODEL 10 PORTABLE SLUDGE GUN
Standard Operating Procedure (SOP) L5

MEASUREMENT OF LAGOON SLUDGE DEPTH WITH MARKLAND MODEL 10 PORTABLE SLUDGE GUN

Standard Operating Procedure (SOP) L5

Prepared by

Chris D. Fullerton and Richard H. Grant

Reviewed by

Bill W. Bogan and Albert J. Heber

Effective Date: November 6, 2006

PURDUE APPLIED METEOROLOGY LABORATORY (PAML)
Agronomy, Purdue University
West Lafayette, IN 47907

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Page

1. Scope and Applicability

1.1. The depth of a livestock waste lagoon can influence emissions from the lagoon.

1.1.1. The ratio of surface area to volume is an important parameter governing emission of NH_3 (Ullman and Mukhtar, 2004).

1.2. Optical transmission of infrared light can be used to detect changes in the solids content of a liquid.

1.3. This SOP document applies only to the Markland Model 10 Sludge Level Detector, or “Sludge Gun”.

1.3.1. The measurement (depth) range of this instrument is 0 to 10 m.

1.3.2. Measurement accuracy (under laboratory conditions) is ±1 cm.

1.3.3. Measurement precision (under laboratory conditions) is ±0.5 cm.

2. Summary of Method

The Markland Model 10 Sludge Level Detector uses high-frequency pulses of a solid-state infrared light-emitting diode, received by a phototransistor, to detect the transmittance of infrared radiation through the liquid enclosed within an open chamber (such as a lagoon or basin). The sensor detects a noise as it receives these pulses; the pitch of this noise increases as the degree of infrared transmittance by the lagoon increases, indicating increasing solid content.

Once during each time the site is set up for a measurement period (one per season), nine individual measurements will be taken from specified areas of the lagoon using the pattern and approximate locations specified on the Depth Plot Worksheet (Appendix D) with the above-described probe. These will be averaged together, and recorded on the “Sludge Depth Field Data Form” (Appendix B). The original Depth Plot Worksheets will then be filed for scanning into the computer and retained according to SOP D1.

3. Definitions

3.1.	SOP	Standard operating procedure

4. Health and Safety

4.1. Wear proper Personal Protective Equipment

4.1.1. Use life jackets at all times when near the edge of the lagoon, and when using the sampling boat.

4.1.2. Always have the life-line rope attached to your waist and in reach of your field partner (on berm) when in the boat.

4.1.3. Do not attempt to take measurements from the lagoon or board the sampling boat if your field partner is not watching from the berm.

- 4.1.4. Do not attempt to take measurements from the lagoon or board the sampling boat if threatening weather is nearby or imminent.
- 4.1.5. Use safety glasses when near the lagoon water, and take care not to splash lagoon contents on clothes.
- 4.1.6. Use rubber gloves when handling the Markland sludge gun, the boat, or any other gear that may have come in contact with the lagoon contents.

4.2. Wash and dry gloves before storing

4.3. Wash hands after working in the lagoon or on anything that may come in contact with lagoon contents.

4.4. Notify your field partner and apply decontamination and correct field dressing if you accidentally cut yourself or puncture the skin in any manner while handling the sludge gun or any material that may have come into contact with the lagoon contents.

4.5. It is recommended to wait until close to the end of the day to take measurements from the lagoon if possible so you can proceed to change clothes and shower as soon as possible afterwards.

- 4.5.1. Have a spare change of clothes at the site with you at all times.

4.6. If you fall into the lagoon or become soaked with fluids from the lagoon:

- 4.6.1. Immediately notify your partner.
- 4.6.2. Immediately wash your face and hands.
- 4.6.3. Locate shower facilities and change clothing if your skin has become soaked.
  - 4.6.3.1. If needed, arrange for transport to your hotel to change clothes and shower, return to work site as soon as possible afterwards.
    - 4.6.3.1.1. Place plastic sheeting on the seats and floor of the work vehicle to avoid contaminating them.

5. Cautions

5.1. Twisting the cable will damage it.

5.2. If the probe is to be lowered in the vicinity of any moving rakes or scrapers, make sure these are stopped first.

5.3. Unwind and rewind cable slowly, to avoid stirring up a large ‘cloud’ of sludge, which would result in inaccurate readings.

5.4. Never drop the probe into any tank with a hard (e.g. concrete) bottom.

6. Interferences

6.1. Battery life is shortened in cold weather. For accurate readings, use new batteries during winter operation (i.e. if temperature is near or below freezing).

7. Personnel Qualifications

7.1. Each member of the field staff must read and understand this SOP before operating this instrument.

8. Equipment and Supplies

8.1. Model 10 Sludge Level Detector (Markland Specialty Engineering, Toronto, Canada)
8.2. Cloth and rubbing alcohol
8.3. Dish soap
8.4. 500-mL beaker to serve as a calibration chamber
8.5. Water softener resin
8.6. 50-ft tape measure with metric markings
8.7. 1-m ruler with float
8.8. 10-cm ruler
8.9. Heavy duty rubber gloves (2 pair)
8.10. (2) Safety glasses
8.11. (2) Life vests
8.12. 300-ft Life-line rope capable of lifting 300 lbs.
8.13. Roll of plastic sheeting (for protecting vehicle from contamination with fecal matter should transport be necessary with contaminated clothing)
8.14. AA alkaline batteries (sensor uses 6)
8.15. Heavy duty two man inflatable raft with oars
8.16. Portable 12-VDC inflation unit.

9. Procedures

9.1. Acceptance
  9.1.1. Unpack the unit and check for visible damage or missing parts.
  9.1.2. Clean the cable using the following method.
    9.1.2.1. Unreel all the cable from the probe and lay it out in a straight line on a clean grassy area. Wipe the entire cable with a clean cloth saturated with rubbing alcohol. Allow a few minutes for the cable to dry.
  9.1.3. Make sure the cable is clean and dry. Starting at the sensor end and working towards the “gun” body, string a 50-ft. tape measure beside the cable, with the zero end of the tape at the sensing window in the probe gap (see Fig. 1). Peel off the numbers provided with the instrument from the manufacturer and place the “1” at the 1-m mark on the cable, “2” at the 2-m mark, etc.
  9.1.4. Calibrate sensor according to Section 9.2
    9.1.4.1. If the sensor cannot be calibrated to within the accuracy and precision limits given in Sections 1.3.2 and 1.3.3, return sensor to manufacturer for repair or replacement.
9.2. Calibration
  9.2.1. Set sensitivity on the Sludge Level Detector in midpoint of range, using the knob on the back of the handle (Fig. 1). Rotate the control knob so that, with the trigger depressed, there is no sound when the probe is in air or in the liquid at the top of the tank, and the high-pitched note sounds when the probe is in the sludge at the lagoon bottom.
  9.2.2. Add 200 mL of resin and 200 mL of tap water to the 500-mL beaker.

- 9.2.3. Record water depth (in mm) to top of resin on calibration form (Appendix A).
- 9.2.4. Clamp sensor portion of the instrument to a stand at a height of < 1 m.
- 9.2.5. Place beaker below sensor.
- 9.2.6. Lower probe into water until sensor speaker makes a sound.
- 9.2.7. Holding the cable at the point where it reaches the water line, remove cable and record length of cable from waterline to sensor on calibration form.
- 9.2.8. Repeat Sections 9.2.4 through 9.2.8 eight additional times.
- 9.2.9. Calculate precision and accuracy from the 9 sets of measurements as indicated on the calibration form (Appendix A).

9.3. Determining average depth of sludge and water for the lagoon

- 9.3.1. Refer to Depth Plot Worksheet (Appendix D) for proper sampling locations.
  - 9.3.1.1. Visualize a grid over the lagoon to be measured consisting of intersecting points by making vertical lines from one edge of the lagoon to the other, at approximately the ¼ point the ½ way point and the ¾ point, and doing the same in the horizontal direction.
- 9.3.2. Switch gun on. A short ‘beep’ indicates nominal operation.
- 9.3.3. Proceed to the first sampling point on the grid.
- 9.3.4. To unwind or rewind cable, point the gun downward and rotate the whole gun in a circular motion. The cable will come off the front of the spool. Unwind only as much cable as needed, then pass it through the pinch-groove at the front of the gun (Fig. 1). To get the cable back up onto the spool, guide the cable with one hand and rotate the whole gun with the other, so the cable comes back onto the spool.
- 9.3.5. Slowly lower the probe while squeezing the probe trigger.
  - 9.3.5.1. If the sensitivity control is set correctly, there will be no sound.
  - 9.3.5.2. If sound is heard, adjust sensitivity according to Section 9.2.1.
  - 9.3.5.3. As the probe nears the sludge bed, the sensor emits a low-pitched sound.
  - 9.3.5.4. The volume and pitch will increase as the solids concentration increases.
  - 9.3.5.5. Keep the trigger depressed and slowly lower the probe to the bottom of the lagoon (the cable will go slack when on the bottom).
    - 9.3.5.5.1. Record the first cable marker number above the waterline on the Depth Plot Worksheet as value “A” for the current location shown on the worksheet.
    - 9.3.5.5.2. Using the one-meter ruler, measure the distance from this marker to the waterline, and record as value “B”.
  - 9.3.5.6. Slowly raise the sensor probe cable until the sound just stops.
    - 9.3.5.6.1. Record the first cable marker number above the waterline as value “C”
    - 9.3.5.6.2. Using one-meter ruler, measure distance from marker to waterline, and record as value “D”.
- 9.3.6. Repeat Section 9.3.5 for each additional required measurement location, filling in all values on the Depth Plot Worksheet.

9.3.7. Determine averages for values A, B, C, and D by adding all the measurements for that value (A, B, C, or D) and dividing by the number of measurement locations (9). Enter the averaged values on the “Sludge Depth Field Data Form” (Appendix B) in the appropriate field. File the completed Depth Plot Worksheet to be scanned and saved according to SOP D1.

9.4. Preventive maintenance after each set of measurements at the field site

9.4.1. Clean sensor and sensor cable with water and soap and dry before storage.

9.4.1.1. Clean sludge depth gun by unwinding cable and lay cable out lengthwise in a clean grassy or snowy area and then wipe sensor and cable with cloth saturated with soap and water and rewind cable using a dry clean cloth.

9.4.2. Inspect sensor cable for damage. Repair or replace as necessary to maintain cable integrity and wire continuity.

9.4.3. Store indoors (i.e. in the open-source instrument trailer) when not in use.

9.5. Troubleshooting

9.5.1. With the probe in air, if a low-pitched ticking occurs as soon as the trigger is depressed, and does not stop upon turning the sensitivity control, this indicates that either the probe is dirty or the batteries need to be replaced.

9.5.1.1. Clean probe and retest.

9.5.1.2. If ticking persists, replace batteries. Remove two screws and take off rear speaker, pull down on the spring-loaded plunger, and slide out the Battery Pack. Insert new batteries, checking orientation against that shown on the pack.

9.5.2. Repeated constant values indicate sensor failure. Replace sensor.

10. Data and Records Management

10.1. Record original calibration and measurement data on appropriate forms (Appendices A and B, respectively), which are kept in a waterproof bound record book designated for lagoon sensors.

10.2. Transfer calibration and measurement data to worksheets of the electronic field notes spreadsheet designated for this method.

10.2.1. Reserve one worksheet for calibration data, and one for measurement data.

10.3. Document all written data and information in site logbooks with permanent ink.

10.4. Overstrike errors in writing with a single line. Initial and date all corrections.

10.5. Manage all data is managed according to SOP D1.

11. Quality Control and Quality Assurance

11.1. Calibrate (Section 9.2) the sensor quarterly.

11.2. Clean sensor and cable (Section 9.4.1) and inspect for damage (Section 9.4.2) after every use.

11.2.1. If damaged, repair wires and encase cable with waterproof heatshrink tubing.

12. References

12.1. Sludge Gun Manual. 2006. Markland Model 10 Sludge Gun Operating Instructions. Markland Specialty Engineering, Ltd., Toronto, Canada

12.2. SOP D1. 2006. Management of Open-source, Weather, and Lagoon-characterization Data. Standard Operating Procedure D1. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.

12.3. Ullman, J.L. and S. Mukhtar. 2004. Implications on ammonia emissions from dairy facilities using dry-lot versus hybrid (free-stall) housing practices. ASAE Paper #044064. American Society of Agricultural Engineers, St. Joseph, MI.

13. Contact Information

13.1. Distributor: Markland Specialty Engineering, Ltd
48 Shaft Road, Toronto, Ontario, Canada M9W 4M2
Tel: 416-244-4980, Fax: 416-244-2287
email: markland@sludgecontrols.com

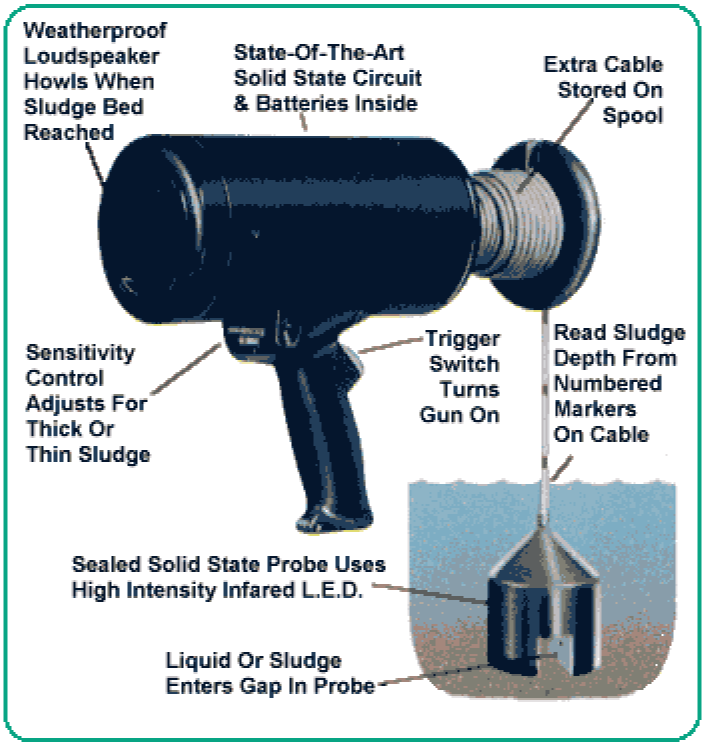

Figure 1. Markland Model 10 Sludge Gun.

Appendix A
Markland Model 10 Sludge Gun Calibration Form

Serial Number ________________ Date (DD-MM-YYYY)
____

Person Calibrating ____ Action:
(Accept / Adjust / Replace)

Actual depth of resin layer (mm)	Measured Depth (mm)
	Trial #1
	Trial #2
	Trial #3
	Trial #4
	Trial #5
	Trial #6
	Trial #7
	Trial #8
	Trial #9
Mean	
Standard Deviation (Precision)	
Accuracy (Measured depth – Actual depth)	

Appendix B
Sludge Depth Field Data Form

Location: ________________________________

Sensor serial number ___________________

<table>
<tr><th rowspan="2">Date
(D-M-Y)</th><th rowspan="2">Time
(EST)</th><th colspan="3">Average Bottom Depth (m)</th><th colspan="3">Average Sludge Depth (m)</th><th rowspan="2">Comments</th><th rowspan="2">Persons measuring</th></tr>
<tr><th>Cable Marker # (A)</th><th>Distance to Waterline (B)</th><th>Bottom Depth (A – B)</th><th>Cable Marker # (C)</th><th>Distance to Waterline (D)</th><th>Depth to Sludge Layer (C – D)</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>/</td></tr>
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</table>

Appendix C

MARKLAND SPECIALTY ENGINEERING LTD.
OPERATING INSTRUCTIONS MODEL 10 SLUDGE GUN®

Cable Markers

Make sure the cable is *clean and dry*. String a 50 ft. tape measure beside the cable, with the zero end of the tape at the Probe. Carefully peel off the numbers and place the "1" at the 1ft. mark, "2" at the 2ft. mark, etc… Metric or any other units can also be used. Placing a strip of black vinyl electrical tape midway between the number markers permits more precision in reading the depth.

Sensitivity Adjustment

This thumb adjustable control is at the back of the handle. Rotate the control knob so that with the trigger depressed, there is no sound with the Probe in air or when it is in the liquid at the top of the tank, and the high pitch note sounds when the probe is down in the sludge. This setting is not critical. The sensitivity control is mainly needed for extremely thick or thin slurries, or for boosting the power as the batteries get weak.

Unwinding/Rewinding Cable

Point the Gun downward and rotate the whole Gun in a circular motion and the cable will come off the front of the spool like a fishing line coming off a reel. Unwind only as much cable as needed, then pass it through the pinch- groove at the front of the Gun. To get the cable back up onto the spool, guide the cable with one hand and again rotate the whole Gun with the other hand so the cable comes back onto the spool. ***Do not twist the cable!***

Finding The Sludge Blanket

Lower the Probe while squeezing the trigger. If the Sensitivity control is set right (see Sensitivity Adjustment) no sound will be heard. As the Probe nears the sludge bed a low pitch sound will come from the speaker. This will increase in volume and rise in pitch as the solids concentration increases. Keep the trigger depressed and lower the Probe to the bottom of the tank (the cable will go slack when on the bottom). Read the cable marker opposite the handrail (for example - 25ft.). The speaker will still be howling with the trigger depressed and the Probe in the sludge. *Slowly* raise the cable until the note starts to become lower pitched, and again read the marker opposite the handrail (for example - 20 ft.). Continue *slowly* raising the Probe until the sound stops and read the cable marker (for example - 18 ft.). In this example, you would have 5ft. of dense sludge, covered by 2 ft. of a partially settled sludge 'cloud'. Remember to move *slowly,* or you will stir up a large 'cloud' and confuse the reading.

Battery Replacement

Batteries will last about one year in normal service. With the Probe in air, if a low pitched ticking is heard as soon as the trigger is depressed, and this cannot be removed by turning the sensitivity control, this indicates that either the Probe is dirty and needs washing, or the batteries are weak and will soon need to be replaced. Ignore the short beep that is heard when the Gun is first switched on. This is normal. Battery life is shorter when the Gun is used at low temperatures. To change batteries, remove two screws and take off rear speaker, pull down on spring loaded plunger and slide out the Battery Pack. Replace with AA size Pencell Alkaline batteries, and be careful to install in the direction shown on the Battery Holder.

Appendix C (continued)

MARKLAND SPECIALTY ENGINEERING LTD.
OPERATING INSTRUCTIONS MODEL 10 SLUDGE GUN®

Cold Weather Operation

Battery output is greatly reduced at low temperatures. It is suggested that the Gun be fitted with new batteries if it is going to be used at temperatures near or below freezing. The Gun should be stored indoors when not in use.

Probe

The solid-state Probe is sealed and requires no maintenance other than washing. The cable is sealed at the Probe and can't be disconnected. If defective, the entire Probe/Cable assembly must be replaced. Care should be taken not to tangle the Probe in Rakes or Scrapers, which should be stopped before lowering the Probe into the tank. Do not drop the Probe onto the concrete tank bottom, lower it slowly. Quickly dropping the Probe stirs up the sludge bed making readings difficult, and could cause Probe damage.

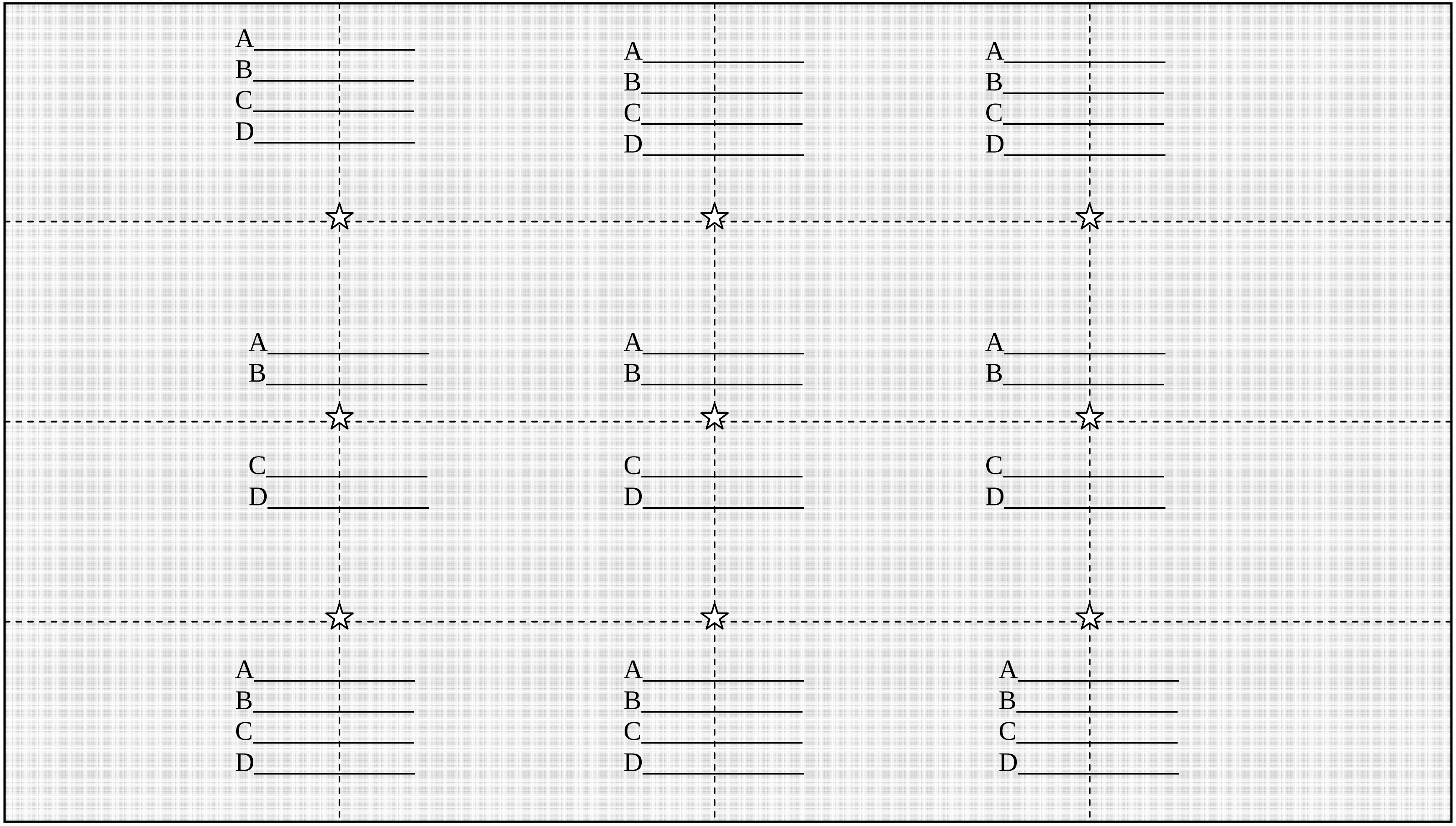
Appendix D

Depth Plot Worksheet

Location: ________________________________ Date:_____________________Operator:__________________________________

Sensor serial number _____________

☆ Denotes approximate measurement locations



A_____________
B_____________
C_____________
D_____________

A_____________
B_____________
C_____________
D_____________

A_____________
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MANURE SAMPLING
Standard Operating Procedure (SOP) M1

MANURE SAMPLING

Standard Operating Procedure (SOP) M1

Prepared by
Sam M. Hanni and Bill W. Bogan

Reviewed by
Albert J. Heber and Teng Teeh Lim

Effective Date: November 6, 2006
Rev. 1.0 Effective Date: March 17, 2008

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

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Page

1. Scope and Applicability

1.1. The release of ammonia from manure in livestock barns and storage areas is affected by manure pH, moisture content, and nitrogen and ammonia contents. Manure must be collected to determine these parameters.

1.2. Data on nitrogen content of manure at the end of its storage period is also needed to develop a N balance for the facility (SOP S5).

1.3. This SOP describes the procedures for collecting manure samples from broiler, layer, dairy, and swine barns, and from manure storage areas, during tests of air emissions.

1.3.1. Manure samples may need to be collected from various types of storage or treatment facilities, including deep pits under buildings, collection channels, drainage pipes, outdoor storage basins, lagoons, and storage piles.

1.4. This SOP provides information on selecting sampling locations and methods to capture representative samples.

1.5. The sampling methods described in this SOP are adapted from References 11.1 – 11.4.

2. Summary of Method

Different sampling equipment and techniques should be selected based on manure characteristics (liquid or dry samples) and the type of facility that is being sampled. Storage basins and lagoons can be sampled with either a conduit-mounted container sampler, a sampling tube with a stopper, or a telescoping ladle. The ladle is also well-suited to sampling collection channels or drainage pipes. Deep pits under slatted floors can be sampled with a sampling tube with a stopper, or with a manure/sludge sampling pump. Manure storage piles that do not contain significant litter, feathers, or other material can be sampled using a tube corer. If, however, litter and feathers are plentiful, sampling can be conducted using a shovel or spade. Several sub-samples can be taken to produce a composite sample. It is important to take a sufficient number of samples to be representative of the manure storage or treatment unit. The times at which manure is sampled will depend on the data required. For example, if the sample is intended to provide data on initial manure parameters (pH, moisture, N and/or NH_3 content) that may affect emissions, it may be desirable to collect fresh manure. If, on the other hand, the final N content of aged manure leaving a storage facility is needed for an N balance, sampling should coincide with the emptying of the storage unit. Exact sampling times for each site will be specified in the Site Monitoring Plans in the QAPP for the specific project.

3. Definitions

3.1.	COC	Chain of custody
3.2.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.3.	QAPP	Quality Assurance Project Plan

4. Health and Safety

4.1. When sampling manure, wear Tyvec suits, shoe covers, and gloves. Wear a respirator to prevent exposure to manure gases.
4.2. Sample, mix, and package all samples in a well-ventilated area.
4.3. Agitation of manure in storage facilities (e.g. deep-pit systems) may release gases that cause very strong odors, and high concentrations that are a severe (i.e. lethal) health hazard (Lorimor et al. 2004).
  4.3.1. If agitation is deemed necessary for accurate sampling, either remove all animals and persons from the facility before beginning agitation, or open or turn on all available ventilation sources (doors, windows, exhaust fans) throughout the agitation and sampling process.
4.4. Be aware of slippery surfaces.
4.5. When collecting samples from confined storage spaces, make sure there is someone watching from a safe area.
4.6. Do not attempt to take samples from manure piles that are too moist and soft to walk on. If the manure becomes too soft, wait to take samples until it is dry enough to walk on, or until it is removed from the building.
4.7. Keep manure sampling equipment and samples away from your mouth and face.
4.8. Be aware of aggressive livestock that may interfere with the sampling process.
4.9. If animals are interfering with the sampling procedure at a particular location, contact the farm manager so that the animals can be temporarily removed from the location.

5. Interferences

5.1. Clean all equipment thoroughly between samplings and sampling locations, using a scrub brush and a bucket of hot, soapy (antibacterial dish soap) water. Check all equipment visually and make sure there is no remaining manure attached.
5.2. Nutrient stratification can occur in non-agitated basins, pits, and lagoons. In these cases, it can be particularly important to collect subsamples from as wide a range of depths as possible, so they can be composited to obtain samples that are representative of the entire vertical profile.

6. Personnel Qualifications

6.1. Personnel should read and understand this SOP and be trained in the use of sampling equipment.
6.2. Personnel should be trained in proper handling and labeling of samples, and in the storage and shipping process.
6.3. The individual taking samples should be able to locate the place from which samples are to be taken.

7. Equipment and Supplies

7.1. Conduit-mounted container sampler (Fig. 1) for sampling basins and lagoons
  7.1.1. The container sampler consists of a long conduit, with a handle at one end and a container with a spring-loaded lid on the other. A cable is attached to the lid of the container, and runs up the conduit and through the handle. When pulled, the cable opens the lid of the container; when released, the spring closes the lid. This type of sampler is particularly useful for collecting samples below the surface of a storage basin or lagoon, if concurrent collection of the surface layer is not required.
7.2. Sampling probe or tube (Fig. 2) for sampling lagoons or deep pits
  7.2.1. Make the sampling tube from a PVC tube.
  7.2.2. For sampling a deep pit, choose a sampler that has an outside diameter smaller than the slot opening of the slats.
  7.2.3. For sampling open pit or lagoon, use a tube with a larger outside diameter (up to 6″) to reduce the sampling time.
  7.2.4. The sampling tube is equipped with a string running the length of the tube. One end of the string is attached to a rubber stopper or ball with a diameter larger than that of the tube; on the opposite end, the string is attached to the sampling tube.
7.3. Telescoping sampler for sampling collection gutters or channels
  7.3.1. CONBAR telescoping dipper, Enviro-Tech Services, Martinez, CA (or equivalent)
  7.3.2. Sampler consists of three nested 4.5′ metal conduit sections, which telescope out to a total length of 12′. The end of the sampler has a screw-tight mounting for a 600-mL polypropylene beaker.
7.4. Manure/sludge sampling pump and collection system for sampling deep pits under slatted floors
  7.4.1. Pump: ¼-horsepower, Gast Model 0523-V191Q-G588DX, or equivalent
  7.4.2. Erlenmeyer filtering flasks (2) 2-L or larger. Polypropylene is preferred over glass for safety reasons.
  7.4.3. Stoppers and tubing to connect the two flasks in series
  7.4.4. Sampling tubing – wall of tubing must be thick enough to withstand collapse under the vacuum from the pump.
  7.4.5. PVC pipe or similar rigid support to guide tubing into the pit and allow sampling at depth
  7.4.6. Cable ties
7.5. Metal tube corer (Fig. 3) for sampling manure piles
  7.5.1. The corer consists of a thin-walled metal tube with a solid metal handle.
7.6. Sledgehammer
7.7. Sharp spade for sampling of feather-containing manure piles
7.8. Five-gallon buckets, hand plungers, and mixing rods for sample homogenization
7.9. Tyvec suits, shoe covers and gloves
7.10. Bucket, scrub brush and antibacterial dish soap
7.11. Freezer for storage of manure samples prior to shipping
7.12. Shipping materials
  7.12.1. Insulated cooler
  7.12.2. One-quart plastic bottles or equivalent

- 7.12.3. 8″ x 10″ and 9″ x 12″ zip-lock plastic bags
- 7.12.4. Moisture-proof labels for sampling containers
- 7.12.5. Shipping peanuts and/or expandable shipping foam
- 7.12.6. “Blue ice” or other cooling agent
- 7.12.7. Duct tape or packing tape
- 7.12.8. Shipping and chain-of-custody (COC) forms

8. Procedures

- 8.1. Sampling basins or lagoons with container sampler
  - 8.1.1. Immerse container portion of sampler below the surface of the basin.
  - 8.1.2. Pull cable to open container lid and allow sample to fill the open container, then release to close. Avoid collecting floating debris, as these may bias the analysis.
  - 8.1.3. Transfer collected sample into a five-gallon bucket.
  - 8.1.4. Take multiple samples in order to make a composite sample.
    - 8.1.4.1. If the composite sample is intended to represent the entire basin or lagoon, take each individual sample at a different location.
    - 8.1.4.2. If the sample is intended to represent fresh manure, sample from the inlet as manure is entering the basin or lagoon.
    - 8.1.4.3. The total number of samples needed from each basin or lagoon, and the number of different locations needed, will be specified in the QAPP for a specific project.
  - 8.1.5. Mix the composite sample with a hand-held plunger (using an up-and-down motion) until it is well-mixed.
  - 8.1.6. While mixing is maintained, withdraw sample using a cup or similar instrument.
  - 8.1.7. Fill a one-quart plastic bottle not more than three-quarters full and cap tightly.
  - 8.1.8. Log the sample (Section 10.1) and follow the shipping procedures in Section 8.7.
- 8.2. Sampling deep pits or lagoons with sampling tube
  - 8.2.1. Insert sampling tube into the lagoon or deep pit until touching the bottom, with the stopper open.
  - 8.2.2. Pull string attached to stopper to seal the end of the sampling tube. Retract the tube, being careful to avoid tipping the tube and spilling the sample.
  - 8.2.3. Release the sample into a five-gallon bucket.
  - 8.2.4. Take multiple samples to make a representative composite sample.
    - 8.2.4.1. If the composite sample is intended to represent the entire deep pit or lagoon, take each individual sample at a different location.
    - 8.2.4.2. If the sample is intended to represent fresh manure, sample from the inlet as manure is entering the lagoon, or from the top layer of the deep pit.
    - 8.2.4.3. The total number of samples needed from each pit or lagoon, and the number of different locations needed, will be specified in the QAPP for the specific project.
  - 8.2.5. Use a mixing rod to stir the contents of the bucket; this will resuspend settled solids.
  - 8.2.6. While agitating the liquid, use a ladle to transfer the sample into a plastic bottle until the bottle is three-quarters full.
  - 8.2.7. Securely fasten the lid onto the container.
  - 8.2.8. Log the sample (Section 10.1) and follow the shipping procedures in Section 8.7.

8.3. Sampling lagoons or collection gutters with telescoping sampler
  8.3.1. If not already attached, attach the polypropylene beaker to the end of the sampler. Extend the sampler to the desired length, and immerse container portion of sampler below the surface of the manure.
  8.3.2. Transfer the collected sample into a five-gallon bucket. Follow Steps 8.2.4-8.2.8 above to collect and mix a composite sample and prepare it for shipping.

8.4. Sampling deep pits under slatted floors with a pump
  8.4.1. Connect two filtering flasks in series with the sampling pump, as shown in Fig. 4.
  8.4.2. Attach the sampling tubing to the PVC pipe or other support using cable ties. Slide the tubing/support into the manure in the pit to the desired depth. Unless it is specifically intended to sample the sludge layer that is most likely present at the bottom of the pit, it may be desirable to avoid lowering the sampling tube all the way to the bottom, as the sludge may block the tubing.
  8.4.3. Turn on the sampling pump. Collect approximately 1 L of manure in the first flask (half full). The second flask should serve as a trap to keep manure from entering the pump.
  8.4.4. Turn off the pump and disconnect the sample flask. Mix the contents, either with a stir bar or by swirling, and transfer (pour) the sample into a plastic bottle until the bottle is three-quarters full. Alternatively, if the sample is to be composited with others before taking the final sample, follow Sections 8.1.3–8.1.7.
  8.4.5. Securely fasten the lid onto the container.
  8.4.6. Log the sample (Section 10.1) and follow the shipping procedures in Section 8.7.
  8.4.7. Discard the remainder of the manure from the sample flask, and rinse the flask before re-connecting to collect the next sample.

8.5. Sampling storage piles with a spade and/or scoop
  8.5.1. With a scoop and a bucket, collect samples throughout the manure storage piles. Take multiple samples in order to make a representative composite sample.
    8.5.1.1. If the composite sample is intended to represent the entire storage pile, take each individual sample at a different location.
    8.5.1.2. If the sample is intended to represent fresh manure, sample from newest portion of the pile (if necessary, consult with farm personnel to identify this portion).
    8.5.1.3. The total number of samples needed from each storage pile, and the number of different locations needed, will be specified in the QAPP for the specific project.
  8.5.2. Once all of the samples have been collected, lay a piece of clean plastic on the ground and place the samples onto the plastic.
  8.5.3. Using a shovel, continuously scoop the outside of the pile to the center of the pile, and mix the center, until the composite pile is thoroughly mixed.
  8.5.4. Use a scoop to collect a composite sample from the mixed pile into a one-quart sealable bag. Fill the bag approximately halfway.
  8.5.5. Squeeze excess air out of the bag, seal the bag, and place the bag into a second bag, which should be larger than one quart (e.g. 9″ x 12″) for ease of handling.
  8.5.6. Log the sample (Section 10.1) and follow the shipping procedures in Section 8.7.

8.6. Use of core sampler for sampling storage pile
  8.6.1. Insert the corer into the manure storage pile. If needed, use a sledgehammer to pound the tube portion of the corer into the manure, until it touches the bottom of the pile.

- 8.6.2. Remove the core sampler from the manure pile.
- 8.6.3. Using a long rod or broom handle, push sample from corer into a clean bucket.
- 8.6.4. Take multiple samples to make a composite sample. The total number of samples needed from each pile will be specified in the QAPP for the particular project.
  - 8.6.4.1. If the composite sample is intended to represent the entire storage pile, take each individual sample at a different location.
  - 8.6.4.2. If the sample is intended to represent fresh manure, sample from newest portion of the pile (if necessary, consult with farm personnel to identify this portion).
  - 8.6.4.3. The total number of samples needed from each storage pile, and the number of different locations needed, will be specified in the QAPP for the specific project.
- 8.6.5. Once all of the samples have been collected, lay a piece of clean plastic on the ground and place the samples onto the plastic.
- 8.6.6. Using a shovel, break up any chunks that may be present. Continuously scoop the outside of the pile to the center of the pile, and mix the center, until the composite pile is thoroughly mixed.
- 8.6.7. Use a scoop to collect a composite sample from the mixed pile into a one-quart sealable bag. Fill the bag approximately halfway.
- 8.6.8. Squeeze excess air out of the bag, seal the bag, and place the bag into a second bag, which should be larger than one quart (e.g. 9″ x 12″) for ease of handling.
- 8.6.9. Log the sample (Section 10.1) and follow the shipping procedures in Section 8.7.

8.7. Handling and shipping samples

- 8.7.1. Label all samples with sample location, date and the name of the personnel who collected the samples. Include a completed COC form with each shipment. Enclose COC form in a zip-lock back to keep it dry and clean.
- 8.7.2. Load all samples into the cooler they will be shipped in. Add the desired amount of blue ice, ice-gel packs, or equivalent. If necessary, add sufficient packing material (such as packing peanuts or expandable packing foam) to keep the samples from shifting. Place the packed cooler in the freezer overnight (at minimum).
  - 8.7.2.1. Make sure that the cooler is not contaminated with chemicals or manure, and that it can be properly sealed. Use duct tape or packing tape to keep the cooler closed during shipping.
- 8.7.3. Use overnight shipping. Arrange shipping and receiving to ensure that samples are not held over a weekend or holiday, and that they do not arrive at the lab on a weekend or holiday.

9. Data and Records Management

- 9.1. Maintain all records in a worksheet of the electronic field notes spreadsheet which is designated for this method. Supplement this electronic record with a bound record book designated for the method, which should contain copies of the electronic record.
- 9.2. Manage data according to SOP B5.
- 9.3. Document all data and information on field data sheets, and within site logbooks, with permanent ink, or in electronic field notes.

10. Quality Control and Quality Assurance

10.1. Log all samples. Identify all collected samples, both on their container and in the site logbook, with the sample name and/or number, location, collection method, and date.
10.2. Check all sampling equipment before each sampling trip to make sure they are functioning properly.

11. References

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11.5. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

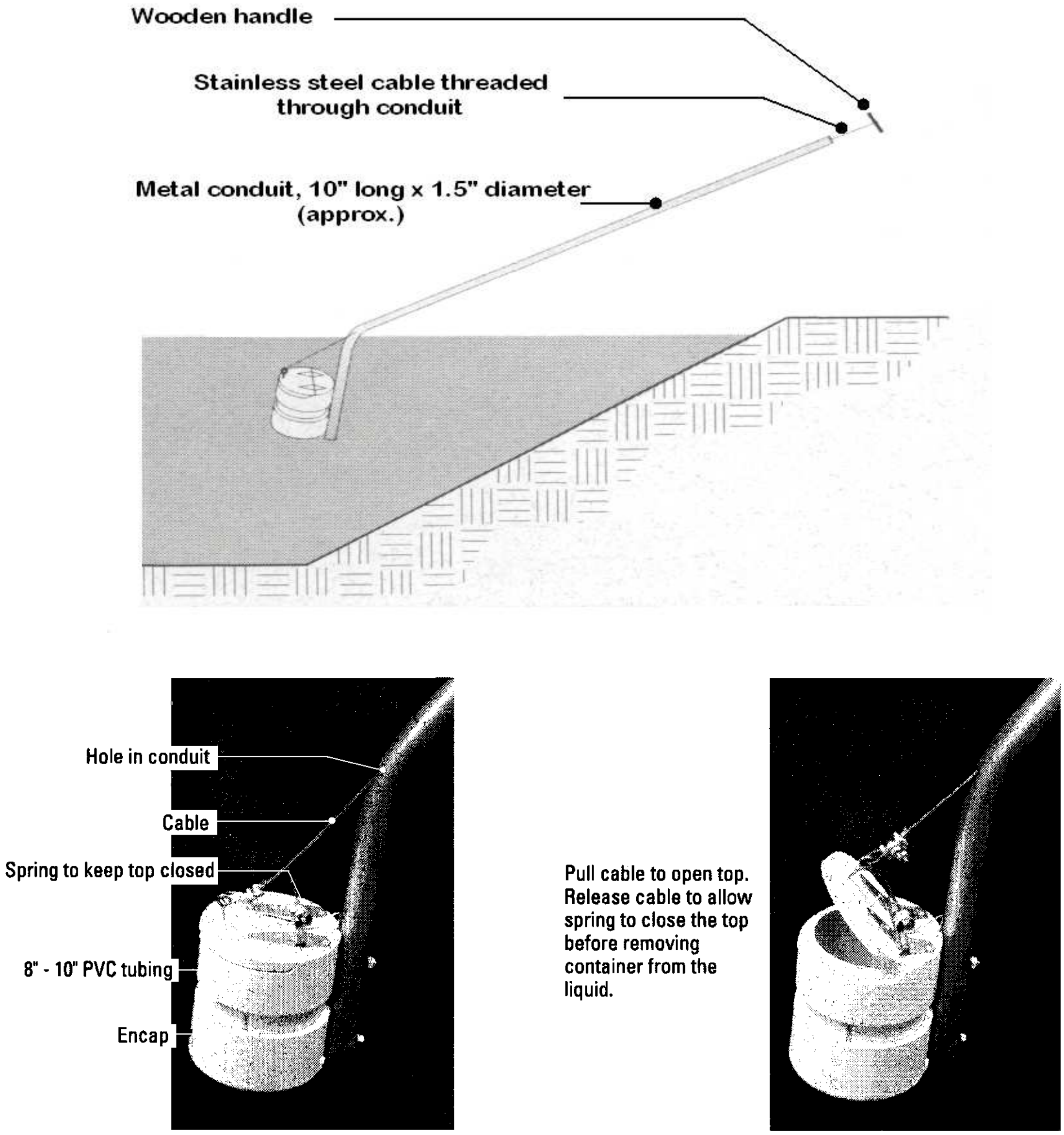

Figure 1. Conduit-mounted container sampler, with close-up showing the operation of the container lid (Lorimor et al, 2004).

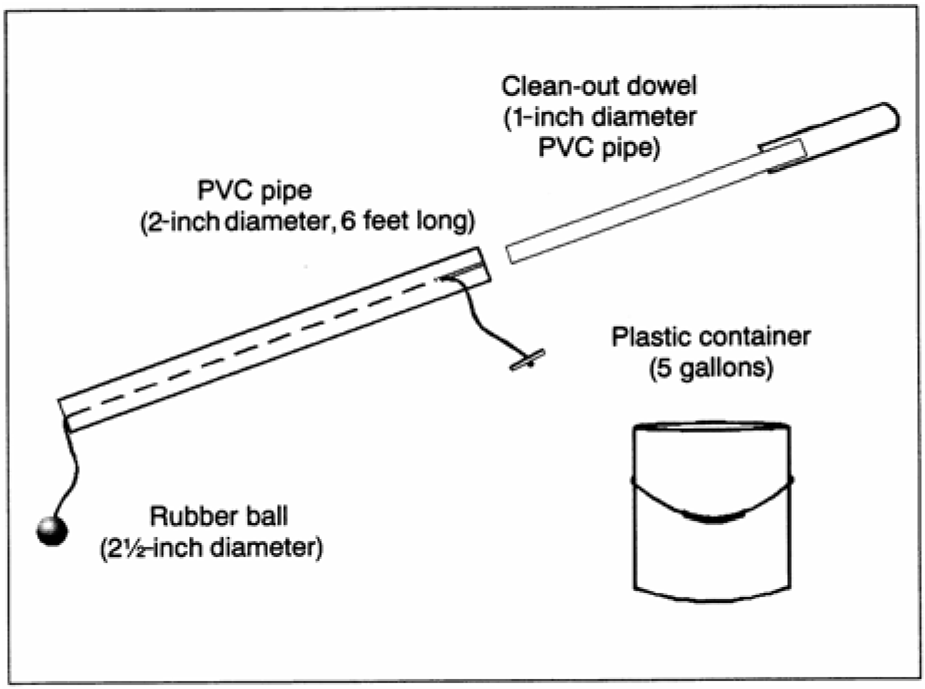

Figure 2. Liquid Slurry Sampling tube (Sonon et al., 2005). Sampler size shown is appropriate for sampling deep pits beneath slatted floors; larger diameters may be used for open lagoons.

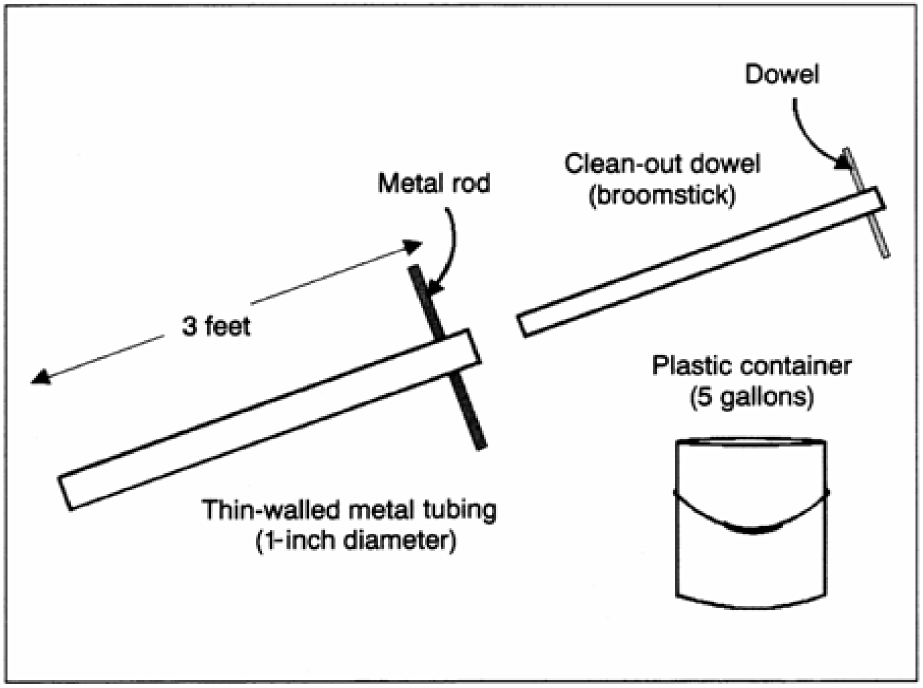

Figure 3. Core Sampler (Sonon et al., 2005).

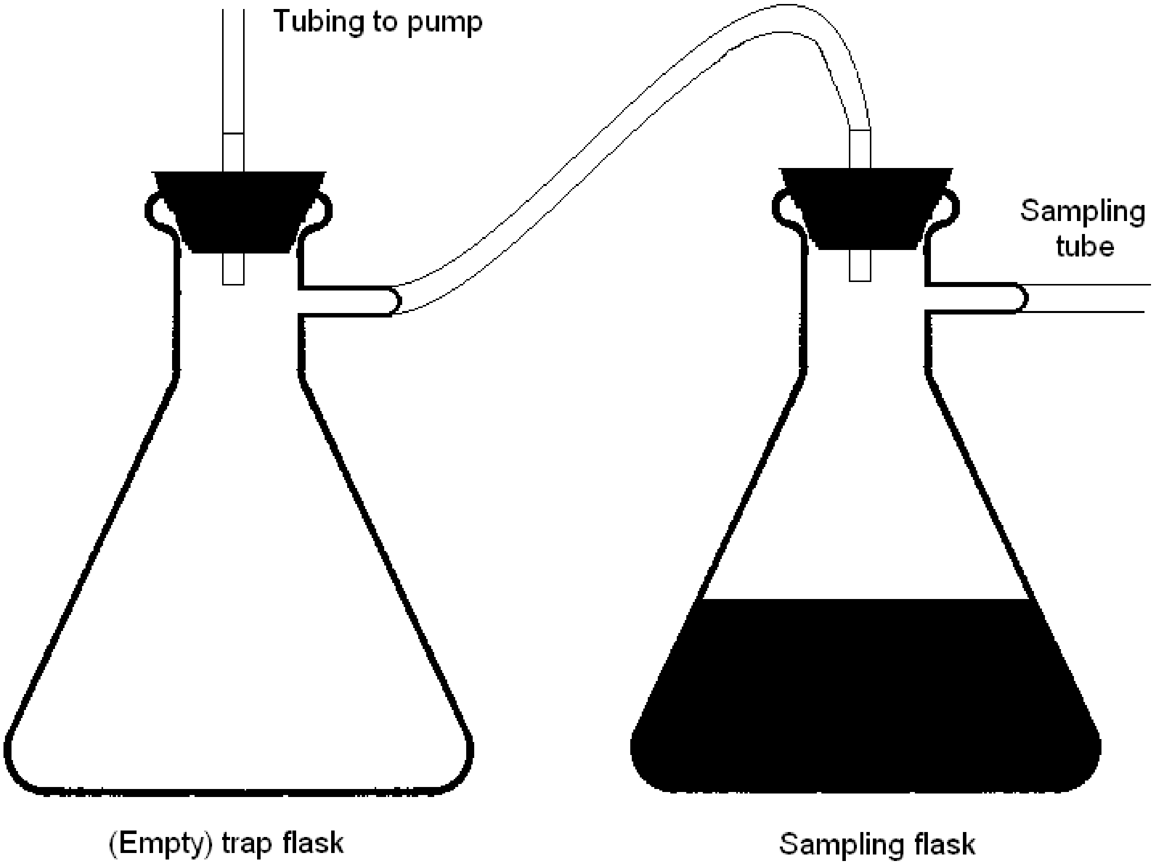

Figure 4. Sampling system for collecting manure from pits under slatted floors (e.g. from deep-pit swine barns).

CONDUCTING pH MEASUREMENTS ON MANURE SAMPLES
Standard Operating Procedure (SOP) M2

CONDUCTING pH MEASUREMENTS ON MANURE SAMPLES

Standard Operating Procedure (SOP) M2

Prepared by
Alan L. Sutton, Brian Richert, Scott Radcliffe, Dan Kelly and Bill W. Bogan

Reviewed by
Albert J. Heber, Harold M. Keener (Ohio State Univ.), and Jerome J. King (Midwest Laboratories, Inc)

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. A range of pH-dependent chemical and biological interactions and processes can affect the odor and overall composition of the manure.
  1.1.1. Emissions of ammonia (NH_3) increase as pH increases.
  1.1.2. Emissions of hydrogen sulfide (H_2S) decrease as pH increases.
1.2. The method detailed here is adapted from USEPA Method 9040C, “pH Electrometric Measurement”, and is therefore suitable for use on aqueous wastes and those multiphase wastes (including manures) where the aqueous phase constitutes at least 20% of the total volume of the waste. Wastes which originally contain less than 20% water by volume are mixed with water, and allowed to equilibrate, prior to taking the pH measurement.
1.3. This procedure measures the pH of a manure sample using the Orion Model 310 pH meter, equipped with a KCl electrode.
  1.3.1. This instrument covers the pH range from 0.00 to 14.00.
  1.3.2. The instrument has a resolution of 0.01 pH units, and a stated accuracy of ±0.02 pH units.
  1.3.3. The Orion Model 310 can be used within the temperature range of 0°C to 100°C, and includes temperature correction over this range. Its temperature resolution is 0.1°C, with a stated relative accuracy of ±0.5°C.
  1.3.4. This instrument can be used in laboratory or on-site settings.
  1.3.5. This method allows for high-throughput analysis of samples, as analysis of one sample generally requires no more than 5 min.

2. Summary of Method

The pH of the sample is determined electrometrically using either a glass electrode in combination with a reference potential, or a combination electrode. The measuring device (pH meter) is calibrated using a series of standard solutions of known pH, which are chosen such that the calibration range brackets the samples whose pH is to be determined. Liquid samples are measured as collected, while solid samples are equilibrated with deionized water in order to obtain a reading. Because measurement of pH is sensitive to temperature, the Orion Model 310 pH meter and 82-02 electrode are equipped with a temperature-correction capability.

3. Health and Safety

3.1. Wear lab coats, gloves and face shields when handling manure samples.
3.2. Buffers may cause eye and skin irritations and may be harmful if inhaled or swallowed.

4. Cautions

4.1. Avoid rubbing or wiping electrode bulb, as this may introduce error due to polarization.
4.2. Do not let stirring bar hit the sensing bulb, as it may crack or break the electrode tip.

5. Interferences

5.1. Glass KCl electrodes, in general, are not subject to solution interferences from any of the following factors:
  5.1.1. Color
  5.1.2. Turbidity
  5.1.3. Colloidal matter
  5.1.4. Oxidizing or reducing agents
  5.1.5. Moderate (<0.1 M) salinity

5.2. Coatings of oily material or particulate matter on the electrode surface can impair its response, and should be removed as they arise. These coatings can usually be removed by gentle wiping with detergent, followed by rinsing with distilled water. An additional treatment with hydrochloric acid (1:10) may be necessary to remove any remaining film.

5.3. Temperature effects on pH measurement using this method arise from two sources:
  5.3.1. Change in electrode output at various temperatures. This interference is controlled by using a pH meter and electrode equipped with temperature compensation.
  5.3.2. Change of pH due to temperature-dependent changes in the sample itself. This error is sample-dependent and cannot be controlled. It should, therefore, be noted by reporting both the pH and temperature at the time of analysis.

5.4. Manures have considerable bacterial populations, and metabolic acids produced by these bacteria can cause rapid fluctuations (decreases) in pH. Keep manure samples cool during shipping (SOP M1), and freeze upon arrival in the lab to minimize bacterial growth and activity. Analyze samples as soon after thawing as possible. Observe the general holding times described in Section 10.1.3.

6. Personnel Qualifications

6.1. Personnel should be trained in the use of the analytical instruments, and in laboratory safety, before initiating the procedure.

6.2. Each analyst must read and understand the entire manuals for the pH meter and electrode, and this SOP, before operating the instruments.

7. Equipment and Supplies

7.1. Orion Model 310 pH meter (Thermo Electron Corp., Beverly, MA), or equivalent

7.2. Orion 82-02 PerpHecT ROSS Combination pH Electrode with automatic temperature compensation (Thermo Electron Corp., Beverly, MA)

7.3. Calibration buffers (VWR International, Chester, PA) - These commercially available solutions have been validated by comparison with NIST standards and are recommended by USEPA for routine use.
  7.3.1. pH 4 Buffer , Cat. No. 34170-127
  7.3.2. pH 7 Buffer, Cat. No. 34170-130
  7.3.3. pH 10 Buffer, Cat. No. 34170-133

7.4. Magnetic stirrer and Teflon-coated stirring bars

8. Procedures

8.1. Select the KCl electrode.
8.2. Lower the plastic band covering the hole on the electrode.
8.3. Set pH meter to “standby”.
8.4. Lift electrode from storage solution.
8.5. Using a wash bottle, rinse electrode with redistilled water into a waste beaker.
8.6. Instrument calibration
  8.6.1. Set meter to “pH” mode.
  8.6.2. Press “CAL” key to initiate calibration sequence. “CAL” is displayed for 2 s.
  8.6.3. Press the “YES” key to accept the last calibration range (7-4 or 7-10) or select one of these calibration ranges using the SCROLL keys. Press “YES” to accept.
    8.6.3.1. When measuring samples with acidic pH, use pH 4 buffer for the second calibration step (Choose 7-4 calibration).
    8.6.3.2. When measuring samples with alkaline pH, use pH 10 buffer for the second calibration step (Choose 7-10 calibration).
  8.6.4. “pH 7” will be displayed for 2 s. Place electrode in pH 7 buffer, using a sufficient volume of buffer in a 50-mL beaker to cover the sensing elements of the electrodes, and to give adequate clearance for the magnetic stirring bar. Reading will be displayed and updated as calibration continues. When the “READY” light comes on indicating electrode stability, press the “YES” key to accept.
  8.6.5. “pH 4” (or “pH 10”) will then be displayed for 2 s. Remove electrode from pH 7 buffer. Rinse with deionized water and place electrode in either pH 4 or pH 10 buffer (depending on calibration range that was selected). When the “READY” light comes on, press the “YES” key to accept buffer value. “SLP” (slope) will be displayed for 2 s, after which the calculated slope will be displayed.
  8.6.6. Meter will automatically go into the “MEASURE” mode, at which point the “READY” light will come on to indicate electrode stability.
8.7. Using a wash bottle, rinse electrode with redistilled water into a waste beaker.
8.8. If sample is a liquid, or a slurry with >20% water by volume, place approximately 30-40 mL of sample to be tested into a beaker and gently stir at a constant rate to provide homogeneity and suspension of solids.
  8.8.1. If sample is a solid, or a slurry with <20% water by volume, mix approximately 5 g of sample with water in a 1:1 ratio in a beaker. Gently stir at a constant rate to provide homogeneity and suspension of solids, and allow sample to equilibrate for 30 min before taking the measurement.
8.9. Submerge electrode; when readout is stable, note and record sample pH and temperature.
  8.9.1. If operating in the LogR mode or using an ATC (Automatic Temperature Compensation) probe, the temperature-corrected pH is displayed.
8.10. Rinse electrode between samples with distilled water into the waste beaker.
8.11. When finished, submerge electrode in storage solution and return pH meter to “standby”.

9. Data and Records Management

9.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

9.2. Manage all data according to SOP B5.

9.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all corrections.

10. Quality Control and Quality Assurance

10.1. Data integrity

10.1.1. A second person will verify that the analyses were conducted properly and provide a signature at the end of the data set run and/or at the end of the working day.

10.1.2. Record the temperature with each set of pH measurements, in accordance with Section 5.3.2.

10.1.3. In accordance with USEPA Method 9040C, analyze all samples as soon after collection as is feasible.

10.1.3.1. Hold refrigerated samples for no more than 7 days prior to conducting this analysis. Archived (frozen) samples can be maintained indefinitely.

10.2. Equipment handling and maintenance

10.2.1. Submerge electrode in storage buffer at all times when not in use.

10.2.2. Maintain the level of filling solution above the reference junction and at least one inch above the sample level when immersed. Add saturated KCl solution to the electrode if it falls below this level.

10.2.3. Calibrate the instrument (See Section 8.6) immediately before each batch of samples, and after each batch as a check of how much drift may have occurred.

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DETERMINING SOLIDS CONTENT OF MANURE SAMPLES
Standard Operating Procedure (SOP) M3

DETERMINING SOLIDS CONTENT OF MANURE SAMPLES

Standard Operating Procedure (SOP) M3

Prepared by
Alan L. Sutton, Brian Richert, Scott Radcliffe, Dan Kelly and Bill W. Bogan

Reviewed by
Albert J. Heber, Harold M. Keener (Ohio State Univ.) and Jerome J. King (Midwest Laboratories, Inc)

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Manure composition significantly affects its emissions of odor and individual chemical components. The solids-to-liquids ratio is an important property.
1.2. This method determines the total solids, volatile solids and fixed solids contents of a manure sample.
1.3. The method described in this SOP is taken from USEPA Method 1684 (2001 Draft version), and is therefore also applicable to soils, sediments, and both raw and processed sludges.
1.4. The stated Method Detection Limits (MDLs) specified for this method are 3 mg/L total solids, 7 mg/L volatile solids, and 7 mg/L fixed solids.

2. Summary of Method

Well-mixed sample aliquots, having a wet weight of between 25 and 50 g, are dried at 103ºC to 105ºC in order to drive off all of the moisture in the sample. This step allows for the determination of total solids. Following cooling, the total-solids portion of the sample is heated to 550ºC, in a step that causes the volatile solids to be released. The sample is again cooled, and the remaining residue represents the fixed-solids portion.

3. Definitions

3.1.	IPR	Initial precision & recovery
3.2.	MDL	Method detection limit
3.3.	OPR	Ongoing precision & recovery
3.4.	QA	Quality Assurance
3.5.	QC	Quality Control
3.6.	Sample batch	All samples which are analyzed at the same time, up to a maximum of twenty (20). If more than 20 samples are analyzed at once, they must be assigned into more than one batch for the purposes of including blanks and OPR standards.

4. Health and Safety

4.1. Use gloves, tongs, and/or suitable sample holders when handling/moving hot sample vessels.

5. Cautions

5.1. When working with wet samples, weigh as quickly as possible after transferring to crucibles (Step 9.2.1), as these can lose water due to evaporation.
5.2. Unless extended drying times are required due to crusting (Section 6.3), do not exceed the drying times specified in this method. Overdrying can result in negative errors due to volatilization of certain salts (Section 6.5), volatilization of organic matter, or heat-

induced chemical decompositions, or to positive errors due to weight gain through sample oxidation.

5.3. Minimize the time that desiccators containing dried samples are open, as samples can adsorb moisture from the air. If strong desiccants are present in the sample (i.e. if weight gain occurs while samples are in the desiccator), use of a vacuum desiccator would be necessary. In all cases, do not remove samples from desiccators until immediately prior to weighing.

6. Interferences

6.1. Keep samples at or below 4°C after collection and during shipping (SOP M1), and prior to analysis, to minimize microbial degradation of sample solids. Analyze all samples within 7 days of collection. Frozen (archived) samples can be maintained indefinitely.

6.2. Samples must be kept homogeneous during the transfer of subsamples to drying vessels, as phase separation at this stage can be a source of considerable error.

  6.2.1. Use a magnetic stirrer (See Step 9.2.1.1).

  6.2.2. If the sample contains visible suspended solids, do not retrieve subsamples with a narrow-bore pipette. Use wide-bore pipettes, spoons or similar appropriate tools.

  6.2.3. If part of the whole sample adheres to the sample container walls despite magnetic stirring, a more intensive homogenization method must be used for mixing. In these cases, sample will be transferred (including scraping of the sample which is adhering to the vessel walls) into a Waring blender and homogenized in this way.

  6.2.4. Do not use a magnetic stirrer if magnetic particles are present in the sample.

6.3. If samples form a crust during the drying stage, this can inhibit further evaporation (either of water or volatile solids), and must be dealt with through special handling (either extended drying times or careful physical disruption (breakage) of the crust).

6.4. Following the initial drying step for total solids determination, some samples may retain small amounts of bound water, either as water of crystallization or interstitial water in crystals. Because the loss of this water is generally very slow, these samples may take longer to reach a constant weight.

6.5. Some samples may exhibit loss of CO_2 as bicarbonate is converted to carbonate. Loss of ammonium carbonate may also occur.

6.6. Samples with high levels of oil and grease may require particularly long drying times to reach a constant weight; it may therefore be difficult to obtain incontrovertible results for these samples.

6.7. Some dried samples may be highly hygroscopic, and contain stronger desiccants than are used in the desiccators themselves. Follow Section 5.3.

6.8. Use the same balance for all weighing steps involving a particular batch of samples.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the analytical instruments.

7.2. Each analyst must read and understand USEPA Method 1684 and this SOP before initiating these procedures, and must demonstrate the ability to generate acceptable data accuracy and precision as outlined in Section 11.2.

8. Equipment and Supplies

8.1. Drying oven
8.2. Muffle furnace
8.3. 15-100-mL crucibles or evaporating dishes made of porcelain or high-silica glass.
8.4. Watch glasses of suitable size to cover the crucibles/evaporating dishes
8.5. Analytical balance: Sartorius Model CP124S, Sartorius AG, Goettingen, Germany (or equivalent) (Capacity = 120 g; Accuracy =0.0001g).
  8.5.1. Reference masses for calibration: 2-mg, 1000-mg, and 50-g class “S” weights
8.6. Magnetic stirrer
8.7. Spatulas
8.8. Desiccator and desiccant (Drierite, Anhydrous Calcium Sulfate)

9. Procedures

9.1. Preparation
  9.1.1. If volatile solids are to be determined, heat crucibles/evaporating dishes and watch glasses to 550ºC for 1 h.
  9.1.2. If only total solids are to be determined, heat crucibles/evaporating dishes and watch glasses to 103ºC to 105ºC for 1 h.
  9.1.3. Cool and store all glassware in a desiccator.
  9.1.4. Prior to use, weigh empty clean crucible and watch glass, and record value (to the nearest 0.01 g) of the two combined.
9.2. Sample handling
  9.2.1. Obtaining subsamples
    9.2.1.1. Fluid (i.e. free-flowing) samples: Stir to homogenize (either by magnetic stirrer or using a spatula). Taking care that the sample remains homogeneous (i.e. that no phase separation occurs), transfer a 25- to 50-g aliquot to a crucible/dish using a pipette, spoon, or other appropriate tool. Spread evenly over the crucible. Replace watch glass and re-weigh; record weight to the nearest 0.01 g.
    9.2.1.2. Wet solid samples: Stir with a spatula to homogenize. Transfer a 25- to 50-g aliquot to a crucible/dish using a spatula, spoon, or other appropriate tool. Spread evenly over the crucible. Replace watch glass and re-weigh; record weight to the nearest 0.01 g.
    9.2.1.3. Dry solid samples: Pulverize the entire sample by hand (using rubber gloves) on a clean surface. Mix, and transfer a 25- to 50-g aliquot to a crucible/dish using a spatula, spoon, or other appropriate tool. Spread evenly over the crucible. Replace watch glass and re-weigh; record weight to the nearest 0.01 g.
  9.2.2. Include one blank (Section 11.8) and one Ongoing Precision and Recovery sample (Section 11.3) with each batch of samples.
  9.2.3. Put in oven to dry for 12 h at 103°C to 105°C.
  9.2.4. Remove from oven with tongs and place in the desiccator to cool to room temperature. Do not remove from desiccator until immediately prior to weighing. See Step 5.3 if working with highly hygroscopic samples.
  9.2.5. Weigh cooled crucible/watch glass/sample, and record value to the nearest 0.01 g.

9.2.6. Place crucible in the (cool) muffle furnace and raise temperature to 550° C and hold for 2 h.
9.2.7. Remove crucible from the muffle furnace with tongs and place in the desiccator to cool to room temperature.
9.2.8. Weigh and record value of crucible/watch glass/ash residue to the nearest 0.01 g.
9.2.9. Return to muffle furnace for 30 minutes, cool and re-weigh. Repeat as necessary until weight change is less than 4% or 50 mg (whichever is less).
9.2.10. Record final value of crucible/watch glass/ash residue to the nearest 0.01 g.

9.3. Calculations
9.3.1. Wet sample weight:
Crucible/watch glass/wet sample (Step 9.2.1) – Crucible/watch glass (Step 9.1.4)
9.3.2. Dry sample weight:
Crucible/watch glass/dry sample (Step 9.2.7) – Crucible/watch glass (Step 9.1.4)
9.3.3. Ash weight:
Crucible/watch glass/ashed sample (Step 9.2.12) – Crucible/watch glass (Step 9.1.4)
9.3.4. % Total Solids = ((Dry sample weight)/(Wet sample weight)) * 100
9.3.5. % Fixed Solids = ((Ash weight)/(Dry sample weight)) * 100
9.3.6. % Volatile Solids = 100% - % Fixed Solids

10. Data and Records Management

10.1. Maintain all laboratory records in an electronic spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Document all data and information on data sheets with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance

11.1. Quality Control (QC) Solutions
11.1.1. One of the following solutions will be employed for QC checks of the procedures described in this SOP:
11.1.1.1. NaCl-KHP QC solution
11.1.1.1.1. Dissolve 0.10 g NaCl in reagent-grade (de-ionized) water.
11.1.1.1.2. Add 0.10 g potassium hydrogen phthalate (KHP), and mix to dissolve. Warm and stir if necessary to dissolve the KHP.
11.1.1.1.3. Dilute with de-ionized water to 1.0 L in a volumetric flask.
11.1.1.1.4. Store at 4°C
11.1.1.1.5. This solution contains 200 mg/L of total solids, 81 mg/L of volatile solids, and 119 mg/L fixed solids.
11.1.1.2. Commercially-obtained QC solution: Wibby Environmental Volatile Solids QC Standard (Catalog # QC-VSOL-WP), Wibby Environmental, Golden, CO (or equivalent).

11.2. Analyst Proficiency Demonstration

11.2.1. Initial Precision and Recovery (IPR): Analyst must demonstrate ability to generate acceptable precision and accuracy. Prepare at least four (4) replicate (50-mL) aliquots of a 12-fold dilution of the QC solution. Process all replicates through each step of the analytical method, and perform all calculations. Using the results of the four or more replicates, calculate the average and standard deviation for the concentrations of total, volatile and fixed solids. Compare to the following table:

Analyte	Expected value	Acceptable range	Acceptable S.D.
Total solids (mg/L)	16.7	14.2 – 18.4	10%
Volatile solids (mg/L)	9.92	7.44 – 10.91	30%
Fixed solids (mg/L)	6.75	5.06 – 7.42	20%

11.2.1.1. If averages and standard deviations do not fall within these acceptable ranges, analyst must identify his/her source(s) of error and repeat the IPR procedure.

11.3. Ongoing Precision and Recovery (OPR)

11.3.1. Prepare an OPR solution identical to the IPR solution described in Step 11.2.1 (i.e. a 12-fold dilution of the QC solution).

11.3.2. Include one (1) OPR sample (25-50 mL) with each sample batch, and subject it to all steps of the analytical method.

11.3.3. Concentrations determined from the OPR sample must fall within the following ranges (in mg/L):

- Total solids: 13.4 – 18.4
- Volatile solids: 6.94 – 10.91
- Fixed solids: 4.90 – 7.42

11.3.4. If recovery of any analyte falls outside the acceptable range for a given OPR sample, repeat analysis of that sample batch after appropriate troubleshooting and correction of the problem.

11.4. QC Charts

11.4.1. Track all IPR and OPR results to keep a graphical representation of continued laboratory performance.

11.5. Method Modifications & Re-validation

11.5.1. Each time any modification is made to this method, the analyst will verify that the modified method meets or exceeds the Method Detection Limit and Initial Precision and Recovery achieved by the same analyst using the original (unmodified) method.

11.5.2. Verify MDLs by diluting either the NaCl-KHP QC solution (Section 11.1.1.1) or the commercial standard (Section 11.1.1.2) to the extent(s) necessary to achieve the solids contents listed in Section 1.4. Analyze each of these diluted solutions by the modified method to verify that the analyte can be detected at that level.

11.5.3. The laboratory will maintain records of any modifications made to the method. At minimum, these records must include the following:

11.5.3.1. Names, titles, and contact information for analyst who initiated the modifications and for the QA officer who witnessed and approved the modifications.

11.5.3.2. Narrative stating reason(s) for the modification

11.5.3.3. Results from all QC tests comparing the modified method's performance to that of the original method:

- Initial Precision and Recovery
- Accuracy
- Blanks
- Ongoing Precision and Recovery

11.6. Data Integrity

11.6.1. A second person will be present to verify that analyses were conducted properly and provide a signature at the end of the data set run and/or the end of the working day.

11.7. Replication

11.7.1. Run at least 10% (one in ten) of the samples in each batch in duplicate, with at least one duplicate per batch. Initial masses (i.e. wet weights) of the duplicates will not differ by more than 10%. Replicates must agree to within 10% of their average (% total solids); if not, rerun this batch.

11.8. Blanks

11.8.1. One blank (25-50 mL of deionized water) must be included with each sample batch, and be subjected to all steps of the analytical method.

11.8.2. If material is detected in the blank at or above the MDLs stated in Section 1.4, stop analysis until the source of contamination is identified and eliminated (i.e. a new blank shows no evidence of contamination).

11.9. Instrument Calibration and Standardization

11.9.1. Analytical balance

11.9.1.1. Full calibration (annually at a minimum).

11.9.1.1.1. Calibrate at 2 mg and 1000 mg using class "S" weights.

11.9.1.1.2. Instrument readings must be within ±10% at 2 mg (i.e. ±0.2 mg) and ±0.5% at 1000 mg (i.e. ±5 mg). If these are not achieved, re-calibrate the balance.

11.9.1.2. Calibration check (daily before any samples are weighed)

11.9.1.2.1. Place a 50-g weight and the 2-mg weight on the balance together. Verify that the balance reads 50.002 g (±0.0002 g).

12. References

12.1. USEPA. 2001. Method 1684 – Total, Fixed, and Volatile Solids in Water, Solids, and Biosolids. EPA-821/R-01-015 (CD). Office of Water, Office of Science and Technology. Washington, DC.

12.2. Hoskins, B. 2003. "Laboratory Procedures". Recommended Methods of Manure Analysis (J. Peters, ed.). University of Wisconsin-Madison Cooperative Extension Publishing, pp. 12-13. Online at http://learningstore.uwex.edu/Recommended-Methods-of-Manure-Analysis-P106C0.aspx. Accessed 9/6/2007.

12.3. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.4. SOP M1. 2006. Manure Sampling. Standard Operating Procedure M1. Purdue Ag Air Quality Lab.

DETERMINING TOTAL (KJELDAHL) NITROGEN CONTENT OF MANURE SAMPLES

Standard Operating Procedure (SOP) M4

DETERMINING TOTAL (KJELDAHL) NITROGEN CONTENT OF MANURE SAMPLES

Standard Operating Procedure (SOP) M4

Prepared by
Alan L. Sutton, Brian Richert, Scott Radcliffe, Dan Kelly and Bill W. Bogan

Reviewed by
Albert J. Heber and Jerome J. King (Midwest Laboratories, Inc)

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Manure composition can significantly affect its emissions, both in terms of general odor and individual chemical components. The total nitrogen content is an important manure property that affects emission of ammonia and other nitrogen-containing compounds. Thus, this parameter is important for both barn and open-source systems.

1.2. This method determines the total Kjeldahl nitrogen (TKN) content of a manure sample, Kjeldahl nitrogen being the sum of ammoniacal nitrogen and organic nitrogen.

1.3. The digestion method described in this SOP is taken from USEPA Method 1687 (2001 draft version), and is therefore also applicable to wastewaters, drinking water or groundwater, and industrial and other wastes.

1.4. The distillation and titrimetric procedures are described in USEPA Method 351.3.

1.4.1. This method has a working range of ca. 0.5-10 mg N/g manure (wet weight basis).

1.4.2. The stated detection limit for the method (Reference 12.4) is 0.01% (0.1 mg/g) N.

2. Summary of Method

Organic nitrogen in a manure sample is first converted to ammonia by metal-catalyzed acid digestion (with the exceptions listed in Section 6.7). The ammonia in the digested sample (the sum of nitrogen that was originally present in the ammoniacal form, plus that which is liberated from organic compounds) is then distilled away from the rest of the sample, at which point it is captured in a dilute sulfuric acid/boric acid solution containing bromocresol green/methyl red indicator. The ammonia concentration of the distillate is then determined by titration with sulfuric acid. Cupric sulfate/titanium dioxide ($CuSO_4$/TiO_2) is used as the sole catalyst in the digestion process. This avoids the toxicity and waste-disposal problems posed with mercury- and/or selenium-containing compounds. A QA/QC section is provided to discuss the calibration and periodic testing of the analytical method to ensure reliable data.

3. Definitions

3.1.	COD	Chemical oxygen demand
3.2.	CV	Calibration verification
3.3.	IPR	Initial precision and recovery
3.4.	MDL	Method detection limit
3.5.	MgO	Magnesium oxide
3.6.	MS	Matrix spike
3.7.	NaOH	Sodium hydroxide
3.8.	OPR	Ongoing precision and recovery
3.9.	QA/QC	Quality assurance/quality control
3.10.	Sample batch	A group of samples analyzed at the same time, up to a maximum of twenty (20). If more than 20 samples are analyzed at a time, divide them into multiple batches for the purpose of including blanks and CV and PR standards.
3.11.	SOP	Standard operating procedure
3.12.	TKN	Total Kjeldahl nitrogen

4. Health and Safety

4.1. Use gloves, tongs, and/or suitable sample holders when handling hot sample tubes.

4.2. Treat each chemical compound as a potential health hazard, and reduce exposure to chemicals to the lowest possible level.

  4.2.1. Wear protective clothing (gloves, lab coats, protective eyewear) when working with chemicals.

  4.2.2. Conduct all sample digestions in properly-ventilated fume hoods. Use a manifold to remove acid fumes.

  4.2.3. Keep analytical balances and other work areas clean; deal promptly with spills.

  4.2.4. When using concentrated acids and bases, keep a fully-stocked spill kit (including suitable neutralizers and absorbents) in the work area.

4.3. Maintain a current awareness file of Occupational Safety and Health Administration (OSHA) regulations pertaining to the chemicals specified in this method.

4.4. Maintain a reference file of material safety data sheets, which will be available to all personnel involved in these analyses.

4.5. Sulfuric acid digest is classified as a hazardous waste. Dispose of accordingly.

5. Cautions

5.1. Considerable heat is generated when dissolving sodium hydroxide (NaOH) in water (Step 8.7.2), or by mixing acids with water. Cool the container in an ice bath when preparing NaOH solutions or when mixing acid and water.

5.2. Excessive foaming during distillation can cause foam to pass into the condenser, which can contaminate the receiving flask and condenser with alkaline salts. Treat heavily-foaming samples with an anti-foaming agent.

6. Interferences

6.1. Keep samples at or below 4°C after collection and during shipping (SOP M1), and prior to analysis, to minimize microbial activity. Analyze all samples within 7 days of collection. Frozen (archived) samples can be maintained indefinitely.

6.2. Use only ammonia-free water, which can be prepared by passing reagent water through an ion-exchange column that is packed with a mixture of both strongly acidic cation- and strongly basic anion-exchange resins. Regenerate this column periodically according to the manufacturer’s instructions.

6.3. Ammonia gas in the lab can deposit into the sample. Minimize sample exposure to air.

6.4. Nitrate in large quantities (>10 mg/L) will oxidize ammonia produced by the digestion and can introduce a substantial negative error. Although this interference cannot be prevented, its effect can be predicted and accounted for on the basis of preliminary nitrate determination of the sample. Whenever high nitrate levels are a potential issue, nitrate analyses of the sample should be conducted first.

Inorganic salts or solids will increase digestion temperature; however, conducting digestion at temperatures in excess of 400°C will cause pyrolitic loss of nitrogen. If high levels of salts and/or solids are suspected, adding extra H_2SO_4 can partially circumvent this problem. Approximately 1 mL H_2SO_4 per g of salt/solid will preserve the proper ratio, and allow digestion to proceed at the target temperature. Monitoring of digestion temperature will indicate if problems are occurring.

6.5. Large amounts of organic matter can consume the acid in the digestion reagent, causing the digestion temperature to rise above 400°C. Adding 10 mL H_2SO_4 per 3000 mg COD will prevent this. Monitor digestion temperature and pH if this correction is used.

6.6. Nitrogen occurring in certain organic compounds will not be measured by this method. These compounds include those in which the nitrogen occurs in the following forms:

- azide
- azine
- azo
- hydrazone
- nitrate
- nitrite
- nitrile
- nitro
- nitroso
- oxime
- semicarbazone

6.6.1. Levels of these compounds in manure are expected to be negligible.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the equipment before initiating the procedure.

7.2. Each analyst must read and understand this SOP, as well as USEPA Methods 1687 and 351.3, before initiating this procedure, and must show the ability to generate acceptable data accuracy and precision (Section 11.3).

8. Equipment and Supplies

8.1. Copies of USEPA Methods 1687 and 351.3

8.2. Tecator Instrument Model 2020 digester block and aspirator for sample digestion

8.3. Foss Kjeltec Model 2300 automated distillation and titration analyzer (FOSS Analytical, Hilleroed, Denmark), or equivalent

8.4. Flasks: 100-mL Kjeldahl and 50-mL Erlenmeyer flasks

8.5. Magnetic stirrer and Teflon-coated stir bars

8.6. Spatulas

8.7. Analytical balance (Capacity = 410 g; Accuracy = 0.001 g)

8.7.1. Reference weights for calibration: 2-mg, 1000-mg, and 50-g class “S” weights

8.8. Reagents

8.8.1. Sulfuric acid: Concentrated, 0.020N & 0.25N H_2SO_4, certified (Midland Scientific, Omaha, NE)

8.8.2. Sodium hydroxide: 40% NaOH solution, certified (Midland Scientific, Omaha, NE)

8.8.3. Digestion reagent: TT-43 Pro Pac Kjeldahl digestion tablets (Alfie packers, Inc, Omaha, NE)

8.8.4. Boric acid indicator

8.8.4.1. Add 0.10 g bromocresol green, 0.10 g methyl red, 100 g boric acid, and 20 mL of 0.10N NaOH to a 2-L flask that is half-full of NH_3-free water and dissolve all reagents

8.8.4.2. Add NH_3-free water to the 2-L mark on the flask.

8.8.4.3. Quantitatively transfer contents of the flask to the receiving solution reservoir below the Foss Kjeltech Model 2300.

8.8.4.4. Add 8 moreL of NH_3-free water to the reservoir, for a total of 10 L of solution.

8.9. Standards

8.9.1. Ammonia standards

8.9.1.1. Ammonia stock solution (1000 mg/L NH_3-N): Dissolve 0.382 g of anhydrous ammonium chloride (NH_4Cl), which should be dried at 105°C immediately prior to use, in NH_3-free water and dilute to 100 mL in a volumetric flask with NH_3-free water.

8.9.1.2. Ammonia working standard (10 mg/L NH_3-N): Dilute 10 mL of ammonia stock solution to 1 L in a volumetric flask with NH_3-free water.

8.9.2. Nicotinic acid standard (Contains 100 mg/L organic N): Dissolve 21.637 g nicotinic acid in ~ 150 mL NH_3-free water. Dilute to 200 mL with NH_3-free water.

8.9.3. Calibration standards

8.9.3.1. Prepare calibration standards by spiking 5-g aliquots of blank sand or diatomaceous earth (Section 8.10) directly with nicotinic acid standard solution (Section 8.9.2).

8.9.3.2. Prepare a minimum of five calibration standards, at five different concentrations to produce a calibration curve with at least five points.

8.9.3.3. At least one of the calibration standards should correspond to a sample concentration at or below that necessary to meet the data quality objectives of the project. The QAPP for a particular project will state the specific concentration needed for this standard.

8.9.3.4. The remaining standards should correspond to the concentration range found in actual samples, without exceeding the titration-based system's working range.

8.9.4. Calibration Verification (CV) standard

8.9.4.1. Prepare the CV standard such that its N concentration approximates the midpoint of the calibration curve.

8.9.4.2. The source used to prepare the CV standard should be different from that used to prepare the calibration standards. Use either a different bottle of nicotinic acid, or a different compound altogether.

8.9.4.3. If a different ammonium compound is used for the CV stock, adjust the amount weighed according to the ratio of N weight to the molecular weight. Nicotinic acid has one atom of N per molecule and a formula weight of 123.11; it is, therefore 11.37% N by weight (14/123.11). If, for example, nicotinamide (2 N per molecule, formula weight 122.12, 22.93% N) is used as the CV standard, and X mg of nicotinic acid was needed to yield the desired N concentration, then (11.37/22.93) X, or 0.496 X g of nicotinamide would be needed.

8.9.5. Quality control sample (QCS): Standard Reference Material 1570a (Spinach Leaf). National Institute of Standards & Technology, Gaithersburg, MD.

8.10. Blank sand or diatomaceous earth

8.10.1. Bake 500 g diatomaceous earth or clean sand at 400°C for 8 h. Cool and store in a glass container with a sealing lid.

9. Procedures

9.1. Sample Preparation

9.1.1. In a fume hood, preheat the digestion block of the Model 2020 to 380ºC.

9.1.2. Obtain percent total solids of each sample to be analyzed, according to SOP M3.

9.1.3. Label digestion tubes as necessary to accommodate all samples, plus the various QA standards (Duplicates, Precision and Recovery Samples, Calibration Verification Standards, Quality Control Standards, Matrix Spikes, and/or Blanks) as required (See Sections 11.4 through 11.9 for the frequency that these must be included).

9.1.4. Bring samples to room temperature. Thoroughly homogenize the sample. Transfer 50 mL of sample into a digestion tube, and obtain and record the sample weight.

9.1.5. Add Kjeldahl digestion tablets (Section 8.8.3) and 20 mL of concentrated H_2SO_4, and place tube in the preheated digestion block.

9.2. Digestion

9.2.1. Immediately set up the exhaust system, and place the exhaust manifold so that it covers the mouth of each digestion tube. Turn water to vacuum on low.

9.2.2. Digest for 2 h.

9.2.2.1. Be sure that the manifold and hood fan are operating properly to remove the fumes released in the digestion process.

9.2.3. Remove tubes from digestion block with tongs and transfer to cooling tray to cool, leaving the exhaust manifold in place for a minimum of 30 min after the end of digestion. After 30 min, turn off water to vacuum, and remove exhaust manifold.

9.2.4. Add NH_3-free water to each tube to the level of the top horizontal support on the cooling rack (~50 mL). Place samples in the cooler and cool to <20 ºC.

9.3. Distillation

9.3.1. Place samples on the Model 2300 and select “Kjeldahl 5”. This selection ensures that the instrument will dispense a sufficient amount of NaOH to the sample.

9.3.1.1. Use 0.020 N H_2SO_4 for low-N samples, and 0.25 N for all others. Most samples associated with livestock manure, feed, and bedding are assumed to require 0.25 N H_2SO_4.

9.4. Calculations

9.4.1. Calculate TKN (in units of mg/g) in the sample as follows, correcting the amount of titrant (0.25N H_2SO_4) added to each sample by subtracting that needed to titrate a blank to endpoint:

$$\text{TKN} = \frac{\text{Titrant}_{\text{sample}}\,(\text{mL}) - \text{Titrant}_{\text{blank}}\,(\text{mL})}{\text{Sample wt (g)}} \times 3{,}500^*$$

*If 0.25N H2SO4 is used in the distillation/titration step. If 0.02 N acid is used, replace 3,500 with 280.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstirke errors in writing with single lines.
10.4. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Reagent Purity
  11.1.1. Use only NH_3-free water in this method. See Step 6.1 for the methodology used to remove ammonia from water for use in these procedures.
  11.1.2. All other reagents will be ACS Reagent Grade or better.
11.2. Instrument Calibration and Standardization
  11.2.1. Calibrate analytical balance annually (at a minimum).
    11.2.1.1. Calibrate at 2 mg and 1000 mg using class "S" weights.
    11.2.1.2. Instrument calibration must be within ±10% at 2 mg (i.e. ±0.2 mg) and ±0.5% at 1000 mg (i.e. ±5 mg). If these limits are not achieved, the balance must be re-calibrated.
    11.2.1.3. Place a 50-g weight and the 2-mg weight on the balance together. Verify that the balance reads 50.002 g (±0.0002 g).
11.3. Initial Demonstration of Analyst & Laboratory Proficiency
  11.3.1. The following steps are to be followed by every new analyst performing this method, in order to assure the quality of his/her technique. No analyst may perform analyses of actual samples until he/she has passed all of the following:
    11.3.1.1. Determine Method Detection Limit (MDL)
      11.3.1.1.1. Prepare a group of at least seven (7) MDL determination samples by mixing 5-g aliquots of blank sand (or diatomaceous earth) (Section 8.10) with 10 mL NH_3-free water, and spiking each with nicotinic acid standard (Section 8.9.2) such that the organic N concentration of each MDL sample is one to five times the estimated detection limit (Section 1.4.2).
      11.3.1.1.2. Using the seven replicates; process each through every step of the method. Calculate the N concentrations (Section 9.4.1) for each aliquot, and compare with the expected concentrations.
      11.3.1.1.3. If, on average, the calculated concentrations are within 20% of the expected concentrations, analyst and system performance are acceptable .
    11.3.1.2. Initial Precision and Recovery (IPR)
      11.3.1.2.1. Prepare a group of at least four (4) IPR samples by mixing 5-g aliquots of blank sand (or diatomaceous earth) with 10 mL NH_3-free water, and spiking the slurries with nicotinic acid standard so that the organic N concentration of each PR sample is on the order of 1%. Process each sample through every step of the method. Perform the TKN calculations in Section 9.4.1, and determine

the percent recovery by comparing these to the known input amount.

11.3.1.2.2. Using the results of the set of four analyses, compute the average percent recovery (X) and the standard deviation (s) of the percent recovery for TKN.

11.3.1.2.3. The required performance specifications are 110% ≥ X ≥ 90%, and s ≤ 5%.

11.3.1.2.4. If X and s meet the acceptance criteria, analyst and system performance are acceptable..

11.3.1.2.5. If s exceeds the precision limit (5%), and/or X falls outside the range for recovery, analyst and/or system performance is unacceptable. In this event, correct the problem, and repeat the test.

11.3.1.3. Blank

11.3.1.3.1. Include a minimum of one blank (Section 11.9) to verify that nitrogen is not detected in the blank at a concentration greater than the aqueous or solid MDL (Section 11.4.1.1).

11.3.1.4. Linearity of calibration curve

11.3.1.4.1. Analyst will prepare a five-point calibration curve (Section 8.9.3) to verify his/her ability to generate linear results over the concentration range of interest. If the linear correlation coefficient (r^2) of the calibration curve is ≥0.96, analyst and system performance are acceptable.

11.3.1.5. CV Standard

11.3.1.5.1. Include a minimum of one CV Standard (Section 8.9.4) to verify that the analyst can meet the acceptance criteria outlined in Section 11.6.1.1.

11.4. Ongoing Precision and Recovery (OPR)

11.4.1. MDL

11.4.1.1. Re-determine/verify MDLs annually.

11.4.1.2. Re-determine/verify MDLs whenever a modification is made to the method or analytical system.

11.4.2. Precision and Recovery (PR) samples

11.4.2.1. Each batch of samples (Section 3.10) must contain a minimum of one PR sample. Run solid samples with solid PR samples, and slurry samples with slurry PR samples.

11.4.2.1.1. Prepare a solid PR sample by spiking 5 g of blank sand (or diatomaceous earth) with nicotinic acid standard such that the organic N concentration of the PR sample is approximately five times the MDL (Section 1.4.2).

11.4.2.1.2. Prepare a slurry PR sample by mixing 5 g of blank sand (or diatomaceous earth) with 10 mL NH_3-free water, and spiking the slurry with nicotinic acid standard such that the organic N concentration of the PR sample is approximately five times the MDL (Section 1.4.2).

11.4.2.2. Carry the spiked PR sample through the entire analytical process, and calculate percent recovery.

11.4.2.2.1. If recovery falls within 90 to 110%**,** the system performance is acceptable.

11.4.2.2.2. If recovery falls outside 90% to 110%, system performance is unacceptable, and the problem must be identified and resolved prior to further analyses.

11.4.2.3. All samples must be associated with an acceptable PR standard before their results may be reported.

11.5. Calibration curves

11.5.1. Generate a new calibration curve (containing a minimum of five points as described in Section 8.9.3) whenever a new standard is obtained.

11.6. Calibration Verification (CV) standards

11.6.1. A Calibration Verification Standard (solid or slurry, as appropriate) must be run once per sample batch (every twenty analyses – Section 3.10).

11.6.1.1. Acceptance criteria for the CV Standard is 100% ± 5%.

11.6.1.2. If the CV does not meet acceptance criteria, the problem must be identified and corrected, including possible recalibration of the system if the problem cannot be corrected by other means.

11.6.1.3. All samples must be associated with an acceptable CV Standard before their results may be reported.

11.7. Quality Control standards

11.7.1. In accordance with Method 1687, analyze a QC standard with each day's distillations, or every 12 h, whichever is more frequent.

11.8. Matrix Spikes

11.8.1. To assess the performance of the method on a given sample matrix, spike (in duplicate) a minimum of 5% (1 sample in 20) of the samples from a given site.

11.8.2. Ensure that the concentration of nitrogen spiked into each MS sample is 1-5 times the background (i.e. existing) concentration expected for that particular sample.

11.8.2.1. The spiking level may be established *a priori* based on existing information (either analyst's previous experience or existing literature values) for N content of manures from the particular species.

11.8.3. The concentration added should be expressed as mg/kg, and should be calculated for a 1-g aliquot by multiplying the N concentration (mg/L) added (as nicotinic acid) by the conversion factor 100 (mg/L x 0.1L/0.001kg = 100).

11.8.4. Do not use blanks for MS analysis.

11.8.5. Assessing spike recovery

11.8.5.1. Calculate the percent recovery of TKN in the duplicate matrix spike samples (corrected for the background concentration measured in the corresponding unspiked sample which was used as the basis for the MS samples), as well as the relative percent difference (RPD) between the two values.

11.8.5.1.1. Percent recovery is calculated as follows:

$$\text{Percent Recovery} = \frac{(C_s - C_b)}{S} \times 100$$

Where:
C_s = Sample N concentration determined after spiking
C_b = Sample N concentration determined before spiking
S = Known concentration of the spike

11.8.5.1.2. RPD is calculated as follows:

$$\text{RPD} = \frac{(|D_1 - D_2|)}{D_1 + D_2} \times 100$$

Where:
D_1 = TKN concentration of MS sample #1
D_2 = TKN concentration of MS sample #2

11.8.5.2. Percent recoveries for the matrix spikes should be within three (3) standard deviations above or below the mean, with RPD ≤ 20%.

11.8.5.3. If either the percent recovery or the RPD of TKN in the MS samples falls outside the designated range, while the percent recovery in the PR sample is within the acceptable range, the problem encountered with the MS sample is judged to be matrix-related instead of method-related.

11.9. Blanks

11.9.1. Run a minimum of one blank with each batch of samples (Section 3.10).

11.9.2. Run aqueous (slurry) samples with an aqueous blank (10 mL NH_3-free water), and solid samples with a solid blank (a 5-g aliquot of blank sand).

11.9.3. If material is detected in the aqueous or solid blank at a concentration greater than the MDL (Section 1.4.2), halt analysis of samples until the source of contamination is eliminated and a new blank shows no contamination.

11.9.4. All samples must be associated with an uncontaminated laboratory blank before their results may be reported.

11.10. QC Charts

11.10.1. Track all IPR, OPR, Calibration Verification, QC Standard, MS and Blank results to provide graphical representations of continued laboratory performance.

11.11. Method modifications & re-validation

11.11.1. If any modification is made to this method, verify that the modified method meets or exceeds the Method Detection Limit (11.3.1.1) and Initial Precision and Recovery (11.3.1.2) achieved by the same analyst using the original (i.e. unmodified) method.

11.11.2. Maintain records of any modifications made to the method. At minimum, these records must include the following:

11.11.2.1. Names, titles, and contact information for analyst who initiated the modifications and for the QA Officer who witnessed and approved them

11.11.2.2. Narrative stating reason(s) for the modification

11.11.2.3. Results from all QC tests comparing the modified method's performance to that of the original method:

- Initial Precision and Recovery
- Ongoing Precision and Recovery
- Results with CV, QC Standard, MS samples and Blanks

11.12. Duplication

11.12.1. Run a minimum of 10% of samples (1 in 10) in duplicate, with a minimum of one duplicate per batch. Replicates must agree to within 10% of their average TKN content; if not, the batch of samples must be re-run.

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DETERMINING AMMONIA CONTENT OF MANURE SAMPLES
Standard Operating Procedure (SOP) M5

DETERMINING AMMONIA CONTENT OF MANURE SAMPLES

Standard Operating Procedure (SOP) M5

Prepared by

Alan L. Sutton, Brian Richert, Scott Radcliffe, Dan Kelly and Bill W. Bogan

Reviewed by

Albert J. Heber and Jerome J. King (Midwest Laboratories, Inc)

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The composition of manure can significantly affect its emissions, both in terms of general odor and individual chemical components. The ammonia content of a manure is generally a good indicator of readily available nitrogen, and therefore affects emission of both ammonia and other nitrogen-containing compounds.

1.2. This method determines a manure sample's total ammoniacal nitrogen (NH_3-N) content.

1.3. The distillation and titrimetric analyses are described in USEPA Method 350.2 and elsewhere (Bremner and Keeney 1965).

1.3.1. This method has a working range of approximately 0.5-10 mg NH_3 per g of manure (wet weight basis), and a minimum detection limit of approximately 0.1 mg/g.

1.3.2. The digestion and distillation method described in this SOP has been scaled down to "micro-Kjeldahl" scale in accordance with Reference 12.2.

2. Summary of Method

The ammonia in a manure sample is distilled away from the rest of the sample, at which point it is captured in a dilute boric acid solution which contains a bromocresol green methyl red indicator. The ammonia concentration of the distillate is then determined by titration with a known concentration of sulfuric acid. A quality assurance/quality control (QA/QC) section is provided to discuss the calibration and periodic testing of the analytical method to ensure that reliable data are collected.

3. Definitions

3.1.	CV	Calibration verification
3.2.	IPR	Initial precision and recovery
3.3.	MDL	Method detection limit
3.4.	MgO	Magnesium oxide
3.5.	MS	Matrix spike
3.6.	NaOH	Sodium hydroxide
3.7.	OPR	Ongoing precision and recovery
3.8.	PR	Precision and recovery
3.9.	QA/QC	Quality assurance/quality control
3.10.	RPD	Relative percent difference
3.11.	Sample batch	A group of sample analyzed at the same time, up to a maximum of twenty (20). If more than 20 samples are analyzed at a time, they must be divided into multiple batches for including blanks and QA standards.
3.12.	SOP	Standard operating procedure

4. Health and Safety

4.1. Treat each chemical compound as a potential health hazard, and reduce exposure to chemicals to the lowest possible level.

- 4.1.1. Wear protective clothing (gloves, lab coats, protective eyewear) when working with chemicals.
- 4.1.2. Conduct all operations involving solvents in properly-ventilated fume hoods.
- 4.1.3. Keep analytical balances and other work areas clean; deal with spills promptly.
- 4.1.4. When using concentrated acids and bases, keep a fully-stocked spill kit (including suitable neutralizers and absorbents) in the work area at all times.

4.2. Maintain a current awareness file of Occupational Safety and Health Administration (OSHA) regulations regarding the safe handling of the chemicals specified in this method.

4.3. Maintain a reference file of material safety data sheets (MSDS), which will be available to all personnel involved in these analyses.

5. Cautions

5.1. Considerable heat is generated when dissolving sodium hydroxide (NaOH) in water, or when mixing acid with water. Cool the container in an ice bath when preparing NaOH solutions, or when mixing acid with water.

5.2. Excessive foaming during distillation can cause foam to pass into the condenser, which can contaminate the receiving flask and condenser with alkaline salts. Treat heavily-foaming samples with an anti-foaming agent.

6. Interferences

6.1. Keep samples at or below 4°C after collection and during shipping (SOP M1), and prior to analysis, to minimize microbial activity. Analyze all samples within 7 days of collection. Frozen (archived) samples can be maintained indefinitely.

6.2. Use only ammonia-free water, prepared by passing reagent water through an ion-exchange column packed with strongly acidic cation- and strongly basic anion-exchange resins. Regenerate this column periodically according to the manufacturer’s instructions.

6.3. Ammonia gas in the lab can deposit into the sample. Minimize sample exposure to air.

6.4. Nitrate in large quantities (>10 mg/L) can oxidize ammonia in the sample and introduce negative error. Although this interference cannot be prevented, its effect can be predicted and accounted for on the basis of preliminary nitrate determination of the sample. Whenever high nitrate levels are a potential issue, conduct nitrate analyses of the sample before attempting an ammonia analysis.

6.5. Volatile nitrogen-containing compounds such as hydrazine and some amines can cause overestimates of ammonia content. The levels of these in manure should be negligible.

6.6. Any residual Cl^- in the sample must be removed using sodium thiosulfate. This is most often associated with aqueous samples, or samples containing free water, and generally does not affect manure/biosolid samples.

7. Personnel Qualifications

7.1. Personnel should be trained in conducting these analyses before initiating the procedure.

7.2. Each analyst must read and understand this SOP, SOP M3, and USEPA Methods 351.3

and 1687 before initiating this procedure, and must show the ability to generate acceptable data accuracy and precision (Section 11.3).

8. Equipment and Supplies

8.1. Copies of PAAQL SOP M3 and USEPA Methods 351.3 and 1687
8.2. Foss Kjeltec Model 2300 automated distillation and titration analyzer (FOSS Analytical, Hilleroed, Denmark), or equivalent
8.3. Flasks: 100-ml Kjeldahl and 50-ml Erlenmeyer flasks
8.4. Analytical balance (Capacity = 410 g; Accuracy = 0.001 g)
  8.4.1. Reference weights for calibration: 2-mg, 1000-mg, and 50-g class “S” weights
8.5. Reagents and buffers
  8.5.1. Sulfuric acid: Concentrated, 0.020N & 0.25N H_2SO_4, certified (Midland Scientific, Omaha, NE)
  8.5.2. Sodium hydroxide: 40% NaOH solution, certified (Midland Scientific, Omaha, NE)
  8.5.3. Boric acid indicator:
    8.5.3.1. Add 0.10 g bromocresol green, 0.10 g methyl red, 100 g boric acid, and 20 mL of 0.10N NaOH to a 2-L flask that is half-full of NH_3-free water. Dissolve all reagents
    8.5.3.2. Add NH_3-free water to the 2-L mark on the flask.
    8.5.3.3. Quantitatively transfer flask contents to the receiving solution reservoir below the Foss Kjeltech Model 2300.
    8.5.3.4. Add 8 more liters of NH_3-free water to the reservoir, for a total of 10 L of solution.
8.6. Standards
  8.6.1. Ammonia standards
    8.6.1.1. Ammonia stock solution (1000 mg/L NH_3-N):
      8.6.1.1.1. Dry anhydrous ammonium chloride (NH_4Cl) at 105°C immediately before use.
      8.6.1.1.2. Dissolve 0.382 g of this dried NH_4Cl in NH_3-free water and dilute to 100 mL with NH_3-free water in a volumetric flask.
    8.6.1.2. Ammonia working standard (10 mg/L NH_3-N): Dilute 10 mL of ammonia stock solution to 1 L in a volumetric flask with NH_3-free water.
  8.6.2. Calibration standards
    8.6.2.1. Prepare calibration standards by spiking 5-g aliquots of blank sand or diatomaceous earth (Section 8.7) directly with ammonia standard solution (Section 8.6.1).
    8.6.2.2. Prepare a minimum of five calibration standards, at five different concentrations to produce a calibration curve with at least five points.
    8.6.2.3. At least one of the calibration standards must correspond to a sample concentration at or below that necessary to meet the data quality objectives (DQOs) of the project. The QAPP for the particular project will state what concentration meets the DQOs.

8.6.2.4. The remaining standards should correspond to the concentration range found in actual samples, without exceeding the titration-based system's working range.

8.6.3. Calibration Verification (CV) standard

8.6.3.1. Prepare the CV standard so its NH_3 concentration approximates the midpoint of the calibration curve.

8.6.3.2. Prepare solid CV standards for use with solid samples, and slurry CV samples for use with slurry samples.

8.6.3.3. The source used to prepare the CV standard should be different from that used to prepare the calibration standards. Use either a different bottle of the same compound, or a different NH_3-containing compound altogether.

8.6.3.4. If a different ammonium compound is used for the CV stock, adjust the amount weighed according to the ratio of NH_3-N atomic weight to molecular weight. Ammonium chloride has one NH_4 group per molecule and a formula weight of 53.49; it is, therefore 31.78% NH_3 by weight (17/53.49). If, for example, dibasic ammonium phosphate (2 NH_4 per molecule, formula weight 132.06, 25.75% NH_3) is used as the CV standard, and X mg of ammonium chloride was needed to yield the NH_3 concentration at the midpoint of the calibration curve, then (31.78/25.75) X, or 1.23 X g of dibasic ammonium phosphate would be needed to yield the same NH_3 concentration.

8.6.4. Quality Control Sample (QCS): A prepared quality control sample from a standards vendor. Environmental Resource Associates (Arvada, CO) Catalog #545, or equivalent.

8.7. Blank sand or diatomaceous earth

8.7.1. Bake 500 g diatomaceous earth or clean sand at 400 °C for 8 h. Cool and store in a glass container with a sealing lid.

9. Procedures

9.1. Sample Preparation

9.1.1. Obtain percent total solids of each sample, according to SOP M3.

9.1.2. Label Kjeldahl distillation flasks as necessary to accommodate samples, in duplicate, as well as all necessary duplicates, Precision and Recovery Samples, Calibration Verification Standards, Quality Control Standards, Matrix Spikes, and/or Blanks (See Sections 11.4 - 11.9 for the frequency that these must be included).

9.1.3. Add sample.

9.1.3.1. Solid samples: Bring to room temperature. Thoroughly homogenize the sample. Weigh 1-2 g of sample into the Kjeldahl flask.

9.1.3.2. Slurry samples: Bring to room temperature. Mix the sample thoroughly. Transfer (by pipette or spatula) 1-2 mL (or 1-2 g) of sample to the distillation flask, and record the weight of the added sample.

9.2. Distillation

9.2.1. Place samples on the Model 2300 and select "Kjeldahl 5". This selection ensures that the instrument will dispense a sufficient amount of NaOH to the sample.

9.2.1.1. Use 0.020 N H_2SO_4 for low-N samples, and 0.25 N for all others. Most samples associated with livestock manure will require 0.25 N H_2SO_4.

9.3. Calculations

9.3.1. Calculate NH_3-N (in units of mg/g) in the sample as follows, correcting the amount of titrant (0.25N H_2SO_4) added to each sample by subtracting that needed to titrate a blank to endpoint:

$$NH_3\text{-N} = \frac{\text{Titrant}_{\text{sample}}\,(\text{mL}) - \text{Titrant}_{\text{blank}}\,(\text{mL})}{\text{Sample wt (g)}} \times 3{,}500^*$$

*If 0.25N H2SO4 is used in the distillation/titration step. If 0.02 N acid is used, replace 3,500 with 280.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line.

10.4. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Reagent Purity

11.1.1. All water used in this method must be NH_3-free. See Step 6.1 for the methodology used to remove NH_3 from water for use in these procedures.

11.1.2. All other reagents will be ACS Reagent Grade or better.

11.2. Instrument calibration and standardization

11.2.1. Calibrate the analytical balance annually (at a minimum).

11.2.1.1. Calibrate at 2 mg and 1000 mg using class “S” weights.

11.2.1.2. Instrument calibration must be within ±10% at 2 mg (i.e. ±0.2 mg) and ±0.5% at 1000 mg (i.e. ±5 mg). If these limits are not achieved, the balance must be re-calibrated.

11.2.1.3. Place a 50-g weight and the 2-mg weight on the balance together. Verify that the balance reads 50.002 g (±0.0002 g).

11.3. Initial demonstration of analyst & laboratory proficiency

11.3.1. The following steps are to be followed by every new analyst performing this method, in order to provide an assurance of the quality of his/her technique. No analyst may perform analyses of actual samples until he/she has passed all of the following:

11.3.1.1. Determine Method Detection Limit (MDL)

11.3.1.1.1. Prepare a group of at least seven (7) MDL determination samples by mixing 5-g aliquots of blank sand (or diatomaceous earth) (Section 8.7) with 10 mL NH_3-free water, and spiking each with ammonia standard (Section 8.6.1) such that the organic NH_3 concentration of each MDL sample is one to five times the estimated detection limit (Section 1.3.1).

11.3.1.1.2. Using the seven replicates; process each through every step of the method. Calculate the NH_3 concentrations (Section 9.3) for each aliquot, and compare with the expected concentrations.

11.3.1.1.3. If, on average, the calculated concentrations are within 20% of the expected concentrations, analyst and system performance are acceptable.

11.3.1.2. Initial Precision and Recovery (IPR)

11.3.1.2.1. Prepare a group of at least four (4) IPR samples by mixing 5-g aliquots of blank sand (or diatomaceous earth) with 10 mL NH_3-free water, and spiking the slurries with ammonia standard such that the NH_3 concentration of each PR sample is on the order of 1%. Process each sample through every step of the method. Perform the % NH_3 calculations in Section 9.3, and determine the percent recovery by comparing these to the known input amount.

11.3.1.2.2. Using the results of the four analyses, compute the average percent recovery (X) and the standard deviation (s) of the percent recovery for ammonia.

11.3.1.2.3. The required performance specifications for PR samples are a recovery of $110\% \geq X \geq 90\%$, and precision $(s) \leq 5\%$.

11.3.1.2.4. If s and X meet the acceptance criteria, analyst and system performance are acceptable.

11.3.1.2.5. If s exceeds the precision limit (5%), and/or X falls outside the range for recovery, system performance is unacceptable. In this event, correct the problem, and repeat the test.

11.3.1.3. Blank

11.3.1.3.1. Analyst will include a minimum of one blank (Section 11.9) to verify that he/she does not detect NH_3 in the blank at a concentration greater than the stated MDL (Section 1.3.1).

11.3.1.4. Linearity of calibration curve

11.3.1.4.1. Analyst will prepare a five-point calibration curve (Section 8.6.2) to verify his/her ability to generate linear results over the concentration range of interest. If the linear correlation coefficient (r^2) of the calibration curve is ≥ 0.96, analyst and system performance are acceptable.

11.3.1.5. CV Standard

11.3.1.5.1. Analyst will include a minimum of one CV Standard (Section 8.6.3) to verify that he/she can meet acceptance criteria (Section 11.6.1.1).

11.4. Ongoing Precision and Recovery (OPR)

11.4.1. MDL

11.4.1.1. Re-determine/verify method detection limits annually.

11.4.1.2. Re-determine/verify method detection limits whenever a modification is made to the method or analytical system.

11.4.2. Precision and Recovery (PR) Samples

11.4.2.1. Each batch (up to 20 samples) (Section 3.11) must contain a minimum of one PR sample. Run solid samples with solid PR samples, and slurry samples with slurry PR samples.

11.4.2.1.1. Prepare a solid PR sample by spiking 5 g of blank sand (or diatomaceous earth) with ammonia working standard such that the NH_3 concentration of the PR sample is approximately five times the MDL (Section 1.3.1).

11.4.2.1.2. Prepare a slurry PR sample by mixing 5 g of blank sand (or diatomaceous earth) with 10 mL NH_3-free water, and spiking the slurry with amoonia working standard such that the NH_3 concentration of the PR sample is approximately five times the MDL (Section 1.3.1).

11.4.2.2. Carry the PR sample through the entire analytical process, and calculate percent recovery.

11.4.2.2.1. If recovery falls within the range of 90% to 110%**,** the system performance is acceptable.

11.4.2.2.2. If recovery falls outside the range of 90% to 110%, the system performance is unacceptable, and the problem must be identified and resolved before performing any further analyses.

11.4.2.3. All samples must be associated with an acceptable PR standard before their results may be reported.

11.5. Calibration curves

11.5.1. Generate a new calibration curve (containing a minimum of five points as described in Section 8.6.2) whenever a new standard is obtained.

11.6. Calibration Verification Standards

11.6.1. Run a Calibration Verification Standard, either solid or slurry as appropriate based on the sample matrix, once per sample batch (every 20 analyses – Section 3.11).

11.6.1.1. Acceptance criteria for the CV Standard is 100 % ± 10%.

11.6.1.2. If the CV does not meet the acceptance criteria, the problem must be identified and corrected, including possible recalibration of the system if the problem cannot be corrected by other means.

11.6.1.3. All samples must be associated with an acceptable CV Standard before their results may be reported.

11.7. Quality Control (QC) Standards

11.7.1. In accordance with Method 1687, analyze a QC standard with each day's distillations, or every 12 h, whichever is more frequent.

11.8. Matrix Spikes (MS)

11.8.1. To assess the performance of the method on a given sample matrix, spike, in duplicate, a minimum of 5% (one sample in 20) of the samples from a given sampling site.

11.8.2. The concentration of NH_3-N spiked into each MS sample shall be 1-5 times the background concentration for the corresponding batch of samples.

11.8.2.1. The spiking level may be established *a priori* based on existing information (either analyst's previous experience or existing literature values) for NH_3 content of manures from the particular species.

11.8.3. The concentration added should be expressed as mg/kg, and should be calculated for a 1-g aliquot by multiplying the N concentration (mg/L) added (as ammonium chloride) by the conversion factor 100 (mg/L x 0.1L/0.001kg = 100).

11.8.4. Do not use blanks for MS analyses.

11.8.5. Assessing spike recovery

11.8.5.1. Calculate the percent recoveries of NH_3-N and relative percent difference (RPD) of the duplicate matrix spike samples (corrected for the background concentration measured in the corresponding unspiked sample which was used as the basis for the MS samples).

11.8.5.1.1. Calculate percent recovery as follows:

$$\text{Percent Recovery} = \frac{(C_s - C_b)}{S} \times 100$$

Where:
C_s = Sample NH_3-N concentration determined after spiking
C_b = Sample NH_3-N concentration determined before spiking
S = Known concentration of the spike

11.8.5.1.2. Calculate RPD as follows:

$$\text{RPD} = \frac{(|D_1 - D_2|)}{D_1 + D_2} \times 100$$

Where:
D_1 = NH_3-N concentration of MS sample #1
D_2 = NH_3-N concentration of MS sample #2

11.8.5.2. Percent recoveries for the matrix spikes should be within three standard deviations of the mean value, with RPD ≤ 20%.

11.8.5.3. If either the percent recovery or the RPD of NH_3-N in the MS samples falls outside the designated range, while the percent recovery in the PR sample is within the acceptable range, the problem encountered with the MS sample is judged to be matrix-related instead of method-related.

11.9. Blanks

11.9.1. Run a minimum of one blank with each batch of 20 samples (Section 3.11).

11.9.2. Suitable blanks are 10 mL of NH_3-free water, or 5 g of blank sand.

11.9.3. If NH_3-N is detected in the blank at a concentration greater than the MDL stated in Section 1.3.1, halt analysis of samples until the source of contamination is eliminated and a new blank shows no contamination.

11.9.4. All samples must be associated with an uncontaminated laboratory blank before their results may be reported.

11.10. QC Charts

11.10.1. Track all IPR, OPR, Calibration Verification, QC Standard, MS and Blank results to provide graphical representations of continued laboratory performance.

11.11. Method Modifications & Re-validation

11.11.1. Each time any modification is made to this method, the analyst will verify that the modified method meets or exceeds the Method Detection Limit and Initial Precision and Recovery achieved by the same analyst using the original (unmodified) method.

11.11.2. The laboratory will maintain records of any modifications made to the method. At minimum, these records must include the following:

11.11.2.1. Names, titles, and contact information for analyst who initiated the modifications and for the QA Officer who witnessed and approved them

11.11.2.2. Narrative stating reason(s) for the modification

11.11.2.3. Results from all QC tests comparing the modified method's performance to that of the original method:

- Initial Precision and Recovery
- Ongoing Precision and Recovery
- Results with Calibration Verification, QC Standard, MS samples and Blanks

11.12. Replication

11.12.1. Run duplicates of 10% of the samples in each batch, with a minimum of one duplicate per batch. Initial masses (i.e. wet weights) of the duplicates will not differ by more than 10%. Replicates must agree to within 10% of their average NH_3 content; if not, the batch of samples must be re-run.

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MEASUREMENT OF BARN INLET AND EXHAUST PARTICULATE MATTER (TSP, PM10, PM2.5) CONCENTRATIONS USING THE THERMOFISHER SCIENTIFIC - SOP P1

MEASUREMENT OF BARN INLET AND EXHAUST PARTICULATE MATTER (TSP, PM_{10}, $PM_{2.5}$) CONCENTRATIONS USING THE THERMO ELECTRON (RUPPRECHT AND PATASHNICK) TEOM SERIES 1400A PM MONITOR

Standard Operating Procedure (SOP) P1

Prepared by
Bill W. Bogan and Teng Teeh Lim

Reviewed by
Lingying Zhao (Ohio State Univ.) and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The Rupprecht and Pataschnick (R&P) TEOM 1400a monitor will be used for continuous monitoring of the total suspended particle (TSP), PM_{10}, (particulate matter of 10 microns and smaller), and $PM_{2.5}$ concentrations, of ambient air and in the exhaust air of confined animal houses or barns. The TEOM instrument is a continuous PM-monitoring device designated by USEPA as an equivalent method (EPA Designation No. EQPM-1090-079) for PM_{10}.
1.2. Measurement range of the TEOM 1400a is 0 to 5,000,000 µg/m³, with a minimum detection limit of 0.06 µg/m³ (1-h average).
1.3. Use of the TEOM 1400a is appropriate for air temperatures in the range of -40 to 60°C, although the sensor and control units must be maintained between 2 and 40°C. If field temperatures outside this range are expected, this is accomplished by keeping the sensor and control units inside the on-farm instrument shelter (OFIS).
1.4. This procedure applies only to the Thermo Electron TEOM 1400a PM Monitor.

2. Summary of Method

The TEOM 1400a PM monitor works by extracting air into an inlet head that inertially separates PM_{10} particles, and collects a portion of the PM_{10} particles onto a Teflon-coated glass fiber filter. A sensitive mass transducer determines the mass of PM accumulated on the filter by measuring the change in vibratory frequency in a hollow, tapered element that holds the filter cartridge. Changes in the resonant frequency are sampled electronically in quasi-real time, providing both continuous and time-averaged measures of mass accumulation that are directly proportional to instantaneous and time-averaged mass concentrations in air, respectively. The instrument samples the vibratory frequency of the element every two seconds and the instrument microcomputer calculates the new system mass (element + filter + collected PM). The device operates at an industry-standard, volume-controlled flow rate of 16.7 L/min. The sample stream is preheated to 50°C before entering the mass transducer so that the filter always collects under conditions of very low (and therefore relatively constant) humidity.

3. Definitions of Terms and Acronyms

3.1.	AK	Standard protocol for communication among instrumentation. It is used by the RP_{COMM} software for internal data logging.
3.2.	A/O	Analog output
3.3.	atm	atmosphere, 1013 mBar
3.4.	Mass Concentration	Mass of substance per unit volume of gas
3.5.	OFIS	On-farm instrument shelter
3.6.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.7.	PCB	Printed circuit board
3.8.	PM	Particulate matter
3.9.	PM_{10}	PM of 10 microns diameter and under

3.10.	$PM_{2.5}$	PM of 2.5 microns diameter and under
3.11.	R&P	Rupprecht and Patashnick
3.12.	RH	Relative humidity
3.13.	TEOM	Tapered Element Oscillating Microbalance
3.14.	TSP	Total suspended particle or total suspended particulate (matter)

4. Health and Safety

4.1. Be careful when working with electrical power connections. Repair of instruments should only be carried out by trained personnel, and in accordance with procedures detailed in the instrument manual.

5. Cautions

5.1. When sampling the exhaust air stream, locate the TEOM PM_{10} inlet near the inlet of the fan (or upstream of the fan), however, far enough away to avoid concerns about anisokinetic sampling. As a safe precaution, the air velocity around the sampling head should be 2 m/s (400 ft/min) or less. This corresponds to the designed air velocity of a tunnel-ventilated barn.

5.2. Protect the instrument from exposure to harsh environments with the outdoor enclosure unit. However, the outdoor enclosure unit may be too large for most exhaust air sampling locations in the barn. If the sampling location is 20 m or less from the on-farm instrument shelter, place the sampling pump and control unit in the OFIS (On-Farm Instrument Shelter) and protect the sensor unit with a custom-made enclosure (See Appendix A).

5.3. Prevent damage by rodents, flies and animals. All the openings of the enclosure should be sealed. Mothballs can be used inside the enclosure; however, adverse effects of the performance of a TEOM equipped with a filter dynamics measurement system (FDMS) in the presence of mothballs has been reported. The instrument should be isolated from moisture and manure, and mechanical vibration. Locate the sensor unit where external objects are not likely to disturb the instrument enclosure or the air sampling tube.

5.4. Protect instrument from adverse weather, especially precipitation. When the instrument control unit is installed on top of the enclosure unit, be certain the sampling tube leading out of the building or enclosure has a watertight fit.

5.5. Ensure that adequate power is available at the site. Lack of a stable power source can result in the loss of data because of power interruptions. The system resets itself every time when power is regained, requiring a period of stabilizing before providing valid data. An uninterruptible power supply with battery backup should be used to prevent damage and data loss in case of power failure. Furthermore, a lightning arrestor will protect the entire on-farm instrument shelter and secondary surge suppressors will protect the PC and the instruments from electrical surges.

5.6. The TEOM is a complex instrument and requires some special training (Section 7) in its use and operation to obtain consistently good data. Although it is capable of automatic operation, the menu structure is complex and is easily misused.

6. Interferences

6.1. Relative humidity fluctuations of the sample stream may cause measurement accuracy to decrease due to the inlet system's inability to adjust the temperature to that specified by the software.
6.2. Mechanical vibration which is transferred to the instrument can interfere with the vibrational frequency of the TEOM's tapered element, and can therefore lead to inaccurate measurements.
6.3. The sensor inlet should be directly below the flow splitter. Improperly locating the sensor inlet relative to the flow splitter can cause particulate to settle out of the air stream and collect on the tubing walls prior to reaching the filter, thus yielding inaccurate results.
6.4. Dust buildup on the external screen of the PM_{10} Inlet can trap particulate matter, preventing it from reaching the sensor.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the instrument before initiating the procedure. Training requires about four hours.
7.2. Each analyst must read and understand the entire instrument manual and this SOP before operating the instrument.
7.3. Personnel should also be trained to interpret the analyzer output signal (including the interference by relative humidity), set up the internal data logger, and interpret the selected logged parameters.

8. Equipment and Supplies

8.1. TEOM Series 1400a ambient particulate monitor (Thermo Electron Corporation, East Greenbush, NY)
8.2. TEOM sensor unit
8.3. TEOM $PM_{2.5}$ inlet
8.4. TEOM PM_{10} inlet
8.5. TEOM TSP inlet
8.6. TEOM flow splitter assembly
8.7. Filter exchange tool
8.8. Electric and air cable assembly for connecting the control unit to the sensor unit
8.9. Consumables to be kept on hand at each monitoring site include the following:
    8.9.1. One box of 20 TX40 TEOM filters (R&P #57-007225-0020)
    8.9.2. Four large bypass in-line filters (R&P #57-002758)
    8.9.3. One piston pump rebuild kit (R&P #59-008630)
8.10. The following spare parts (one each) should be kept on hand at PAAQL for a network of 10 TEOMs:
    8.10.1. Frequency counter printed circuit board (PCB) (R&P #10-000394)
    8.10.2. Main computer PCB (R&P #10-001594-0006)

8.10.3. Analog I/O PCB (R&P #57-001595-0016)
8.10.4. Dual flow controller (R&P #55-007675)
8.11. Mass calibration verification kit (R&P #59-008298-0005)
8.12. Calibrated 3 ½ digit multimeter & 30 cm (12") jumper wire (for analog board calibration)

9. Procedures

9.1. Instrument setup
9.1.1. Check all components carefully to assure they are free of visible defects or damage.
9.1.2. Set up the control and sensor units (Section 2.3 of manual). Ensure that all air tubes are pushed completely into the fitting so that they cannot be pulled out.
9.1.3. Connect analog output (0-5 or 0-10 VDC) of the analyzer to the data acquisition system (SOP B2). The three analog output channels of the instrument are accessible from the identical 15-pin connectors on the front and back panels of the control unit. Details regarding the pin assignments and voltage (VDC) outputs are given in the operating manual (Section 5.1). To bring up the Set Analog Output Screen, press <A/O>, or select “Set Analog Output” from the Menu Screen, or press 04<Enter>.
9.1.4. Route the electric cable and air tubes to the sensor unit so that the cable is protected and the sample and bypass tubing are not kinked. Extensions of the air tube (1/4" or 3/8” diameter) and cables (9-pin for temperature probe or 25-pin for sensor unit) can be used, if needed. The extension cables are straight-through with male-female connectors.
9.1.5. Installing the Sampling System:
9.1.5.1. Set up sampling hardware (Section 2.4 of manual). Ensure that the inner tube of flow splitter is 15.5 cm (6 in) from the open end of the outer tube.
9.1.5.2. If used for ambient monitoring, install the TEOM either with the environmental controlled outdoor unit or on top of an instrument shelter (SOP U2).
9.1.5.3. Use a custom-made small enclosure (Appendix A) for the sensor unit and keep the control unit and sampling pump inside an instrument shelter (Fig. 1).
9.2. Installing/Replacing the filter cartridge (Refer to Section 3.2 of Operating Manual for detailed procedures)
9.2.1. Press the <Data Stop> key before opening the door of the sensor unit to stop measurement temporarily.
9.2.2. Store the loaded filters for further analysis or for recycling.
9.3. Installing and cleaning the $PM_{2.5}$ sampling inlet
9.3.1. For $PM_{2.5}$ measurement, install the $PM_{2.5}$ inlet over the open end of the flow splitter (Fig. 2).
9.3.2. The sampling inlet requires the use of a PM_{10} inlet. Install the PM_{10} inlet onto the air entrance part of the $PM_{2.5}$ inlet.

Figure 1. TEOM sensor unit in a custom-made enclosure.

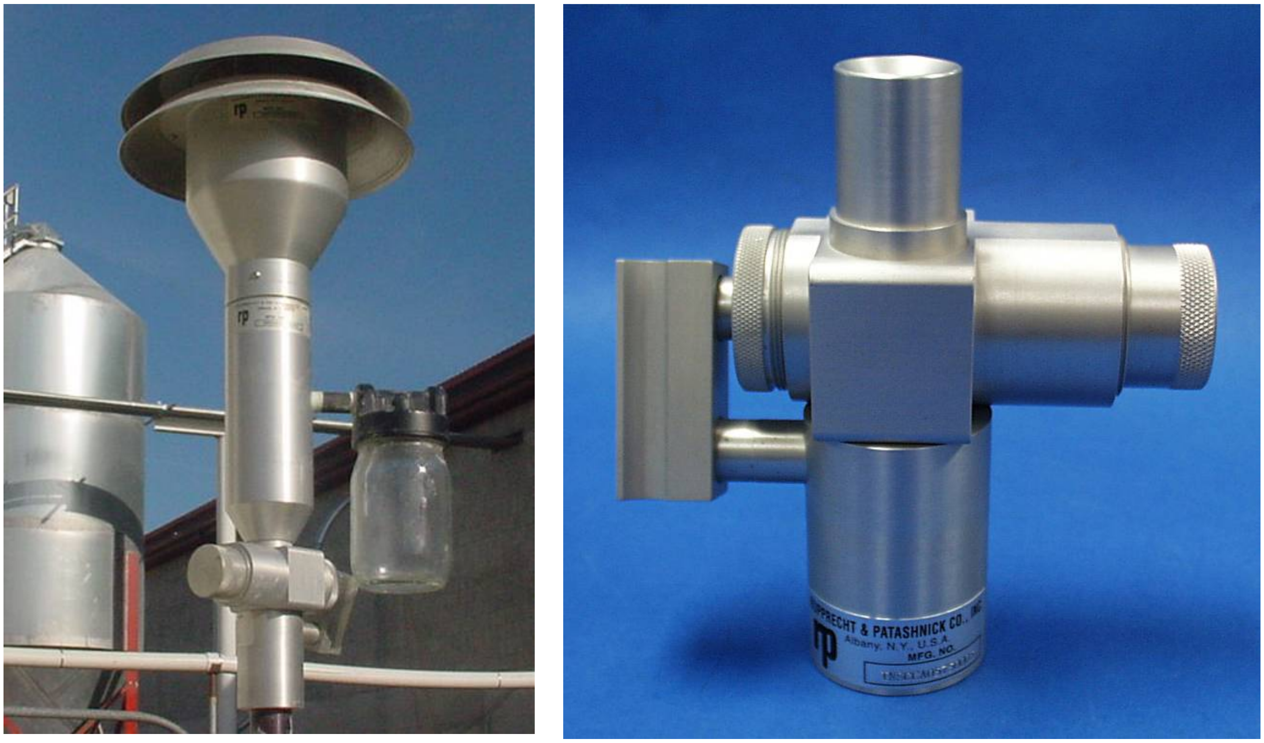

Figure 2. TEOM PM_{10} and $PM_{2.5}$ inlets (left), and a closeup of the $PM_{2.5}$ inlet (right, photo provided by TEC).

9.3.3. Cleaning the $PM_{2.5}$ sample inlet:

9.3.3.1. Push the <Data Stop> button on the keypad. Remove the PM_{10} and $PM_{2.5}$ inlets, and replace with an in-line filter to prevent contamination of the inlet tube.

9.3.3.2. Detach the transfer tube (the rectangular-shape part on the left, left photo of Fig. 2). If it is too tight to be removed by hand, pry it off with a rigid plastic lever.

- 9.3.3.3. Remove the top cap and grit pot by unscrewing.
- 9.3.3.4. Use a wet, lint-free wipe to remove all visible PM deposits. It is recommended to use mineral-free (de-ionized) water and lint-free laboratory wipes, and use ultrasonic cleaning for stubborn deposits. The PM are most likely found at the bottom of the cone and inside the grit pot.
- 9.3.3.5. After cleaning, check the o-rings, for shape and integrity, and replace if needed. Apply silicone grease as needed to maintain a thin layer on the surfaces around the o-rings.
- 9.3.3.6. Carefully reassemble all the parts back, and reinstall. Also check and lubricate the transfer tube if needed to ease assembly and prevent leakage.
- 9.3.3.7. Press <Data Stop> on the controller. This prevents the recording of skewed data.
- 9.3.3.8. Instrument will automatically resume recording in approximately 30 min. Scheduled inlet cleaning may be combined with the filter exchange to minimize downtime.
- 9.3.3.9. Clean the PM_{10} sample inlet following the procedures listed below.

9.4. Installing and cleaning the PM_{10} sample inlet
- 9.4.1. For PM_{10} measurement, use only the PM_{10} inlet over the open end of the flow splitter.
- 9.4.2. Cleaning the PM_{10} sampling inlet:
  - 9.4.2.1. Similar to the procedures of cleaning the $PM_{2.5}$ inlet, always push the <Data Stop> button before and after the cleaning, and use an in-line filter to prevent contamination of the inlet tube if necessary.
  - 9.4.2.2. Unscrew the acceleration assembly from the collector assembly. Using pressure air or a can of pressurized Dust Remover (available at most hardware and electronics stores), blow the inlet screen on the acceleration assembly until visibly clean. Then blow the inside of the acceleration assembly through the bottom tube. Also blow off the internal areas of the Collector Assembly.
  - 9.4.2.3. If necessary, use a wet and lint-free wipe to clean the surfaces carefully.
  - 9.4.2.4. Check the o-rings, located on the lower part of the Acceleration Assembly and on the lower part of the Collector Assembly, for the presence of silicon grease. Apply silicone grease as needed to maintain a thin layer on the surfaces around the o-rings.
  - 9.4.2.5. Carefully replace the inlet unit, and press <Data Stop> on the controller. This prevents the recording of skewed data.
  - 9.4.2.6. Instrument will automatically resume recording in approximately 30 min. Scheduled inlet cleaning may be combined with the filter exchange to minimize downtime.

9.5. Installing and cleaning the TSP sampling inlet
- 9.5.1. For TSP measurement, install only the TSP inlet over the open end of the flow splitter (Fig. 3).
- 9.5.2. Cleaning the TSP sample inlet:
  - 9.5.2.1. Similarly, always push the <Data Stop> button before and after the cleaning.
  - 9.5.2.2. Remove the TSP inlet from the flow splitter, and blow off deposited PM inside and outside of the inlet, by using a can of pressurized Dust Remover inside.

Figure 3. TEOM PM_{10} (left) and TSP inlets (right).

9.5.2.3. Check the o-rings, located on the lower part of the inlet for integrity and presence of silicon grease. Apply silicone grease as needed.
9.5.2.4. Carefully replace the inlet unit.
9.5.2.5. Instrument will automatically resume recording in approximately 30 min.

9.6. Installing and cleaning external screen for PM_{10} inlet
9.6.1. A wire-mesh external screen was designed to encircle the PM_{10} inlet to keep flies and large dust particles out. The additional external screen is made of 8x8 mesh stainless steel wire cloth. The diameter of the screen is about 25 cm (10 in), just slightly bigger than the PM_{10} inlet, enclosing the entire inlet area (Fig. 4). This external screen requires cleaning every 3 to 7 d, depending on PM concentration.
9.6.2. Carefully remove the external screen, and, in an area downwind of the inlet unit, brush or if needed, clean with water and allow to dry.
9.6.3. After all visible dust has been removed from the external screen, carefully replace it onto the PM_{10} inlet, so as not to disturb the sensor unit.

9.7. Leak check (Section 7.6 of manual). Perform the leak check with NO sample filter attached to the mass transducer, which will prevent accidental damage from occurring to the sample filter cartridge when exposed to the high pressure drop (vacuum) in the sample line that the leak check creates. Leakage flow rates should indicate less than 0.15 L/min for the sample main flow and less than 0.6 L/min for the auxiliary flow or bypass flow with the end of the sample line closed. If not, systematically check plumbing for connector leaks.

Figure 4. TEOM PM_{10} inlets with external screens installed.

9.8. Flow rate audits (Section 8.6 of manual). Use the flow audit adapter with a capped nut for closing the flow splitter bypass line port to check the sample and total flow rates. The volumetric flow rates should be within ±7% (±0.20 and ±1.17 L/min for the sample and total flow rates, respectively) of the set points. Large errors in the flow may indicate other sources of error, such as a malfunctioning flow controller, a system leak, or improper temperature and pressure settings.

9.9. Mass transducer calibration verification (Section 8.6 of manual). The calibration constant should differ less than 2.5% from the original calibration constant. Notify PAAQL and Thermo Electron if the value is greater than 2.5% as indicated in the manual.

9.10. Setting/Checking time and date (Section 4.10 of manual). Check time and date when data is downloaded.

9.11. Internal data storage and retrieval (Section 4.11 of manual)

  9.11.1. Internally logged data are stored in a circular buffer. To view data from the control unit, press <Store>, and select “View Storage”, or enter 08<Enter> from any screen, or download the data via the RS-232 serial port. The instrument stores the time, date, and station number in each record in addition to the data fields selected by the user. The storage capacity (Fig. 4-11 of manual) is about 1.7 weeks of 8 data fields per record, using a storage interval of 10 min.

  9.11.2. Ensure that the communication software is set for the same communication parameters as the instrument. The default and best protocol to use is “AK protocol.” Connect a compatible computer to an RS-232 port using the provided 9-to-9 pin computer cable. Make sure the latest version of the RPComm software is installed properly onto the computer. Bring up the software and wait for a while or click on the front pages. A small window of the software will display the keyboard and 4-line text display as shown on the front panel of the control unit. Use the “Download storage” command to download stored data in the data logger.

  9.11.3. Toggle the instrument between the View Storage Screen and Set Storage Screen with the <Step Screen> key, or by pressing 09<Enter> to gain direct access to the Set

Storage Screen from any other screen. The first eight lines of the Set Storage Screen contain the titles of the variables currently being stored by the data logger (See the Appendix A for the Program Register Codes). Use specific program register codes (Table 1) to change the parameter for each of the channel. “Interval” variable is the number of seconds between successive data in the circular buffer.

Table 1. Some common program register codes

Code	Variable	Units
008	Mass concentration	$\mu g/m^3$
009	Total mass	µg
035	Filter loading	%
039	Current main flow	L/min
040	Current auxiliary flow	L/min
041	Status condition	code
057	30-min average mass concentration	$\mu g/m^3$
130	Current ambient temperature	^oC
131	Current ambient pressure	atm

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet that is designated for this method. Supplement this electronic record with a bound record book designated for the method, which should also contain bound copies of the electronic record.
10.2. Manage data according to SOP B5.
10.3. Document all data and information on field data sheets, and site logbooks with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance Section

11.1. Exchange TEOM filter cartridges before the % loading figure reaches 70% (suggested for most tubing length) or when the increase from the new-filter value reaches 50% (e.g. from 35%-new to 85%-loaded). This is necessary because some new filters will show higher loading rates when the tubing is long and the large-in-line filter is loaded with PM. Minimizing the filter loading is necessary because when the filter is heavily loaded, the interference of water on high-frequency PM readings is high, and the mass of PM collected on the filter is sensitive to sudden changes in the humidity of the sample air.
11.2. Exchange or install filter cartridges only when the instrument is in the Initialization Mode or Data Stop Mode, or when the instrument is turned off, and not when the TEOM system is taking data (i.e., when the instrument is in the Run Mode).
11.3. Replacing and pre-conditioning filters
11.3.1. At a flow rate of 3 L/min, 100% filter loading generally corresponds to a total mass accumulation of approximately 3 to 5 mg of particulate. Filter lifetime at a main flow rate of 3 L/min is generally 21 d at an average PM_{10} concentration of 50 µg/m3.

11.3.2. Store filters inside the sensor unit for convenience, and to keep them dry and warm. There is a storage position for the next filter available on the mass transducer that keeps the new filter closer to the sampling conditions. Two posts are along the right side of the mass transducer when open.

11.3.3. Do not handle filters with fingers. Use the filter exchange tool and follow the procedures given in this SOP, and in the operating manual. Never twist the filter or apply sideways force to the tapered element. Minimize the temperature upset to the system when changing filters by keeping the door of the instrument open for the shortest time possible.

11.4. If the filter loading percentage is high immediately after placing a new TEOM filter on the mass transducer, or if the lifetime of TEOM filter cartridges becomes noticeably shorter, this usually indicates that the in-line filter in the main flow line needs to be replaced.

11.5. If a actual quality control audit is determined to be out of the ranges as specified by the manufacturer, the data since the last audit should be carefully reviewed and invalidated if needed. The factory-recommended schedule of periodic maintenance, as well as the schedule to be adopted for use in livestock buildings, are as follows:

Table 2. Periodic maintenance of the TEOM instrument.

Maintenance item	**Factory**	**This Project**	**Corrective Action**
Clean external screen	-	As necessary	
Clean PM_{10} inlet	Upon filter exchange	Weekly	
Exchange in-line filters	6 month or when loaded	When loaded	
Clean air inlet system	6 month	Bimonthly	
Leak test	Annually	Bimonthly	Locate and repair leak
Flow audit	Annually	Bimonthly	Check for leak and recalibrate
Mass flow controller calibration	Annually	Every 6 month	Recalibrate
Analog board calibration	Annually	Every 6 month	
Mass transducer calibration verification	Annually	Bimonthly	Check system or return to PAAQL

Source: Adapted from Heber et al. (2006)

12. References

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12.2. Heber, A.J., J.-Q. Ni, T.T. Lim, R. Chervil, P.C. Tao, L.D. Jacobson, S.J. Hoff, J.A. Koziel, Y. Zhang, D.B. Beasley, and J.M. Sweeten. 2005. Aerial pollutant emissions from two high-rise layer barns in Indiana. A&WMA's 98th Annual Conference & Exhibition, Minneapolis, MN, June 21-24. AWMA, p.15.
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12.6. SOP B3. 2006. Air Data Pre-Processing Software. Standard Operating Procedure B3. Purdue Ag Air Quality Lab.
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12.10. USEPA. 1999. Determination of PM_{10} in Ambinet Air Using a Continuous Rupprecht and Pataschnick (R&P) TEOM® Particle Monitor. Method IO-1.3 in Compendium of Methods for the Determination of Inorganic Compounds in Ambient Air. Center for Environmental Research Information, Cincinnati, OH.

13. Contact Information

13.1. Manufacturer: Thermo Electron Corporation, 26 Tech Valley Drive, East Greenbush, NY 12061.
13.2. Manufacturer Technical Support: 518-452-0065. General e-mail: rpcoinfo.eid@thermo.com
13.3. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

Appendix A. Design and Specifications of TEOM Cabinets.

The vertical rod shown in Figs. A1, A3, and A4 is the mounting rod that holds the inlet pipe of the TOEM sensor unit vertical.

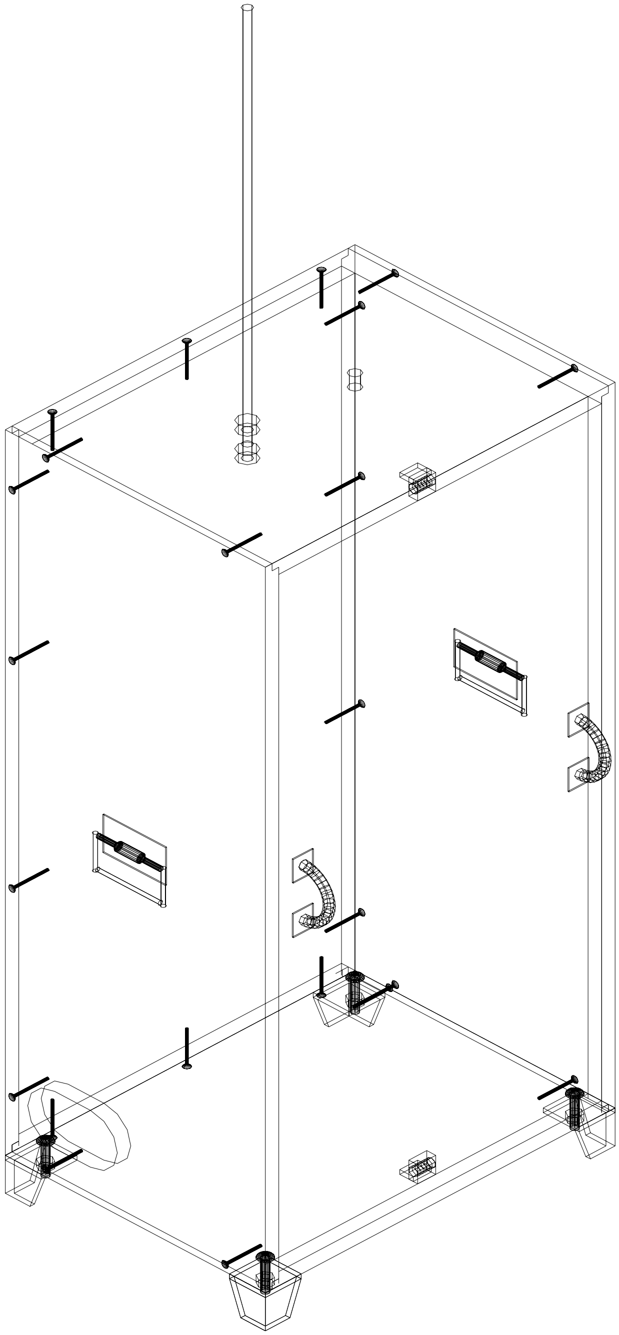

Figure A1. 3-D view.

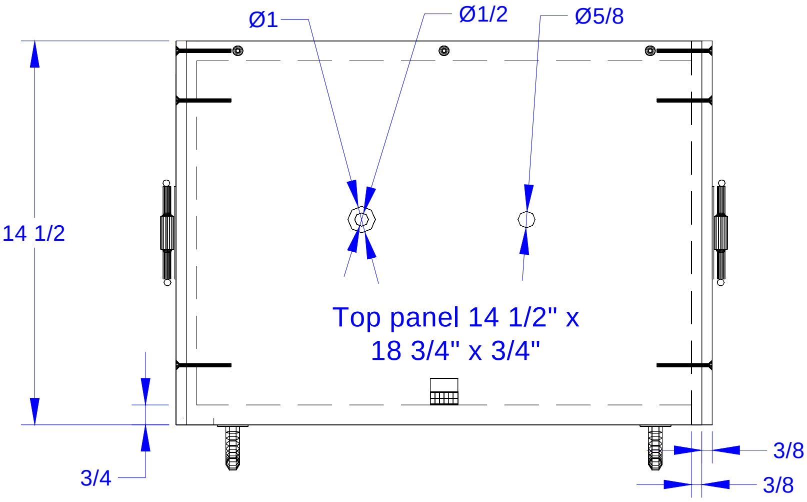

Figure A2. Top view.

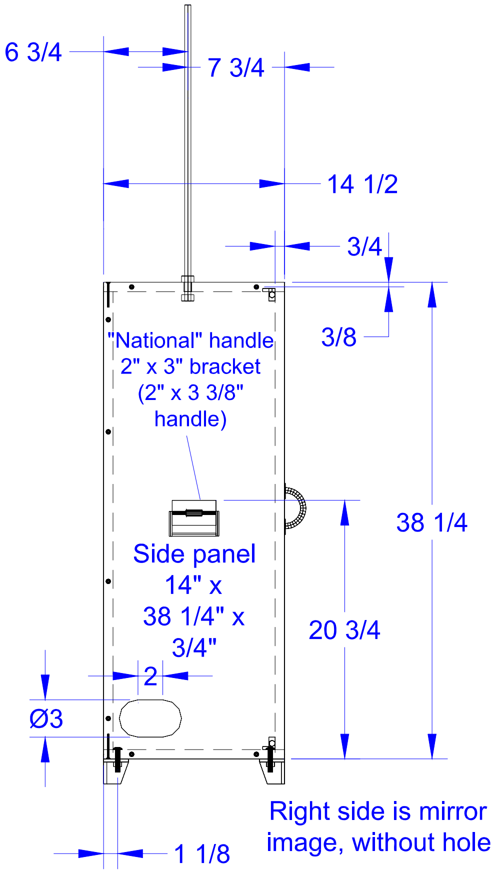

Figure A3. Left side view.

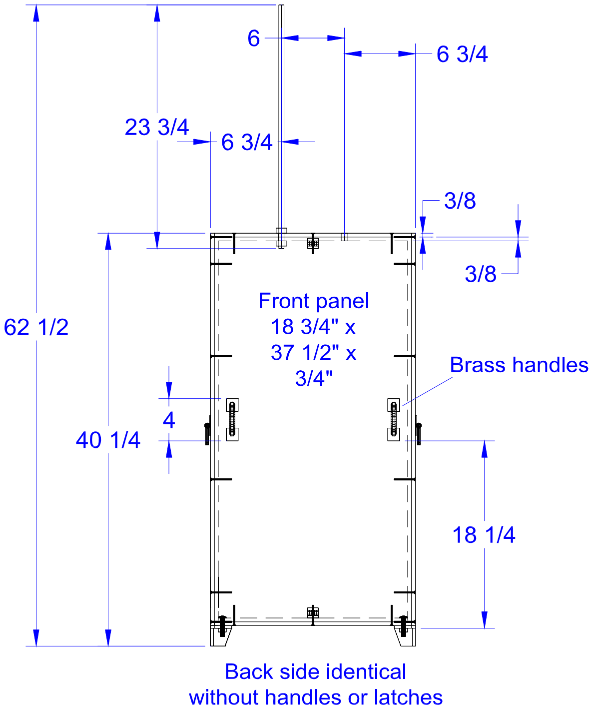

Figure A4. Front view.

Specifications

1. ¾” plywood (A-C ext.) on all sides.
2. Aluminum feet. ¼” thick aluminum. 2”x2”x1-15/16” angle reducing to 1-1/2” angle at the bottom welded onto 2”x2” plate which is bolted to plywood.
3. Metal handles on door. National N243-766 170. Sash Lift Brt. Brass finish 4”.
4. Metal handles on sides of cabinet. Chest handles. 3-1/2”. National N117-002 V175.
5. 40-3/16 inch working height.
6. Top panel is 14-1/2”x19”x3/4”.
7. Side panels are 14”x38-1/4”x3/4”.
8. Front panel is 18-3/4”x37-1/2”x3/4”.
9. Mounting rod is 23.75”x1/2”
10. Mounting rod is 1/2” dia and is threaded at the bottom.
11. Door handles are brass and 4”x1-1/8” and stick out 1”.
12. Side handles stick out 3/8”.
13. Screws are 2” long #8 drywall screws.
14. One coat of exterior polyurethane.

MEASUREMENT OF BARN EXHAUST TOTAL SUSPENDED PARTICULATE CONCENTRATIONS USING AN ISOKINETIC MULTIPOINT GRAVIMETRIC METHOD

Standard Operating Procedure (SOP) P2

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Standard Operating Procedure (SOP) P2

Prepared by

Juan Carlos Ramirez and Teng-Teeh Lim

Reviewed by

Bill W. Bogan, Yuanhui Zhang (Univ. of Illinois at Urbana-Champaign),
and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

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1. Scope and Applicability

1.1 This procedure presents the methodology and instrumentation to measure total suspended particulate (TSP) concentration in the exhaust air of confined animal houses using an isokinetic multipoint system.

1.2 An integrated isokinetic gravimetric sampling system using critical flow rate control was developed by the University of Illinois at Urbana-Champaign (UIUC) and has been used since 1999 (Wang and Zhang, 1999; Jerez et al., 2006), and can be purchased via CCC Technologies.

1.3 Sampling is typically conducted at the minimum ventilation fan that is continuously operating at full speed.

1.4 The sampling duration is typically 24 h or a multiple of 24 h, depending on the PM concentration. Higher PM concentrations load the filter more rapidly, requiring shorter sampling times.

1.5 The sampling flow rate is 20 L/min ±10% for each of the three sampling nozzles, which are positioned vertically along the height of the fan and pointing into the direction of the exhaust air stream.

2. Summary of Method

The system which is used for TSP sampling consists of a vacuum pump, three critical venturi and three isokinetic sampling heads, polyethylene (PE) sampling tubes and fittings, and filters. The TSP system samples at the inlets of the exhaust fans using the critical venturi method (Jerez et al., 2006). Each conical isokinetic sampling head is attached to a 37-mm open-faced filter cassette, which is fitted with conditioned and weighed filters. The sampling nozzles should be located at three representative heights, which are carefully selected by using a portable anemometer to match the airstream velocity for isokinetic sampling. The isokinetic conditions are achieved by adjusting the positions of the sampling nozzles near the fan until the air speed at each nozzle inlet is approximately 2±0.2 m/s. Different sizes of the sampling nozzle may be used to match the sampling velocity requirement. TSP sampling can also be conducted without an isokinetic sampling head; this is done in very low air speeds (lower than 0.3 m/s) or calm air sampling conditions. Following EPA Method 17 procedures for recovering PM from stack sampling probes, the inside surfaces of the nozzles are rinsed with acetone, and brushed with a nylon bristle brush. TSP concentrations are determined by combining the mass of TSP collected in the acetone rinse and the desiccated filters, and dividing the combined mass by the total sample air volume. This procedure includes descriptions of how to condition, install, and retrieve the filters for their initial and final weighing and storage.

3. Definitions

3.1	Isokinetic	Air velocity at inlet tip exactly matches surrounding velocity, such that streamlines do not converge into the inlet or diverge around the inlet.
3.2	OFIS	On-farm instrument shelter
3.3	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4	PE	Polyethylene
3.5	PM	Particulate matter
3.6	QAPP	Quality Assurance Project Plan
3.7	SOP	Standard operating procedure
3.8	TSP	Total suspended particulate.
3.9	UIUC	University of Illinois at Urbana-Champaign

4. Health and Safety

4.1. The system has a pump operating at 120 VAC. Be careful when working with the electrical power connections, especially if located in wet or moist conditions.

4.2. Be careful when working near the ventilation fan. The high-speed fan blades can be a hazard, especially if they are not protected by fan shutters.

5. Cautions

5.1. Protect the sampling system from exposure to harsh environments by storing the sampling pump in the OFIS or in an enclosure unit near the sampling location. Prevent damage by rodents, flies and animals. The sampling system should be isolated from moisture and manure. Locate the system where external objects are not likely to disturb the pump or the sampling system.

5.2. When the vacuum pump is kept in the OFIS, make sure the long tube between nozzles and pump does not create a pressure drop that affects the critical pressure of the venturi. Provide adequate heating to the vacuum tube to prevent condensation.

5.3. Ensure adequate and continuous power is available for the sampling pump. Lack of a stable power source can result in the loss of quality data because of power interruptions. The system is not equipped with a sampling flow rate monitoring device; thus, any power interruption will not be detected or recorded. For example, if the power supply is part of the automated lighting system, which is shut off in the evening, the sampling is then interrupted, although the system appears to be running continuously. Use a vibration sensor (See SOP A7), mounted on the pump, to record pump operations.

5.4. Verify and record any change in the internal disposition that affects the flow pattern in the sampling area. If something changes (for example, the height of the manure after a cleanup, fan maintenance or cleaning), adjust the sampling head locations to meet the isokinetic conditions if the sampling is used with sampling nozzles.

5.5. Verify that the glass fiber filter is properly sitting on the bottom piece of the filter cassette, such that all of the sampling air must go through the filter. Make sure that the filter does not move freely after the middle ring is pushed down to the bottom piece of the cassette. Any gap in between will allow the filter to move, and could possibly cause the collected PM cake to fall off, especially when a back pressure is created by detaching the sampling cassettes. Note that the ring does not usually sit firmly against the filter. Use a light soft-faced hammer or mallet to tap the middle ring until it sits closely on the bottom of the cassette.

5.6. When using desiccant dryer, minimize the time the filter/cassette is exposed to room air before and after weighing. The collected PM is usually very hygroscopic. Minimize the times the desiccant cover is removed to reduce the amount of moisture introduced into the desiccant drier. This is especially important when the humidity of room air is not controlled.

5.7. Transport the capped filter cassettes to the laboratory in an upright position for conditioning and weighing. Use the entire filter cassette (including the top cap) during storage and transportation, to protect the filter from contamination.

5.8. Remove the top piece of the filter cassette when conditioning the filters, to accelerate the conditioning process. The PM collected onto the ring and bottom piece does not usually attach to the top piece, especially when a nozzle is used; the PM mainly collects onto the lower part of the ring and the filter.

5.9. Before or after assembly of the filter cassette components, label each piece (except the filter) so that it is clear which top, ring, and bottom piece go with which “assembly”. This will make it easier to track possible contamination later. An example would be labeling the top, ring, and bottom piece as 01T, 01R, and 01B respectively.

5.10. Previous studies have not accounted for sampling nozzle-deposited PM. An analysis was conducted to determine the importance of collecting PM from cleaning the heads (Lim et al., 2005). It was found that the PM deposited on the nozzle contained 15% of the total PM mass collected. It is therefore very important to recover the nozzle-deposited PM by rinsing the nozzle with acetone and determining the rinsate mass.

6. Interferences

6.1. Positioning any large object within 0.3 m of the sampling system can affect the airflow near the sampling nozzle.

6.2. The activity involved in maintaining the system, or other equipment around the sampling area, can induce more PM (for example, by stirring up dust on surfaces), thus affecting the measurements.

6.3. Excessive amounts of PM collected on the filters may reduce the sampling flow rate.

6.4. Continuous operation of the fan may be interrupted by erroneous ventilation stage control or fan failure. Monitor and ensure continuous fan operation, using a device such as vibration sensor (SOP A7) or vane anemometer (SOP A3).

7. Personnel Qualifications

7.1. Personnel must read this SOP and be trained in the use of the sampling system before initiating the procedures.

7.2. In addition, the operator must be trained to conduct leak check, flow rate, and air velocity measurement.

8. Equipment and Supplies

8.1. **Table 1. List of parts for one TSP sampling system for 2 m/s sampling velocity.**

Description	**Quantity**	**Supplier**	**Catalog/ Part Number**
14.6 mm aluminum isokinetic sampling nozzle - 2 m/s (±5%)	3	CCC Technologies	IKS-2.0-AL
20 L/min (±5%) critical venturi	3	CCC Technologies	V-20-BN
Monitor case, empty, transparent, 3 piece compression fir, with end caps, 50/Pk	1 pkg	Fisher Scientific	M000037A0
Whatman binder-free glass micro-fiber filters, 37-mm, 100/Pk	3 pkg	Fisher Scientific	09-874-12B
Tubing adapter, male Luer, 10/Pk	12	Fisher Scientific	XX6200005
1/3-HP gas vacuum pump	2	Grainger	4F740
Commercial vacuum gauge, dial size 2.5″, NPT 1/4″ lower connection, 30-0"Hg	2	Grainger	2C537
Female tee, Size 1/4″, brass pipe fitting, 10/Pk	2	Grainger	6MN49
Street elbow, Size 1/4″, brass pipe fitting, 10/Pk	2	Grainger	6MN80
Hex nipple, Size 1/4″, brass pipe fitting, 10/Pk	4	Grainger	6MN97
3/8″ brass hose barb to 1/4″ NPT male	2	Grainger	4A487
Masterkleer general purpose clear PVC tubing 3/8″ ID, 5/8″ OD, 1/8″ wall thickness	50 ft	McMaster Carr	5233K65
Masterkleer general purpose clear PVC tubing 1/4″ ID, 7/16″ OD, 3/32″ wall thickness	15 ft	McMaster Carr	5233K57
Nylon multi-barbed tube fitting reducing coupling for 3/8″ x 1/4″ ID tube	10	McMaster Carr	5372K517
Nylon multi-barbed tube fitting 90° elbow for 3/8″ ID tube	6	McMaster Carr	5372K372
Nylon multi-barbed tube fitting tee for 3/8″ ID tube	10	McMaster Carr	5372K615

9. Procedures

9.1. Sampling system installation

9.1.1. General information

9.1.1.1. Conduct a practice assembly in the laboratory to make sure all necessary parts and tools are gathered before proceeding to the field.

9.1.1.2. There are three assemblies, as follows:

9.1.1.2.1. The filter cassette assembly consists of only the clear plastic filter cassette (3 pieces and caps) and the filter.

9.1.1.2.2. The sampling nozzle-filter-venturi assembly contains the sampling nozzle, partial filter assembly, male Luer adapter, 1/4″ ID PVC tube, reducing coupling for 3/8″ x 1/4″ ID tube, 3/8″ ID PVC tube, and critical venturi.

9.1.1.2.3. The TSP sampling system assembly includes the sampling head-filter assembly, the vacuum pump, and necessary fittings and tubes.

9.1.2. Filter cassette assembly

9.1.2.1. Figure 1 shows the filter cassette fitted with a glass fiber filter. The filter cassette is made of clear plastic, and consists of three main parts: the top, ring and bottom. In addition, there are two caps that seal the top and bottom of the cassette, for a total of five pieces. The bottom part is where the filter sits. The ring holds the filter down and the top and caps protect the filter during handling.

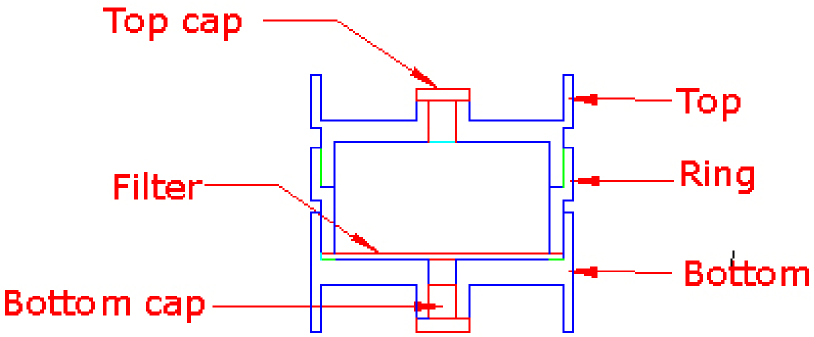

Figure 1. Filter cassette assembly.

9.1.2.2. Filter assembly procedure

9.1.2.2.1. Use tweezers, or wear clean powder-less gloves, when handling the filters.

9.1.2.2.2. Place the filter inside the bottom piece of filter cassette during assembly, with the smoother side facing down.

9.1.2.2.3. Place a ring inside the bottom piece and push down so that the two pieces are held tightly together. Make sure the filter covers the entire bottom cassette and is pressed down tightly. Use a light, soft-faced hammer to carefully tap the ring and bottom cassette together if needed.

9.1.2.2.4. Attach the top piece and the top and bottom caps to the assembly.

9.1.2.2.5. Label every piece of the cassette (except the filter) so that it is clear which top, bottom, etc. go with which “assembly”.

9.1.3. Figure 2 shows the sampling nozzle-filter assembly. This section consists of the sampling nozzle, a partial filter cassette assembly, the critical venturi and the necessary tubing and fittings.

9.1.3.1. Connecting the sampling head-filter-venturi system

9.1.3.1.1. First, assemble the section up to the filter cassette (from the right) when setting up the initial system. The assembly should resemble Figure 2.

9.1.3.1.2. The Luer adapter is a fitting that fits inside the bottom of the filter cassette and connects it to 1/4” ID tubing.

9.1.3.1.3. Transition the 1/4” tubing to 3/8” ID tubing, using the provided adapters, so that the critical venturi can be inserted.

9.1.3.1.4. Verify that there is a minimum of one inch between the venturi and any other fittings to allow for proper air flow development.

9.1.3.1.5. The section described thus far will be a relatively permanent installation. Once installed, there will be minimal need to change it.

9.1.3.1.6. If using an isokinetic sampling nozzle, remove the top piece of the cassette, insert the nozzle into the ring (similar to the way the top was) so that it fits snugly.

9.1.3.1.7. Place the filter cassette bottom onto the Luer adapter.

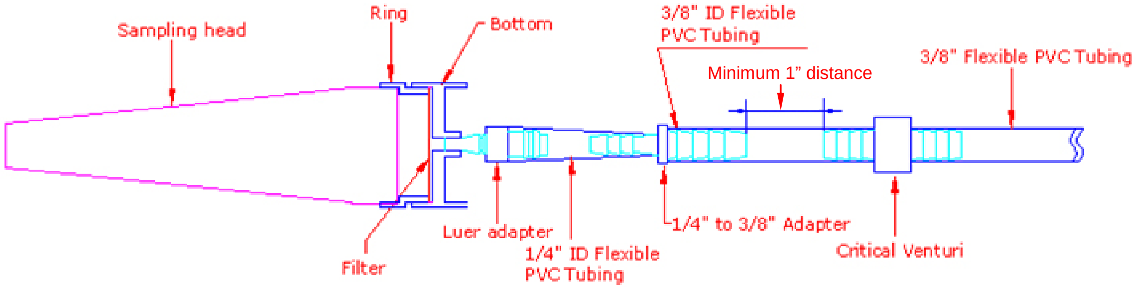

Figure 2. Sampling head–filter-venturi assembly, there are three of such assembly in a complete TSP sampling set.

9.1.4. Figure 3 shows the complete TSP system assembly, in which the three sampling filter assemblies are supported by utility clamps that are attached to a stand, and the vacuum pump is stored in an enclosure.

9.1.4.1. The tubing is likely to be longer and the heads further apart or closer, depending on the needs of each individual user and sampling location. The heights of the filter assemblies can be easily adjusted. In some cases it may be necessary to suspend the stand from the ceiling.

9.2. Location of the Sampling Head

9.2.1. Determine the locations and orientations of the sampling heads according to the desired local air velocity. The local air velocity refers to the face velocity at the sampling head. It is typically 2 m/s.

9.2.1.1. Measure the local air velocity and choose a plane where the velocity equals the designed isokinetic sampling velocity of the head, within 10%. Generally, this velocity should be found within two diameters of the fan.

Figure 3. A TSP sampling system (three filter cassettes, tubing, and the white sampling pump box on the left) with sampling filters and tubes attached to a sturdy 2x4 post.

9.2.1.2. Locate the three sampling nozzles so that they are equally distributed along the height of the sampling fan. All heads do not have to be on the same plane, but they should all be on the same velocity contour to ensure isokinetic sampling.

9.2.1.3. Locate the nozzles facing the incoming air stream to the fan (facing upstream away from the fan itself). If the direction of the air stream deviates significantly from perpendicular to the fan, then angle the nozzles to face into the air stream.

9.2.1.4. Use a recently calibrated air velocity measurement device, such as portable vane thermo anemometer or a hot-wire anemometer, to measure air velocities when determining appropriate sampling locations.

9.2.1.5. Secure sampling system so that it is not easily moved, and clearly mark its proper location.

9.2.1.6. Record distances to the fan and air velocities measured for each nozzle with the sampler running.

9.3. System Leak and Flow Rate Check

9.3.1. System Leak Check

9.3.1.1. Perform a leak check after initial installation, and after any significant changes to the system. It is not necessary to conduct a leak check every sampling event, especially when the individual nozzle flow rates are measured at the beginning and ending of each sampling.

9.3.1.2. Install the entire filter cassette assembly (excluding the bottom cap) to conduct a leak check, with the top cap in place. This should seal the system.

9.3.1.3. Install a flow measurement device (preferably a rotameter) at the vacuum pump outlet. The measurement range of the device should be less than 1 L/min. Turn the pump on and verify that the vacuum gage reads over 25 inches of Hg, and that the flow measurement device reads less than 1 L/min.

9.3.1.4. If these conditions are not met, check all connections and repeat leak check.

9.3.2. Venturi Flow Rate Check

9.3.2.1. Use this procedure primarily as a check, not a calibration.

9.3.2.2. Set up the system in a similar manner as when the system is sampling, but replace the filter cassette top of one sampling nozzle with a flow measurement device.

9.3.2.3. Turn on the pump. Take at least three flow readings, and average them.

9.3.2.4. Verify that this average is within 5% of the calibrated flow rate (the stated venturi flow).

9.3.2.4.1. Check flow meter, leakage, and system setup if flow rate is not within 5% of the calibrated value.

9.3.2.5. Turn off pump, remove flow measurement device, and replace sample nozzle cassette top.

9.3.2.6. Repeat steps 9.3.2.2 – 9.3.2.5 for the other two sampling nozzles.

9.3.2.7. The actual flow rates of the three nozzles will likely vary by approximately 3-5%, due to slight differences in the filters and tubing.

9.4. Filter preparation and weighing

9.4.1. Filter handling

9.4.1.1. Inspect each filter for pinholes, particles, and other imperfections.

9.4.1.2. Be careful to avoid damage of the filter during handling.

9.4.1.3. Handle the filters and cassettes using appropriate tweezers and gloved (clean and powder-less) hands.

9.4.1.4. Place each filter in a uniquely labeled filter cassette before weighing it. Each piece of the filter cassette should be labeled. The filter should remain in this cassette until all conditioning, sampling and weighing has been completed.

9.4.1.5. Archive the filters and cassettes for at least two more sampling rounds in case further analysis is necessary.

9.4.2. Filter conditioning

9.4.2.1. Condition labeled cassettes (with filters) in an environment-controlled room or desiccant drier for at least 24 h before weighing. The environment-controlled room should have temperature and relative humidity (RH) maintained at 25±5.6°C and < 50% RH. RH of the room must be constant within ±5% RH.

9.4.2.2. Weigh each filter in its own cassette with only the bottom cassette and middle ring attached, the top piece is removed.

9.4.2.3. During conditioning and weighing, remove bottom cap to allow faster drying and higher weighing accuracy.

9.4.3. Filter weighing

9.4.3.1. Use a scale with a precision of 0.1 mg or less. The average mass of clean and loaded filters with rings and bottom cassettes ranges from 12 to 14 g, while the filter should collect about 0.115 g of PM during a 48-h sampling period (assuming 20 L/min sampling rate and a TSP concentration of 2000 µg/m³).

9.4.3.2. Close the scale door before taking any readings, and make sure the scale is zeroed before the cassette is put on.

9.4.3.3. Record the mass to the nearest 0.1 mg.

9.4.3.4. Mass should be taken daily until the mass stabilizes, when two consecutive masses differ by less than 1.5 mg (approximately 1.3% of the PM mass).

9.5. Sampling procedures

9.5.1. Start the sampling as follows:

9.5.1.1. Remove the tops of the pre-conditioned and labeled filter-cassette assemblies.

9.5.1.2. If using isokinetic heads, attach cleaned sampling heads to the rings, and check to make sure they are properly attached.

9.5.1.3. Insert the Luer adapters into the bottom cassettes.

9.5.1.4. Secure all three assemblies so that they are fixed at the correct locations and in the correct orientations.

9.5.1.5. Check to make sure the system is complete, and that the heads are not likely to move during sampling.

9.5.1.6. Program the timer (if using one) for the required sampling duration (multiple of 24 h) as listed in the QAPP.

9.5.1.7. Turn on the sampling system.

9.5.1.8. Record sampling details, including barn number, cassette assembly numbers for each of the top, middle, or bottom sampling positions, and sampling starting date and time.

9.5.1.9. Attach a flow measurement device onto each sampling head or filter-cassette assembly to measure the sampling flow rate. Record the values.

9.5.1.10. If using isokinetic sampling heads, conduct an air velocity check. Verify that velocities are within 10% of the design velocity. Record the air velocities and adjust the sampling locations if needed.

9.5.2. At the conclusion of sampling:

9.5.2.1. Measure and record sampling flow rates again before shutting system off.

9.5.2.2. Remove filter-cassette assemblies from the system. Be careful when handling filter-cassettes. Keep assembly upright after it has been exposed. There will likely be a significant PM cake, which can easily fall off if the filter is turned over or shaken.

9.5.2.3. Attach the matching labeled top pieces to the rings. If isokinetic heads are used, remove them without removing the filter cassette rings before attaching the top cassette covers. Rinse the sampling heads with acetone (See Section 9.6) to collect PM which has been deposited on the heads themselves.

9.6. Recovering sampling head-deposited PM

9.6.1. This section applies only to the use of isokinetic sampling heads, and should be skipped if the TSP sampling is conducted without a sampling head (e.g. for still air sampling).

9.6.2. After capping the filter-cassette, individually rinse the inside surfaces of each sampling head with acetone. The amount of acetone used should be 25 to 100 mL.

9.6.3. Brush the inside surfaces with a nylon bristle brush while rinsing. The brush does not usually collect significant amount of PM. However, always spray clean the brush with acetone and visually inspect the brush between nozzle cleaning.
9.6.4. Collect all acetone rinsate in 250-mL glass bottles, and transport to the laboratory to determine PM mass in the rinsate.
9.6.5. Evaporate the rinsate at room temperature in aluminum weighing dishes, and condition and weigh them as specified in section 9.4. Add rinsate PM mass to the TSP collected on the filters to calculate PM concentrations.
9.7. Troubleshooting
9.7.1. If the flow check is out of specification:
9.7.1.1. Check vacuum pump.
9.7.1.2. Check for leakage in the lines, and in the connections of each element.
9.8. Data acquisition, calculations & data reduction requirements
9.8.1. Validation of samples using field blank (FB) filters. Use the FB filters to determine if there is any problem with the filter handling procedures. The validation procedure uses the average of the applicable blanks (BAVG) and the standard deviation of the blanks (Bσ). If the sample mass (Mt, of filter loaded with PM) satisfies: $Mt > B_{Avg} + 5 \text{ x } B_{\sigma}$, Then the sample is valid (McClure et al., 2004).
9.8.2. Concentration and emission calculations
9.8.2.1. Calculate the total air flow of each sampling line based on sampling flow rates and recorded sampling duration. The sampling flow rate is the average of the beginning and final rate of each sampling event.
9.8.2.2. Calculate the concentration by combining the mass of TSP collected in the acetone rinse and on the conditioned filters, then dividing the combined mass by the total sample air volume.
9.8.2.3. Calculate and report the emission rates according to SOP B4.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet that is designated for this method. Supplement this electronic record with a bound record book designated for the method, which should also contain bound copies of the electronic record.
10.2. Manage data according to SOP B5.
10.3. Document all data and information on field data sheets, and site logbooks with permanent ink, or in electronic field notes.
10.4. Maintain a Filter Identification Record for each assembly, tracking each use (time and location), weights, and results of all leak and flow checks.
10.5. Use Chain of Custody forms when shipping filters.

11. Quality Control and Quality Assurance

11.1. Venturi calibration. A certification of calibration can be obtained from the manufacturer (UIUC lab).

11.2. Conduct field blank samples (the numbers and frequency of which will be specified by the QAPP) in the same manner as the normal TSP sampling, but remove the assemblies before the pump is turned on, to avoid exposure to barn airflow.
11.3. Treat blank samples exactly as if they were normal loaded filters for conditioning and weighing.
11.4. Recalibrate or replace venturi when the flow rate is not within 5% of the calibrated flow rate.
11.5. Analytical balance calibration and standardization
  11.5.1. Calibrate the balance annually (at a minimum).
    11.5.1.1. Calibrate at 2 mg and 1000 mg using class "S" weights.
    11.5.1.2. Instrument calibration must be < ±10% at 2 mg (i.e. ±0.2 mg) and ±0.5% at 1000 mg (i.e. ±5 mg). If these limits are not achieved, recalibrate the balance.
    11.5.1.3. Place a 50-g weight and the 2-mg weight on the balance together. Verify that the balance reads 50.002 g (±0.0002 g).

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12.8. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

13. Manufacturer's Contact information

13.1. Fisher Scientific, 2000 Park Lane, Pittsburgh, PA 15275
13.2. Grainger, 100 Grainger Parkway, Lake Forest, IL 60045
13.3. McMaster Carr, 600 County Line Road, Elmhurst, IL 60126
13.4. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com

MEASUREMENT OF PM$_{2.5}$ WITH PARTISOL-FRM MODEL 2000 AIR SAMPLER

Standard Operating Procedure (SOP) P3

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The TEC Partisol-FRM Model 2000 single-channel sampler and the WINS impactor will be used for integrated gravimetric sampling of particulate matter (PM) with an aerodynamic diameter less than or equal to a nominal 2.5 µm ($PM_{2.5}$) in ambient air and in exhaust air of confined animal houses or barns.

1.2. This procedure follows the federal reference method requirements described in 40CFR50 Appendix L.

1.3. $PM_{2.5}$ measurements are a 24-h integrated sample, and samples will be collected (typically) once every one or three days, depending on the PM concentration and availability of the site engineer.

1.4. The $PM_{2.5}$ concentration in barn exhaust air is expected to be less than 100 µg/m^3.

2. Summary of Method

The TEC Model 2000 single channel sampler is designated as a FRM (RFPS-0498-117) for collection of $PM_{2.5}$ (when using the WINS impactor). The sampler's systems perform all the functions required in the instrument specification portion of the $PM_{2.5}$ FRM standard. The federal standard requires a fixed volumetric flow rate of 16.67 L/min, equivalent to a sampling flow rate of one 1.0 m^3/h, using a specified PM_{10} inlet, tubing (downtube), secondary size-selective impactor, filter holder, and filter cassette (Fig. 1). The sampler draws ambient air through its PM_{10} inlet (Fig. 2), $PM_{2.5}$ Well Impactor Ninety-Six (WINS, Fig. 3), and a 47-mm diameter Teflon sample filter, which traps the $PM_{2.5}$ fraction. The sample filter is conditioned and weighed before and after sampling. The resulting difference in weight is the collected $PM_{2.5}$ mass in micrograms (µg). Electronic systems in the sampler are designed to monitor and maintain the volumetric flow rate as well as record the elapsed sampling time enabling the TEC Partisol-FRM Model 2000 to calculate the total sample volume in cubic meters (m^3). With this information, the analyzing laboratory will calculate and report the average $PM_{2.5}$ concentration for the sampling period in µg/m^3. The TEC single-channel sampler monitors regulates the flow rate using the sampler's microprocessor, software, mass flow controller, ambient temperature sensor, and ambient pressure sensor. The sampling period can be between one to three days (24 to 72 h). The flow rate of the sampler must be 16.67 L/min (5-min average over a 24-hr period) ±5%. For a more detailed explanation of the sampler's theory of operation, please read Section 1: Introduction, of the Operating Manual (2004, version B) and see Figs. 1 through 3 below.

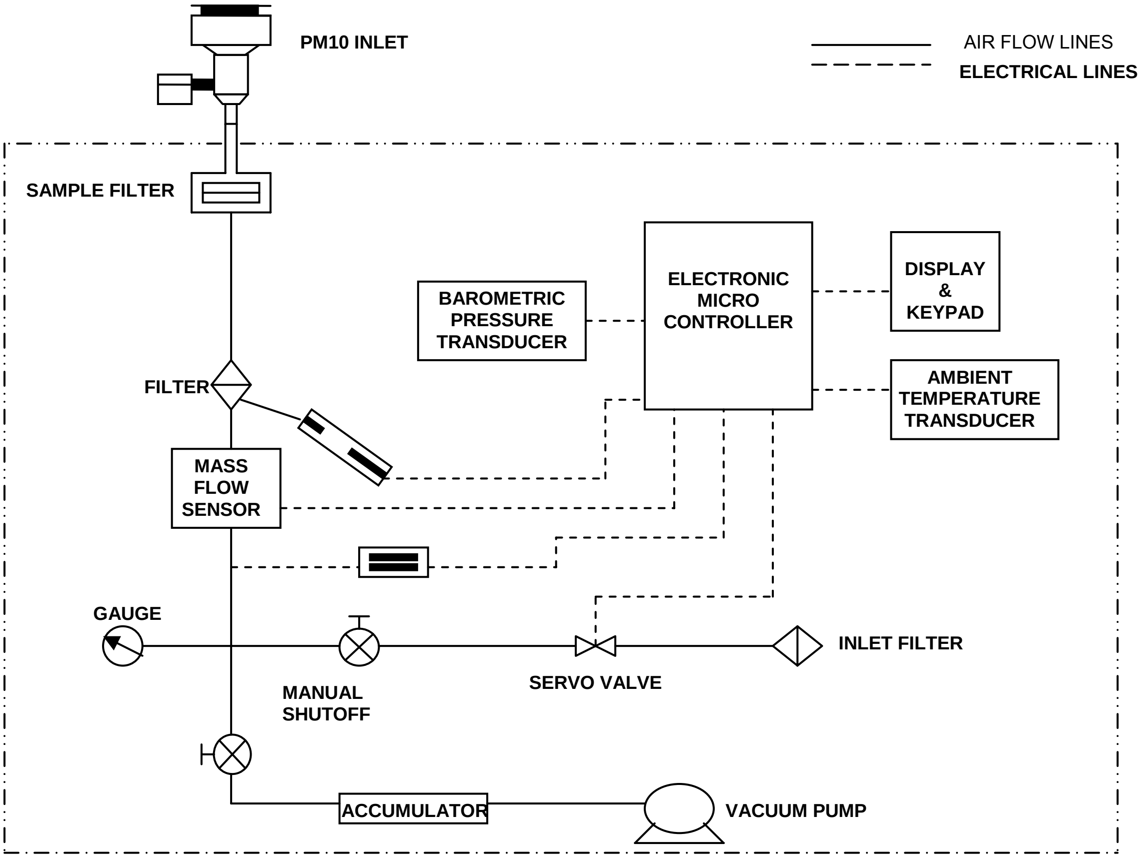


Figure 1. Schematic of TEC Model 2000 $PM_{2.5}$ Single Channel Air Sampler.

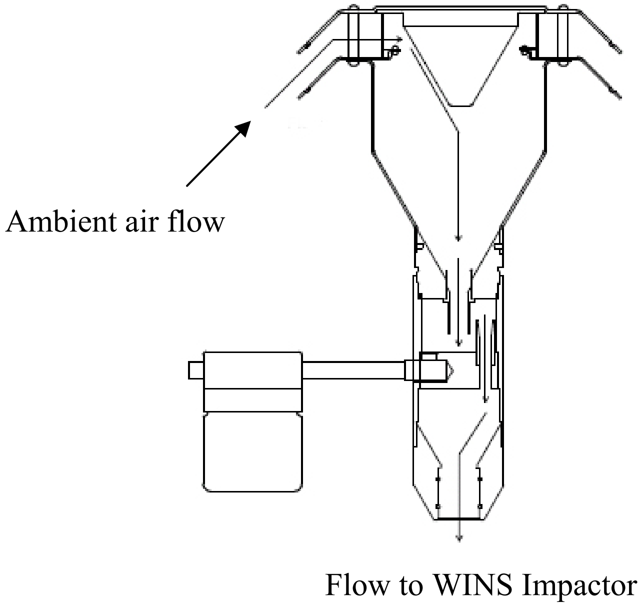


Figure 2. Air flow through the $PM_{2.5}$ sampler impactor.

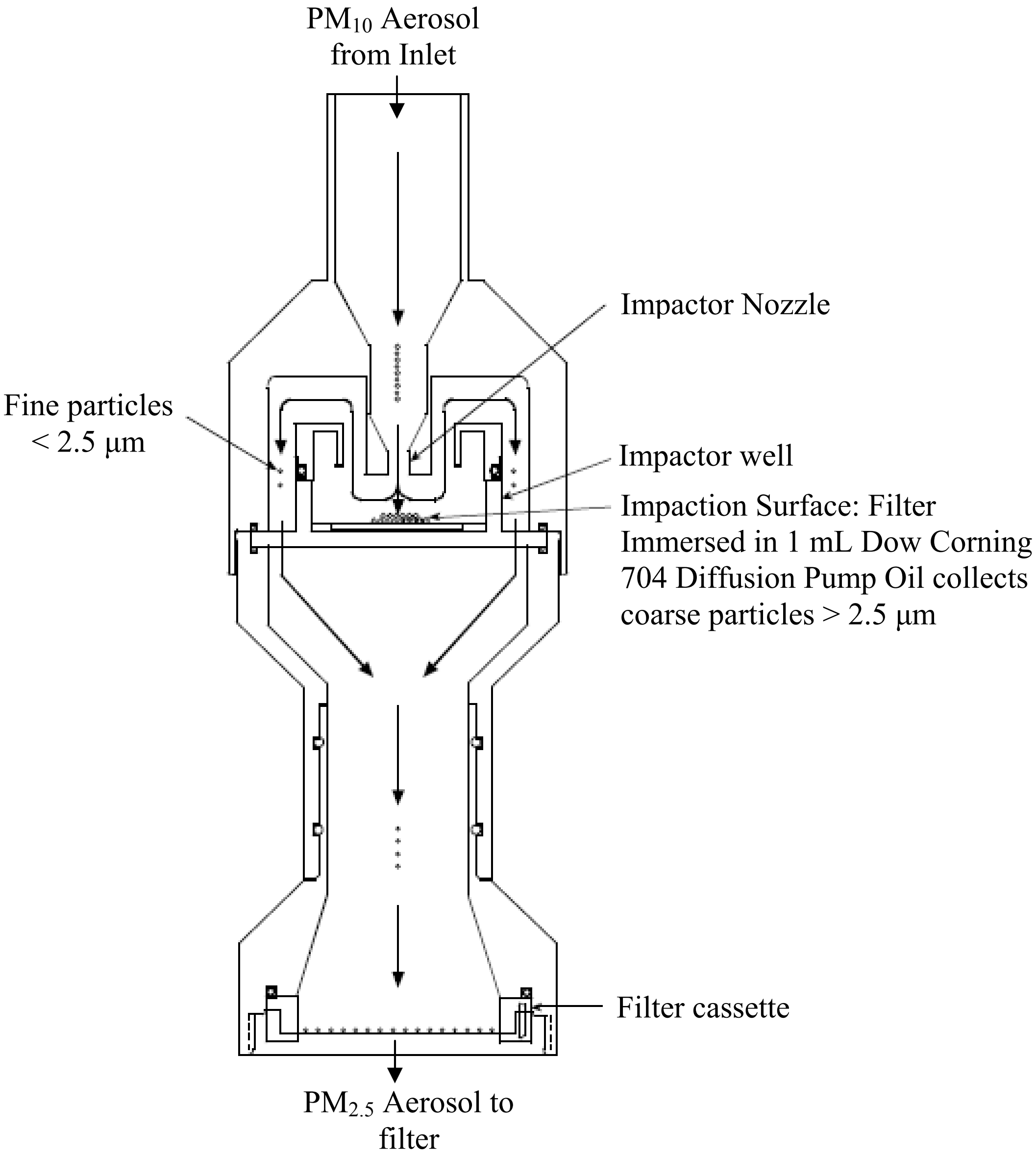


Figure 3. WINS impactor, to separate $PM_{2.5}$ from PM_{10}.

3. Definitions & Symbols

3.1.	A/I	Analog input
3.2.	DVM	Digital volt meter
3.3.	FRM	Federal Reference Method
3.4.	FRS	Flow rate standard
3.5.	FTS	Flow transfer standard
3.6.	GND	Ground connection located on the electronic board of the sampler.
3.7.	NIST	National Institute of Standards and Technology
3.8.	PFM	Primary flow meter

3.9.	PM	Particulate matter
3.10.	$PM_{2.5}$	Particulate matter with an aerodynamic diameter less than or equal to a nominal 2.5 µm
3.11.	QC	Quality control
3.12.	TEC	Thermo Electron Corporation
3.13.	VAC	Voltage alternating current
3.14.	WINS	Well Impactor Ninety-Six (separator used in the FRM for $PM_{2.5}$)
3.15.	<….>	Indicate a command on the screen of the instrument.

4. Health and Safety

4.1. High voltages (120 VAC) are used to power the unit.

4.2. When assembling some components (e.g. the WINS impactor) take care not to pinch fingers between assembly parts.

4.3. Do not use this instrument outdoors without the proper exterior power connection, or in ambient temperatures outside the range of -40° to 50°C (-40° to 122 °F).

4.4. Unplug the sampler whenever possible while working around electrical components. Working outdoors in ambient (wet) weather conditions increases the risk of electrocution.

4.5. Consult the Material Safety Datasheets (MSDS) for safety information about silicon oil, halocarbon grease, and other materials that may be used to clean the TEC sampler parts.

4.6. For additional safety information, read Section 2.2.5: Hardware Installation and Maintenance of the TEC Operating Manual (2004).

5. Cautions

5.1. Installation, operation, maintenance, and calibration of the sampler should only be performed by properly trained personnel.

5.2. Temperature and relative humidity must be controlled during weighing and transporting of the filters according to the specifications for this method.

5.3. Do not calibrate the instrument’s flow rate if the temperature and pressure sensor have not been calibrated first.

5.4. Use proper anti-static protection when the door to the electronics compartment is open and when taking measurements on any electronic components. Failure to use anti-static protection could result in damage to electronic components.

6. Interferences

6.1. Variations in flow rate limit the precision for sampling $PM_{2.5}$. The calibration of the flow rate is of high importance.

6.2. Weight loss due to mechanical removal of particles from the filter is minimized by carefully removing the filter, in its cassette, from the sampler and storing the filter/cassette in a protective container during transit to the weighing laboratory.

6.3. Filter weight loss due to outgassing can be minimized by allowing a six-week period before the filter is used (EPA Quality assurance Document 2.12, Section 7.6, page 7 of

19). Conduct this equilibration period in the same conditioning room, previous to the initial weighing of the filter.

6.4. Weight loss can also be minimized by carefully removing the filter from the cassette, conditioning the filter, and neutralizing the static charge on the filter before weighing.

6.5. Errors in the gravimetric analysis of samples can also result from the buildup of electrostatic charges on filters during their manufacture or during sampling. This static buildup will interfere with microbalance weighing, but can be reduced or eliminated by using Polonium-210 (^{210}Po) antistatic strips before beginning the weighing process.

6.6. If nitric acid vapor is present at a sampling location, it can deposit on a Teflon® filter and cause a small weight gain in proportion to the concentration of nitric acid in the atmosphere. This weight gain may not be controllable.

7. Personnel Qualifications

7.1. The operator of this procedure must be trained in advance, under supervision, before he or she can perform it alone. Analysts must practice filter loading and unloading before performing the procedure with an actual test filter.

8. Equipment and Supplies

8.1. Ensure that each sampler has the supplies included in Table 1.

Table 1. Supplies for the TEC Partisol-FRM Model 2000 $PM_{2.5}$ Air Sampler.

Quantity	Part Description
1	Partisol-FRM enclosure with WINS $PM_{2.5}$ impactor and filter exchange mechanism.
1	Electronic max-min thermometer (to be used in the filter transport container)
1	1st stage PM_{10} inlet
1	Sample tube
1	Flow audit adapter
1	Dual filter transport container with cassettes and carriers
1	Ambient temperature sensor and cable
3	Set of impactor wells and anti-spill rings
4	Set of filter cassettes and backing screens
2	Set of inlet O-rings
1	Bottle (100 mL)) of WINS impactor oil
1	Box (50 count) of glass fiber impactor filters, 37 mm
1	Analog input calibration cable
1	Mating cable connector for four-pin user output connector
1	AKCOMM software diskette
1	9-to-9 pin computer cable
2	Operating manuals
1	Service manual
1	Quick Start Guide

8.2. Upon receipt of the sampler(s), inspect sampler and accessories for shortage and for shipping damage. If shortage or damage is found, immediately notify the site's project manager.

8.3. Keep the following consumables (Table 2), Sampler accessories (Table 3) and batteries (Table 4) on hand with each sampler (i.e. on-site). Part number refers to TEC number.

Table 2 Consumables for the TEC Partisol-FRM Model 2000 PM$_{2.5}$ Air Sampler.

Part Description	Part Number
Polonium-210 (^{210}Po) antistatic strips	N/A
Teflon filters, 2.0 µm pore size, box of 50	10-002322-0050
Single filter carrier	55-004847
Dual-filter transport container	20-004996
Partisol-FRM filter cassette for 47-mm filters	59-004648-0001
5 Partisol-FRM filter cassettes for 47-mm filters	59-004648-0005
10 Partisol-FRM filter cassettes for 47-mm filters	59-004648-0010
Filter cassette screens, package of 5	30-005147-0005
Solid filter leak check/separator disk	36-004768
Tweezers	30-002566
Filter cassette separator tool	38-004892

Table 3 Accessories for the TEC Partisol-FRM Model 2000 PM$_{2.5}$ Air Sampler

Part Description	Part Number
WINS PM$_{2.5}$ impactor	57-004006
Impactor assembly	55-004289
WINS O-ring, 2 3/8" ID x 2 1/2 OD x 1/16", BUNA	22-0002853-3036
Box of 25 glass fiber filters, 37 mm	32-004294
Bottle of WINS impactor oil, 30 ml	59-004292
Bottle of WINS impactor oil, 100 ml	59-004792-0100
PM$_{10}$ inlet	57-004742
PM$_{10}$ inlet O-ring 1 1/4" ID x 1 3/8" OD x 1/16", BUNA	22-00485-1026
PM$_{10}$ inlet O-ring 2 3/8" ID x 2 1/2" OD x 1/16", BUNA	22-000485-1036
Large in-line filters located in the pump compartment (Change every 6 m.)	32-002643

Table 4 Batteries for the TEC Partisol-FRM Model 2000 PM$_{2.5}$ Air Sampler

Part description	Part Number
Round battery for computer board (25 mm dia, Panasonic CR2330)	06-002545
Battery for socket at location U4 (Dallas Semiconductor DS1213C)	06-002565

8.4. Aside from the 47-mm collection filters, the 37-mm WINS impactor glass fiber filters, the impactor oil, and the batteries, the only regular “consumable” item in Tables 1-4 is the large in-line filter located in the pump compartment. This item should be exchanged every six months, as noted in Table 3.

8.5. The equipment necessary to conduct a sampler calibration is presented in Table 5.

Table 5 Apparatus for Partisol-FRM single-Channel Sampler Calibration.

Part description
Certified flow rate standard
Certified reference temperature meter
Certified pressure meter
TEC inlet flow audit adapter
Tubing (Tygon or surgical type)
Blank filter
Calibration forms
Digital Voltmeter (DVM)
Container for temperature calibration
Flow-check filter in transport cassette
Impermeable “filter” disk for internal leak checks
Accurately set timepiece
Hand calculator

9. Procedures

9.1. Equipment and supplies inspection

9.1.1. Table 6 shows acceptance and limits for procurement of equipment and supplies.

9.2. Installation

9.2.1. Physical inspection

9.2.1.1. Upon receipt, inspect sampler and accessories for shortage, and for shipping damage. If shortage or damage is found, immediately notify the site Principal Investigator and/or PAAQL personnel.

9.2.2. Initial sampler installation: Follow directions found in Section 2 of the TEC Operating Manual for installation instructions, and consult with the site Principal Investigator to assure that the installation site complies with the project’s siting criteria for FRM $PM_{2.5}$.

Table 6. Acceptance checks and limits for procurement of equipment and supplies.

Equipment	Acceptance check	Acceptance limits	Action if requirements are not met
Field operations			
Sampler	Sampler and accessories complete; no evidence of damage. Model designated as reference or equivalent method. Pump and display work.	Type as described in Appendix A	Reject sampler
Calibration quality assurance/quality control (QA/QC) equipment for flow rate, temperature, pressure.	Accompanied by certificate. Check values against National Institute of Standards and Technology (NIST)-traceable standards.	Within accuracy limits in Appendix A	Adjust or reject equipment
Audit equipment	Same as for calibration equipment but must not be the same equipment.	Type as described in Appendix A	Adjust or reject equipment
Laboratory operations			
Filters, Teflon®	Of correct type and undamaged.	Type as described in Table 7	Reject filters
Filter cassettes	Of correct type and undamaged.	As specified by sampler manufacturer	Reject filter cassettes
Filter/cassette protective containers	Of correct type and undamaged.	As specified by sampler manufacturer	Reject containers
Filter-handling containers	Of correct type and undamaged.	As specified by sampler manufacturer	Reject containers
Analytical microbalance	Accompanied by certificate; check values against working standards.	Readability: 1 µg, Repeatability: 1 µg	Adjust or reject equipment
Mass reference standards	Check working standards against NIST-traceable primary standards.	Tolerance: ±25 µg from nominal value	Reject standards.

Table 7. Filter specifications (from 40CFR Part 50, App L).

Filter Design Specsifications	Aceptance Criteria
Size	46.2 mm dia + 0.25mm
Medium	Polytetrafluoroethylene
Support ring	Polymethylpentene
	0.38 mm thick
	46.2 mm + 0.25mm outer diameter
	3.68 (+0.00, -0.51mm) width
Pore size	2 µm
Filter thickness	30-50 µm
Max. pressure drop	30 cm H_2O @ 16.67 L/min
Max. Moisture pickup	10 µg increase in 24 hr.
Collection efficiency	99.7%
Filter weight stability	<20 µg
Alkalinity	< 25.0 microequivalents/g

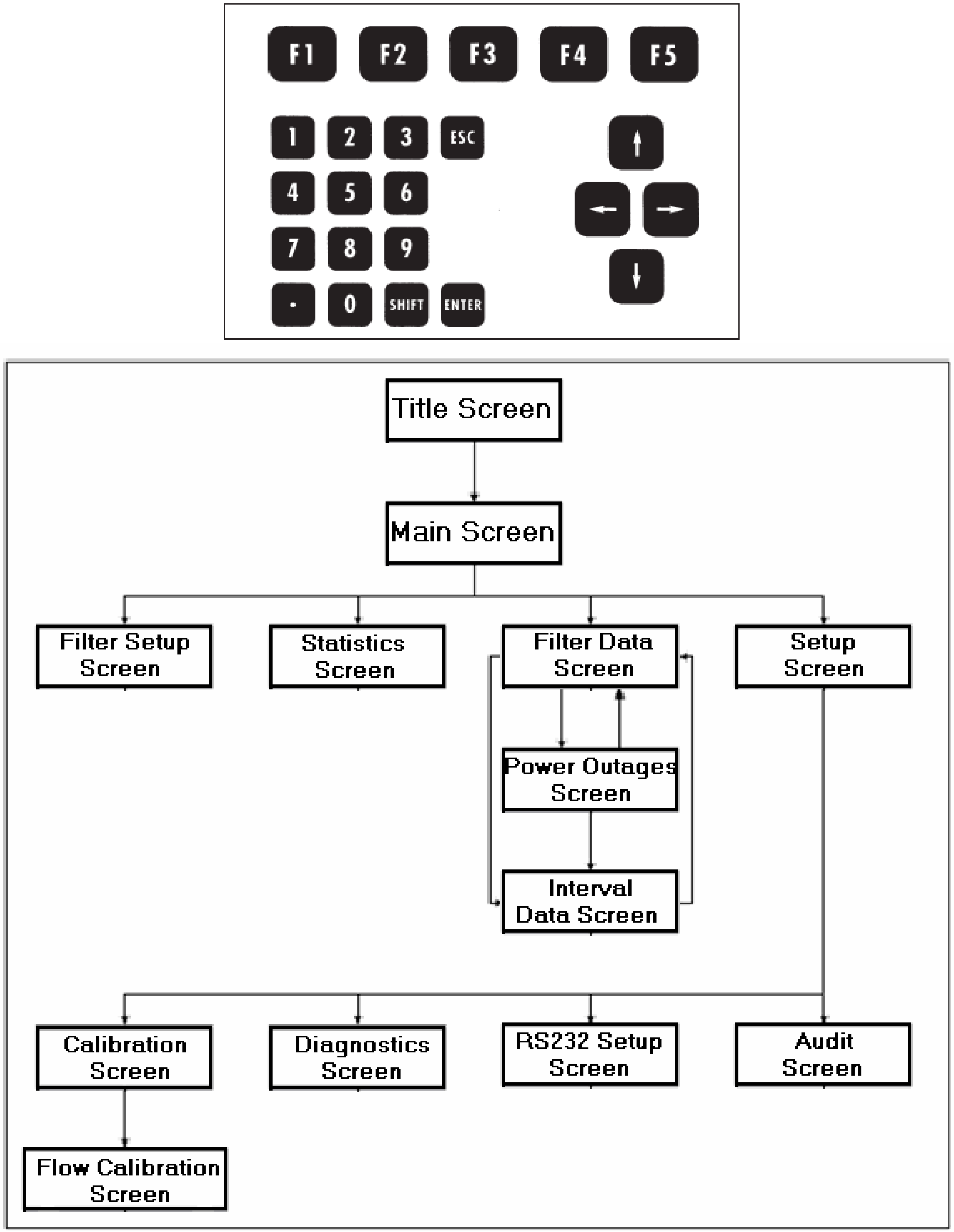


Figure 4. Hierarchy of screens on the TEC Keypad.

9.3. Initial sampler software setup: Follow directions found in Sections 4, 5, and 6 of the TEC Operating Manual.

9.3.1. Current Time: Fig. 4 presents diagrams of the TEC keypad and a hierarchy of screens which can be viewed from the sampler's display screen. From the "Main Screen", ensure the sampler is in the "STOP" operating mode. Then hit <Setup (F5)>, and cursor to the "Current Time". Hit <Edit (F1)> and set the current time.

Note: Set current time to the local standard time.

9.3.2. Start Time: Use the arrow keys to move cursor to "Start Time". Enter as 0.00.

9.3.3. Date: Use the arrow keys to move cursor to "Current Date". Enter the current date as: YY/MM/DD

9.3.4. Duration: Use the arrow keys to move cursor to the default "Duration". Set the duration to 24.00 h.

9.3.5. Flow Rate: Use the arrow keys to move cursor to "Set Flow", and set the flow rate to 16.7 L/min.

9.3.6. Serial Number: Use the arrow keys to move cursor, and enter the last 4 digits (XXXX) of the sampler's serial number into the "serial number" cell.

9.3.7. To save all setup parameters, hit the <ENTER> touch-key.

9.4. Periodic verification/checks

9.4.1. General information

9.4.1.1. QC maintenance procedures (checks) are designed to help assure that valid data is produced as a result of proper sampler operation and maintenance, in accordance with its federal designation and the manufacturers operating manual.

9.4.1.2. The maintenance frequency presented in this SOP should be considered the minimum required, even though the actual frequency of performing some of these checks may vary from site to site due to different environmental factors. These may include the sampling schedule, particulate concentrations, or seasonal factors, which may require an increase in maintenance frequency (Appendix B).

9.4.1.3. In the event that these checks cannot be performed on schedule, the deferred maintenance should be performed as soon as practical. The QC schedule for field equipment is presented in Appendix B.

9.4.1.4. When QC checks are performed, record the date, results, and any pertinent comments onto the Monthly Quality Control Maintenance Checksheet (Appendix C) for the FRM $PM_{2.5}$ Filter Sampler (QC Checksheet) presented in Appendix A. Forward Appendix C to the site project manager on a monthly basis for subsequent review and filing. Make a copy to be kept at the field site for later reference by the operator or a site visitor.

9.4.1.5. Maintenance of the TEC sampler is discussed in Section 10 of the TEC manual.

9.4.2. After each run:

9.4.2.1. Review the summary data for reasonableness and for compliance with the Measurement Quality Objectives for FRM $PM_{2.5}$, (Appendix A, items listed for every 24 h or every sampling period).

9.4.2.2. If questionable summary data for flow, temperature, or pressure are seen, download the 5-min data averages using the data acquisition software, and examine these averages for values outside of the measurement quality objectives presented on Appendix A.

9.4.2.2.1. The volumetric flow rate, measured or averaged over a 24-hour period, shall not vary more than ±5% from the specified 16.67 L/min rate over the entire sample period.

9.4.2.3. Procedures for downloading these data are presented in Section 9 and Appendix D of the TEC manual (2004, Rev. B).

9.4.2.4. In the event that anomalies are present in the 5-min averages, troubleshoot the sampler according to Section 12 of the Appendices of the TEC manual.

9.4.2.5. During the procedure of unloading the sample cassettes from the sampler, record the sample summary data onto the sample cassette's matching Filter Field Sample Report (Appendix D).

9.4.2.6. Keep the filter cassettes clean. Wipe with a clean dry cloth as required. Examine the upper and lower rubber cassette seals and replace if they are cracked or damaged. Keep the rubber seals clean. Also, visually inspect the PM_{10} inlet's water collector jar and drain it if water is present.

9.4.3. After every five (5) sampling runs:

9.4.3.1. Remove the WINS impactor from the sampler and inspect impaction well to determine size of particulate cone, which may have formed in the center of the well. A cone taller than 2 mm, or a cone with its top broken off, indicates a need for more frequent well cleaning to minimize the possibility of particle bounce and re-entrainment of particles larger than 2.5 μm.

9.4.3.2. Clean or replace impactor well with a newly serviced well. Refer to the procedures in Appendix H.2 of the TEC manual for instructions on servicing the impactor. Record performance of this procedure and pertinent comments onto the sampler's QC Checksheet (Appendix C).

9.4.3.3. After servicing the WINS impactor and reinstalling, perform a leak test and record the results on the sampler's QC Checksheet (Appendix C). If the results of the leak check do not meet the criteria, investigate and repair the source of the leak.

9.4.4. Monthly checks

9.4.4.1. Clean the interior of the sampler chassis with a damp cloth. Remove the air intake filter and clean it with soap and water. Verify that the filter is dry before it is installed again.

9.4.4.2. Clean air intake fan blades with a damp cloth or brush if necessary.

9.4.4.3. Inspect the sampler o-rings and gaskets.

9.4.4.4. Verify that the sampler's clock time is within 10 min of standard time, as compared to a clock standard such as the telephone service time. If the difference is > 10 min, reset the sampler's clock to within 1 min of the standard, according to instructions given in Section 4.3 of the TEC manual.

9.4.4.5. Record the date that these procedures were performed and the results obtained onto the sampler's Monthly QC Checksheet (Appendix C).

9.4.4.6. Perform the single-point flow check using an actual flow rate or volume measuring device having an accuracy of at least ±2% of full scale (0-20 L/min vol-o-flow, mass flow meter, etc.) and which is calibrated or certified annually against a NIST-traceable standard (Section 9.5.5.1). If the sampler's flow rate verification (at the sampler's operational flow rate) differs by ± 4% or more from the flow rate measured by the flow rate standard, perform a new multipoint calibration and repeat the flow rate verification. If a cause for the flow discrepancy cannot be found, contact the manufacturer for assistance. Record the date that these procedures were performed and results of the single-point flow check onto the sampler's QC Checksheet (Appendix E).

9.4.4.7. Perform a single-point check of ambient pressure and ambient temperature sensors using a temperature and pressure standard which is calibrated or certified annually against a NIST-traceable standard. Ensure the sampler's measurements are within the acceptance criteria described in Appendix A, Monthly QC checks (± 10 mm Hg for pressure, and ± 2°C for temperature).

9.4.4.8. Trip blanks and field blanks will be initiated by the lab. The lab will designate a sample cassette as a trip blank or a field blank.

9.4.4.8.1. Trip blanks

9.4.4.8.1.1. Ship trip blank filters in cassettes with metal covers on a monthly basis.

9.4.4.8.1.2. Leave the metal cassette covers on the trip blank filters

9.4.4.8.1.3. Leave the trip blank filters in the shipping cylinder.

9.4.4.8.1.4. Record the relevant trip information for the trip blank on the Chain-of-Custody section of the "Filter Field Sample Report" in Appendix D .

9.4.4.8.2. Field blanks

9.4.4.8.2.1. Ship field blanks to each site on a monthly basis.

9.4.4.8.2.2. Take field blanks from the shipping canister and place in the filter transport container.

9.4.4.8.2.3. Take the regular sampling filter and the field trip blank to the location of the sampler.

9.4.4.8.2.4. Remove the previously sampled filter and place in the filter transport container.

9.4.4.8.2.5. Load the new field blank filter into the sampler and leave it there for 1 min.

9.4.4.8.2.6. Remove the field blank filter and cap it with the metal covers.

9.4.4.8.2.7. Place the field blank filter in the filter transport container.

9.4.4.8.2.8. Record the date, time, and length of filter exposure on the Chain-of-Custody section of the "Filter Field Sample Report" in Appendix D, for the field blank.

9.4.4.8.3. Treat these samples in the same manner as a regular sample cassette used for sampling with the sole exception that it will not be used to collect a sample.

9.4.4.8.4. Load and unload the field blank sample cassette from the sampler, transport, store and ship as usual, but do not program the sampler for a sampling event using this cassette. Perform a leak check of the sampler to ensure that a leak has not been introduced by the previous procedures.

9.4.5. Every 14 sampling runs:

9.4.5.1. Disassemble and clean the PM_{10} inlet, sampler downtube, and the entire WINS impactor assembly.

9.4.5.2. Inspect o-rings for abrasions, breaks, tears, deformations or other damage. If necessary, replace o-rings and lubricate them with a light coating of halocarbon or silicone vacuum grease prior to reassembly.

9.4.5.3. Using the same lubricant, also lightly lubricate any aluminum threads and take extra care that the fine threads are not cross-threaded during assembly.

9.4.5.4. Appendix H.1 of the TEC manual discusses the procedure for maintenance of the PM_{10} inlet.

9.4.5.5. After reassembly, perform a leak check according to Sections 10.2.6 of the TEC manual and record the results on the Monthly QC Checksheet (Appendix C). Ensure the results of the leak check meet the criteria in Appendix A.

9.4.6. Semiannual checks (every 6 mos)

9.4.6.1. Perform an as-is calibration verification check of temperature, pressure and flow.

9.4.6.1.1. If any of the sampler's calibrated systems fail to meet the measurement quality objectives presented in Appendix A, calibrator must adjust the parameter to bring it within specification, and conduct a multipoint calibration according to the instrument manual.

9.4.6.2. Inspect the sampler's interior, PM_{10} inlet, and WINS impactor for cleanliness and condition.

9.4.6.3. Replace the large in-line filter. Turn the sampler off for this procedure.

9.4.6.4. Check the voltage level of the main computer board's battery. See Appendix F.1 of the TEC manual for details.

9.4.7. Measure the temperature of the station freezer daily. Post a calendar on the freezer, and record the time checked and the temperature. Initial each day's entry.

9.4.8. Annual checks

9.4.8.1. Re-certify or re-calibrate the flow rate, temperature, and pressure QC verification check measurement standards against a NIST-traceable standard. Record the date that these procedures are performed in the sampler's QC Checksheet.

9.5. Calibration

9.5.1. Scope of the calibration procedures

9.5.1.1. The following procedures describe the techniques used to verify and calibrate the TEC Partisol-FRM Model 2000 $PM_{2.5}$ single-channel air sampler (TEC 2000). The purpose of this written procedure is to outline the techniques that will be used to calibrate the volumetric flow of the TEC 2000 sampler at 16.7 L/min (1 m^3/h) (40 CFR Part 50, Appendix L).

9.5.1.2. The calibration procedures listed in the TEC manual (Section 11) are fairly straightforward with regard to the necessary information and diagrams. This procedure clarifies anomalies in the TEC manual in a step-by-step calibration format.

9.5.1.3. Through the normal course of operation, circumstances may arise in which the sampler will need to be reset. If this occurs, span and offset values may need to be reentered. Keeping an accurate and handy record of the verification and calibration values (see Appendix E, TEC $PM_{2.5}$ Partisol-FRM Single Channel Sampler Calibration Datasheet) can help avoid performing a full calibration after resetting the sampler.

9.5.1.4. Verification techniques are included with the following calibration procedures. When performing routine calibrations at the six-month intervals, follow all verification steps concerning ambient temperature, filter temperature, ambient pressure and flow.

9.5.2. Summary of the calibration procedures

9.5.2.1. The control of a volumetric flow, and the monitoring of the temperature of the exposed filter while still in the sampling position is required for this sampler.

9.5.2.2. To perform these tasks, the sampler uses an ambient temperature sensor (AmbT), a filter temperature sensor (FltT), a pressure sensor (Pres) and a mass flow controller (MFC). These sensors and MFC require calibration when the sampler is installed/replaced and require verification/calibration every 6 mos, or sooner if so specified in the QAPP.

9.5.2.3. If the AmbT sensor and/or the Pres sensor require calibration or adjustment, then the flow must also be verified and probably recalibrated.

9.5.3. Apparatus for calibrating TEC $PM_{2.5}$ FRM Single-Channel Sampler

9.5.3.1. Certified flow rate standard (FRS).
9.5.3.2. Certified reference temperature meter
9.5.3.3. Certified pressure meter
9.5.3.4. TEC inlet flow audit adapter
9.5.3.5. Tubing (Tygon or surgical type)
9.5.3.6. Blank filter (Teflon 47-mm diameter)
9.5.3.7. Calibration forms and/or laptop computer
9.5.3.8. Digital volt meter (DVM)
9.5.3.9. TEC FTS Streamline 0-20 L/min fixed orifice calibration kit (Optional)

9.5.4. Calibration procedures outline (Note: Routine calibration will skip Sections 9.5.4.6 & 9.5.4.7)

9.5.4.1. Verify/calibrate AmbT (± 2ºC).
9.5.4.2. Verify/calibrate FltT (± 2 ºC).
9.5.4.3. Verify/calibrate Pres (± 10mm Hg).
9.5.4.4. Perform leak check.
9.5.4.5. Verify flow (single point verification ± 4% of flow rate standard)
9.5.4.6. Verify/calibrate interface board.
9.5.4.7. Verify/calibrate analog input (A/I).
9.5.4.8. Calibrate flow.
9.5.4.9. Verify calibrated flow (± 2% of 16.7 L/min; 16.4 - 17.0 LPM).

9.5.5. Calibration procedures

9.5.5.1. Perform an external leak check (TEC manual, Section 10.2.4) on the sampler. The leak check procedure is performed to determine if leaks in the sampler exist, and to ensure correct installation of the flow measuring equipment. If the following leak check fails, locate and remedy the problem, then re-verify the flow.

9.5.5.1.1. Carefully remove and replace the 1st stage inlet impactor with the supplied flow audit adaptor and the stopcock valve open.

9.5.5.1.2. Start in the main screen by pressing <ESC> if necessary and make sure that the sampler is in the "stop" operating mode by pressing <F4: Run/Stp> until "stop" is displayed in the upper right hand corner.

9.5.5.1.3. Install a filter cassette containing a 47-mm filter into filter-holding mechanism.

9.5.5.1.4. Press <F5: Setup>, then <F5: Audit>, then <F2: Valve> and then <F3: Pump>.

9.5.5.1.5. Close the stopcock valve on the audit flow adaptor and read the vacuum gauge immediately (the vacuum gauge is located behind the small hinged door below the opening of the filter-holding mechanism).

9.5.5.1.6. Within 30 s, the vacuum gauge should hold at or above 8.5 in of Hg. If the vacuum gauge indicates a value less than 8.5 in of Hg during this 30-s period, locate the leak, fix and re-check.

9.5.5.1.7. When finished, press <ESC> twice to return to the main screen.

9.5.5.2. An as-is flow check verification is the first step for routine calibration of the TEC 2000 (initial sampler setup does not require an as-is flow verification since a full instrument calibration is required). The as-is flow check procedure (TEC manual, Section 10.2.5) verifies the working status of the sampler by ensuring that the calculated true flow at the inlet is ± 4% of 16.7 L/min. If the calculated true flow of the sampler is between 16.0.32 and 17.4 L/min, flow calibration is not necessary unless subsequent sensor or electronics adjustments alter the flow. There are two methods to verify and calibrate flow. The first measures flow directly with a NIST-traceable flow rate standard (FRS); the second method uses the Streamline® Flow Transfer Standard (FTS), which measures a pressure differential. Both FRS and FTS data must be corrected to volumetric flow rate using temperature and pressure data

9.5.5.2.1. Record all calibration measurements and details of standard/audit barometer, thermometer, and FRS calibrations on the Calibration Datasheet, Appendix E.

9.5.5.3. **As-is flow check using a primary flow meter** (such as the Gilian Gilibrator-2 air flow calibration system, Sensidyne Inc., Clearwater, FL) (SOP A9) (Fig. 5): This is the method of choice for verifying inlet flow because this flow rate standard measures flow directly. The following procedure describes how to verify flow with a certified FRS.

9.5.5.3.1. Carefully remove and replace the 1st stage inlet impactor with the flow audit adaptor and open the stopcock valve.

9.5.5.3.2. Connect the FRS flow inlet adaptor to the (Fig. 10.2 of the Sampler Operation Manual).

9.5.5.3.3. Start in the main screen by pressing <ESC> if necessary and make sure that the sampler is in the "stop" operating mode by pressing <F4:Run/Stp> until "stop" is displayed in the upper right hand corner.

9.5.5.3.4. Install a cassette containing a 47-mm filter into the filter-holding mechanism.

9.5.5.3.5. Press <F5: Setup>, <F5: Audit>, <F2: Valve>, and then <F3: Pump>.

9.5.5.3.6. Allow the sampler flow and PFM reading to stabilize, and record the measured flow reading.

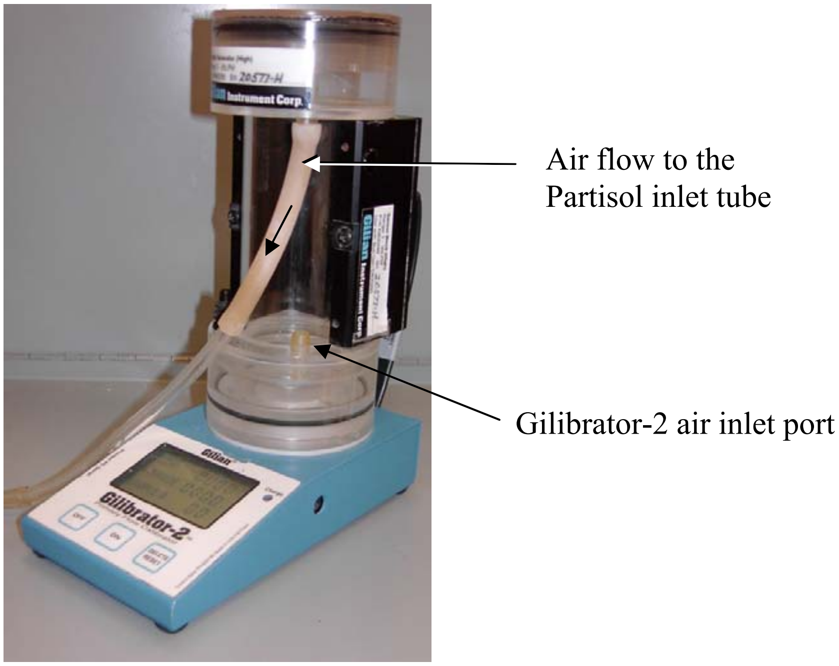


Figure 5. Gilian's air flow primary calibration system (Gilibrator-2).

9.5.5.3.7. If a mass flow rate standard is used, calculate the true flow from the measured flow reading and determine the percent difference from 16.7 L/min. The equation used for calculating true (volumetric) flow is:

$$\text{Volumetric flow} = \frac{(\text{Std. flow}) \times T \times (760 \text{ mm Hg})}{P \times (298\ ^{\circ}\text{K})} \qquad (1)$$

Where:

T = Ambient temperature, °K

P = Ambient pressure, mm Hg

Std. flow = [(FRS disp)(FRS cert. Slope)] + (FRS cert. Intercept)

9.5.5.3.8. If the calculated true flow differs more than ± 4% of the Flow Rate Standard, the sampler flow must be recalibrated. If the flow is out of range or unstable, a leak may be the cause. Check flow check equipment to ensure it is not at fault. The calculation for % difference is:

$$\%\text{ difference} = \frac{(\text{True flow - 16.7 L/min})}{16.7 \text{ L/min}} \times 100\% \qquad (2)$$

9.5.5.3.9. When finished, press <ESC> twice to return to the main screen.

9.5.5.4. **As-is flow check using FTS**: This is the secondary method of choice when used for measuring inlet flow because the FTS measures a pressure differential and must be converted to flow units. The FTS is an accurate device and appears to work well when used as a calibration tool, but when possible, the primary choice for verifying flow should be a flow measuring device. The following procedure describes how to use the FTS as a flow check device.

9.5.5.4.1. Carefully remove and replace the 1st stage inlet impactor with the FTS fixed orifice (the fixed orifice should be connected to the minus (-) port of the digital flow manometer by the supplied piece of black rubber tubing).

9.5.5.4.2. Start in the main screen by pressing <ESC> if necessary and make sure that the sampler is in the “stop” operating mode by pressing <F4: Run/Stp> until “stop” is displayed in the upper right hand corner.

9.5.5.4.3. Install a filter cassette containing a 47-mm filter into the filter holding mechanism.

9.5.5.4.4. With the digital manometer turned on and in "measuring in inches of water", adjust the silver colored knob at the top of the manometer (located between the + and - ports), until a reading of 0.00 in H_2O is reached (zeroing the manometer).

9.5.5.4.5. Press <F5: Setup>, <F5: Audit>, <F2: Valve>, and then <F3: Pump>.

9.5.5.4.6. Allow the sampler flow and FTS reading to stabilize and record the measured pressure reading.

9.5.5.4.7. Calculate true flow from the measured FTS reading and determine the percent difference from 16.7 L/min. The true flow conversion equation, orifice slope and intercept used for calculating true flow is located on the fixed orifice and is as follows:

$$\text{True flow} = \frac{(\text{orifice m}) \times (\text{FTS P} \times \text{T})^{0.5}}{\text{AmbP}} + (\text{orifice b}) \qquad (3)$$

Where:
orifice m = Orifice slope.
orifice b = Orifice intercept.
FTS P = FTS differential pressure reading, inches of H_2O
T = Ambient temperature, ºK
AmbP = Ambient pressure, atm

9.5.5.4.8. If the calculated true flow differs more than ± 2% of 16.7 L/min, the TEC 2000 sampler flow must be recalibrated. If the flow is out of range or unstable, a leak may be the cause. Verify that flow check is not faulty.

9.5.5.4.9. When finished, press <ESC> twice to return to the main screen.

9.5.5.5. Interface Board Verification and Calibration (TEC manual, Section 11.1). The following procedure describes how to check and adjust the Interface (I) board.

9.5.5.5.1. Sampler must be turned on and in the “stop” operation mode.

9.5.5.5.2. Locate the interface board. The interface board is located on the bottom of the electronics compartment. Access the compartment by removing the three screws on the hinged door located above the front digital display. The layout of the interface board is shown in Fig. 6.

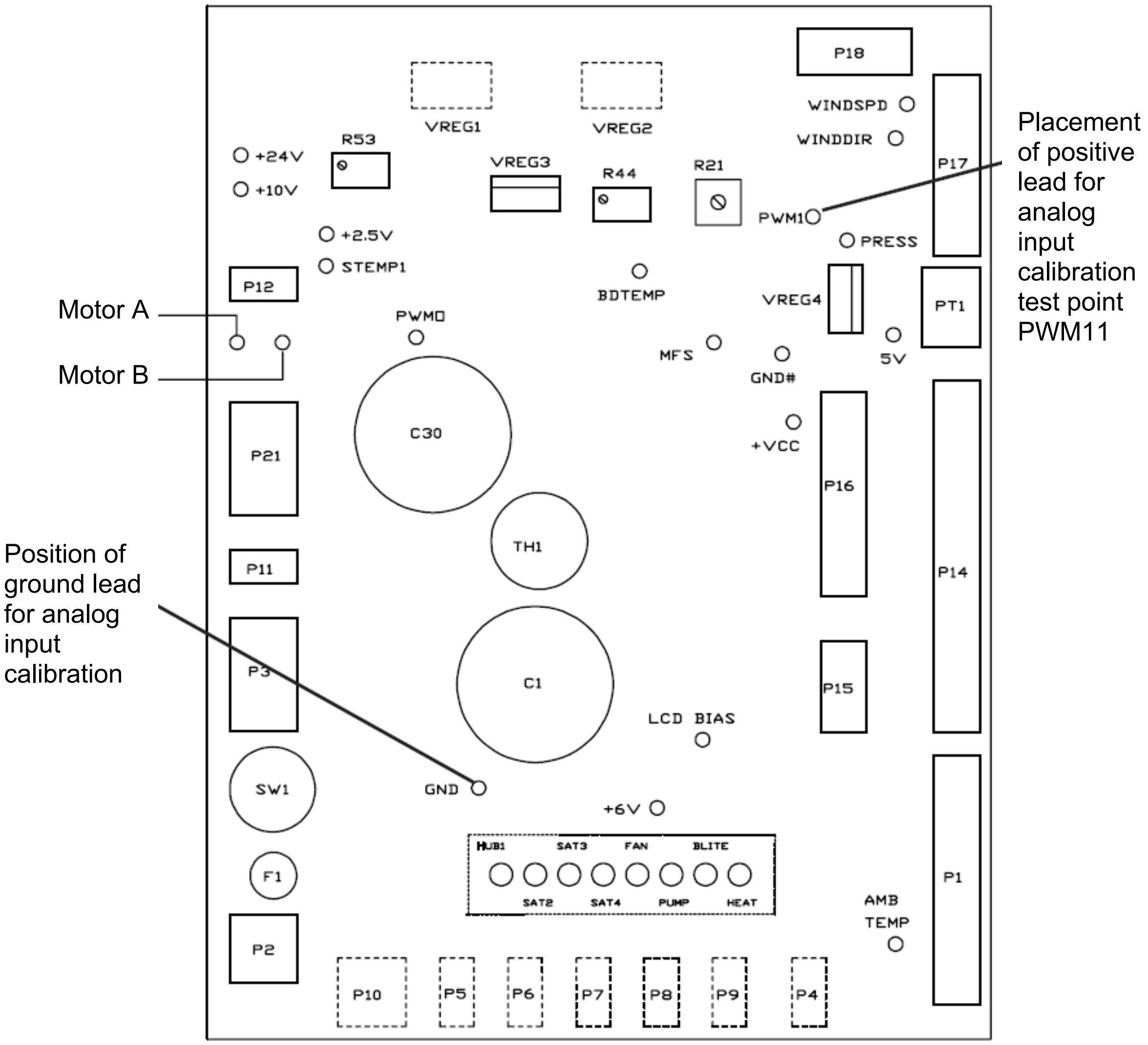


Figure 6. Layout of the interface board indicating the lead locations.

9.5.5.5.3. The digital display backlight must be on (pressing any key on the keypad, such as the <ESC> key, will turn on the backlight).

9.5.5.5.4. Locate the red 2.5-V, 6-V, 10-V and black GND test points and the adjustable pots labeled R21, R44 and R53 on the I board (refer to Fig. 6 for locations).

9.5.5.5.5. Place the positive lead of the DVM on the 6-V test point and the negative lead on the GND test point. Read and record the output.

9.5.5.5.6. If needed, adjust pot R21 until DVM reads 6.0 VDC ± 0.05 V.

9.5.5.5.7. Next, place the DVM positive lead on the 2.5-V test point, read, record and adjust pot R53 until the DVM reads 2.5 VDC ± 0.002 V.

9.5.5.5.8. Now, place the DVM positive lead on the 10-V test point, read, record and adjust pot R44 until the DVM reads 10 VDC ± 0.002 V.

9.5.5.5.9. Leave the electronics compartment door open to calibrate the analog input (A/I) board in the following Section (9.5.5.6).

9.5.5.5.10. The interface board calibration is now complete and should only need checking and calibration when the sampler is moved or when troubleshooting.

9.5.5.6. A/I verification/calibration

After checking/calibrating the interface board, the A/I board must be checked and calibrated as needed (TEC manual, Section 11.2).

9.5.5.6.1. Push the <ESC> key on the keypad to return to main screen and ensure that the sampler is in the "stop" operating mode.

9.5.5.6.2. Locate and unplug the connector cable labeled P18 at the back of the I board by gently pulling the thin brown plastic strap on top of the plug forward (refer to Fig. 6 for location).

9.5.5.6.3. Plug in the analog adaptor plug into P18 (adaptor plug is provided with the sampler, TEC p/n 51-004282).

9.5.5.6.4. Place the DVM positive lead on the green test point labeled PWMI, and the DVM negative lead on the test point labeled GND.

9.5.5.6.5. Press <F5: Setup>, then <F2: Calib> and then <F1: Edit>.

9.5.5.6.6. Move the cursor over to the right hand side of the screen to the row labeled "A/O".

9.5.5.6.7. Choose and enter a value between 0.050 and 0.150 VDC (i.e. 0.100 VDC).

9.5.5.6.8. Observe the number displayed in the column labeled "calc" on the row labeled "A/I". This number should not vary more than ± 0.005 V (from itself) after watching for 5 s. If this number is not stable, choose and enter another value between 0.050 and 0.150 V until the number displayed becomes stable.

9.5.5.6.9. With the DVM in place, read the DVM display.

9.5.5.6.10. Press <F1: EDIT> and using the arrow keys, move the cursor to the column labeled "Act" in the row labeled A/I.

9.5.5.6.11. Enter the DVM reading to three decimals (a.bcd) and press <ENTER> (this calculates offset).

9.5.5.6.12. The number in the "calc" column should match the number on the DVM ± 0.005 V.

9.5.5.6.13. Press <F1: EDIT> again and move the cursor back over to the right hand side of the screen to the row labeled "A/O".

9.5.5.6.14. Choose and enter in a number between 4.800 and 4.900 VDC (i.e. 4.850 V) and press <ENTER>.

9.5.5.6.15. Observe again the number displayed in the column labeled "calc" in the row labeled "A/I". This should not vary more than ± 0.005 V (from itself) after watching it for 5 s (if this number is unstable, choose another number for "A/O" between 4.800 and 4.900 V until stable).

9.5.5.6.16. Press <F1: EDIT> and using the arrow keys, move the cursor to the column labeled "Act" in the row labeled "A/I".

9.5.5.6.17. Type in the DVM reading to three decimals and press <ENTER> (this calculates span). The number now displayed on the DVM should match the number in the column labeled “calc” within ± 0.005 V.

9.5.5.6.18. Remove the adaptor plug and reconnect the cable in location P18.

9.5.5.6.19. The A/I calibration is now complete and should only need checking and calibration when sampler is moved, when troubleshooting or when the interface board is calibrated.

9.5.5.7. Temperature calibration: The TEC single channel $PM_{2.5}$ FRM sampler has two temperature sensors: the ambient and the filter sensors. These two temperature sensors require one temperature data point each to calibrate. The following procedure requires an external certified thermometer.

9.5.5.7.1. Ambient Temperature Check/Calibration

The following procedures are found in the TEC manual, section 11.3.

9.5.5.7.1.1. As-Is Ambient Temperature Check

9.5.5.7.1.1.1. Remove the ambient temperature thermocouple from the external housing.

9.5.5.7.1.1.2. Place the thermocouple and the external thermometer in a similar medium if possible (i.e. packing material). The main point is to place them in as similar an environment as possible.

9.5.5.7.1.1.3. Record and compare sensor and external thermometer readings. The sensor reading must be within 2°C of the external thermometer temperature.

9.5.5.7.1.1.4. If the ambient temperature sensor fails the ambient temperature check, calibrate the sensor.

9.5.5.7.1.2. Ambient temperature calibration

9.5.5.7.1.2.1. To calibrate the ambient temperature sensor, start in the main screen and ensure that sampler is in the “stop” operation mode.

9.5.5.7.1.2.2. Press <F5: Setup>, then <F2: Calib> and then <F1: Edit>.

9.5.5.7.1.2.3. Using the arrow keys, move cursor to the “Act” column in the row labeled “AmbT”.

9.5.5.7.1.2.4. Enter the current temperature as displayed on the external thermometer device (press <SHIFT><F1> to enter a negative number).

9.5.5.7.1.2.5. Press <ENTER> and record the offset number listed under the column labeled “offset” on the Datasheet, Appendix E.

9.5.5.7.2. Filter temperature calibration

The following procedures are found in the TEC manual, Section 11.4.

9.5.5.7.2.1. Filter temperature check

9.5.5.7.2.1.1. The filter sensor is located directly beneath the filter cassette. Open the filter exchange mechanism by pulling on the foam padded handle and remove the filter cassette if present.

9.5.5.7.2.1.2. Place the external thermometer sensor next to the filter sensor so that they share the same environment.

9.5.5.7.2.1.3. Record and compare sensor and external thermometer readings. The sensor reading must be within ±2°C of the external thermometer temperature.

9.5.5.7.2.1.4. If the filter temperature sensor fails the ambient temperature check, calibrate the sensor.

9.5.5.7.2.2. Filter temperature calibration

9.5.5.7.2.2.1. To calibrate the filter temperature sensor, start in the main screen and ensure that sampler is in the “stop” operation mode.

9.5.5.7.2.2.2. Press <F5: Setup>, then <F2: Calib> and then <F1: Edit>.

9.5.5.7.2.2.3. Using the arrow keys, move cursor to the “Act” column in the row labeled “FltT”.

9.5.5.7.2.2.4. Enter the current temperature as displayed on the external thermometer device (press <SHIFT><F1> to enter a negative number).

9.5.5.7.2.2.5. Press <ENTER> and record the offset number located in the column labeled “offset” on the Calibration Datasheet, Appendix E.

9.5.5.8. Ambient pressure calibration

9.5.5.8.1. The ambient pressure calibration (TEC manual, Section 11.5) requires a certified pressure sensor.

9.5.5.8.2. Return the sampler to the Main Screen and make sure that the sampler is in the “stop” operation mode.

9.5.5.8.3. Compare the displayed TEC 2000 pressure reading to the pressure of the certified pressure sensor. The sampler pressure reading should be within 10 mm Hg of the pressure measuring device. If not, then proceed to calibrate.

9.5.5.8.4. Press <F5: Setup>, then <F2: Calib> and then <F1: Edit>.

9.5.5.8.5. Determine the current ambient pressure in mm Hg.

9.5.5.8.6. Using the arrow keys, move the cursor to “Act” column in the row labeled “Pres”.

9.5.5.8.7. Enter the current ambient pressure in mm Hg and press <ENTER>.

9.5.5.8.8. Record the offset number located in the column labeled “offset” on the Calibration Datasheet (Appendix E).

9.5.5.9. Multipoint flow calibration (TEC manual, Section 11.6.2) a minimum of three points are required. The TEC 2000 flow calibration is software driven and offers the option of a one-point or a five-point calibration. Due to U.S. EPA requirements, perform the five-point flow calibration procedure. The mass flow controller of the TEC 2000 can be calibrated using a flow rate standard (FRS) or the Streamline FTS. When using the a mass flow meter (MFM) as the FRS, flow input data must be converted from standard flow to true flow using temperature and pressure data. When using the Streamline FTS, there are no external data conversions. Both procedures are described below.

9.5.5.9.1. Flow calibration using MFM:

9.5.5.9.1.1. Return to the Main Screen and make sure that the sampler is in the “stop” operating mode (by press <F4: Run/Stp> if needed).

9.5.5.9.1.2. Carefully remove the 1st stage inlet from sampler.

- 9.5.5.9.1.3. Carefully install the flow audit adaptor and turn the stopcock valve to the open position.
- 9.5.5.9.1.4. Install a filter cassette containing a 47-mm filter into the filter holding mechanism.
- 9.5.5.9.1.5. Attach the audit flow adaptor to the MFM.
- 9.5.5.9.1.6. Press <F5: Setup>, <F2: Calib>, <F2: FlowCal>, and then <F2: Start>.
- 9.5.5.9.1.7. After a few moments, the flow pump will start. Allow the pump to run for 5 min until both the MFM and the sampler flow display produce a stable reading. At this point, enter the true flow calculated from the MFM reading into the column labeled “Flow” and press <ENTER>. The equations for true (volumetric) and standard flow are the same as those in Section 9.5.5.3.1.7.
- 9.5.5.9.1.8. The sampler will compute span and automatically change the inlet flow for the next point.
- 9.5.5.9.1.9. Repeat Step 9.5.5.8.1.7, until the fifth flow point is entered. When the last point is entered, the sampler will automatically shut off.
- 9.5.5.9.1.10. Record the offset and span value (Appendix E).
- 9.5.5.9.1.11. Return to the main menu by pressing the <ESC> key three times.

9.5.5.9.2. Flow calibration using FTS:

- 9.5.5.9.2.1. This procedure is similar to the FRS procedure, except that the measured data is collected in terms of inches of water (because it uses an orifice to create a differential pressure) in lieu of L/min. Those manometer readings do not require external conversion.
- 9.5.5.9.2.2. Return to the Main Screen and make sure that the sampler is in the “stop” operating mode (by pressing <F4: Run/Stp> if needed).
- 9.5.5.9.2.3. Carefully remove the 1st stage inlet from sampler.
- 9.5.5.9.2.4. Carefully connect the FTS fixed orifice to the inlet of the TEC 2000 (the fixed orifice should be connected to the minus (-) port of the digital flow manometer by the supplied piece of black rubber tubing).
- 9.5.5.9.2.5. Install a filter cassette containing a 47-mm filter into filter holding mechanism.
- 9.5.5.9.2.6. Enter the slope and offset values listed on the fixed orifice by pressing <F5: Setup> and then <F1: Edit>. Arrow down to the “FTS Const M” row, type in the slope of the fixed orifice and press <ENTER>.
- 9.5.5.9.2.7. Press <F1: Edit> again, arrow down to the “FTS Const B” row, type in the intercept of the fixed orifice and press <ENTER>.
- 9.5.5.9.2.8. Press <ESC> until back into the main screen.
- 9.5.5.9.2.9. To start the calibration, press <F5: Setup>, then <F2: Calib>, then <F2: FlowCal>, and then <F2: Start>.
- 9.5.5.9.2.10. After a few moments, the flow pump will start. Allow the pump to run for a few minutes until both the FTS and the sampler flow display read a stable value. At this point, enter the manometer reading in inches of water into the column labeled “FTS” and press enter.
- 9.5.5.9.2.11. The sampler will compute span and automatically change inlet flow for the next point.

9.5.5.9.2.12. Allow flow to stabilize for a few minutes and enter the next manometer reading.
9.5.5.9.2.13. Repeat Sections 9.5.5.8.2.8 through 9.5.5.8.2.12 until the fifth flow point is entered. When the last point is entered, the sampler will automatically shut off.
9.5.5.9.2.14. Record the offset and span value.
9.5.5.9.2.15. Return to the main menu by pressing the <ESC> key three times.
9.5.5.9.3. Verify the calibrated flow of the sampler. This post calibration flow check is essential to verify the accuracy of the sampler flow. Follow procedures described in Section 9.6.5.3 or 9.6.5.4 (9.6.5.3 is preferred, as stated above). Record the final flow value.
9.6. Sampler filter handling procedures
9.6.1. Overview
9.6.1.1. $PM_{2.5}$ measurements is a 24-h integrated sample, and samples will be collected (typically) once every one or three days, depending of the PM concentration and availability of the site engineer.
9.6.1.2. Use care in handling the samples so that the filters arrive in the lab with the same mass that was collected at the end of the sample run. Do not contaminate the filters with fugitive particulate matter, and do not lose mass from the filters by allowing particles to shake loose from the filter or heating the filters and driving off heat-sensitive particulate matter.
9.6.1.3. Accurately and completely fill in the Filter Field Sample Report (Appendix D) associated with each filter.
9.6.1.4. Send the filter to the lab within the appropriate time and temperature constraints.
9.6.2. Field filter preparation
9.6.2.1. Keep the filter cassette assembly in its protective container until installation. Never remove the filter from the cassette.
9.6.2.2. In the field office or a dust-free work environment, place an unsampled filter cassette into a filter cassette holder. Do this by removing the metal cassette cover from the bottom of the cassette. Snap the cassette into the cassette holder, leaving the top cassette cover in place to protect the filter until installation into the sampler.
9.6.2.3. Take the removed metal cassette cover to the sampler.
9.6.2.4. Place the filter cassette holder into a filter cassette transport container.
9.6.2.5. Fill in the Filter Field Sample Report (Appendix D). Include the site name, site number, operator name, cassette ID#, scheduled sampling date and sampler serial number.
9.6.2.6. Take the filter, Filter Field Sample Report Appendix D), and Monthly QC Maintenance Checksheet (Appendix C) to the field sampling location.
9.6.2.7. Remove the previous filter (NOTE: Always exchange filter cassettes with the sampler in the “STOP” mode.)
9.6.2.8. Remove sample from the TEC sampler within 96 h (4 d) of the end of the run.
9.6.2.9. Open the door of the sampler and observe the status of the previous sample run. In the upper left hand corner, “STAT” should indicate “OK”. If there was an occurrence of any status condition, its code should be displayed (reference the

Filter Field Sample Report and/or Section 6 of the TEC Operating Manual).

9.6.2.10. Observe the sampler mode condition. If the sampler has completed a sample run, the condition should indicate “DONE”, unless an error condition (“ERR”) was encountered during the sampler run.

9.6.2.11. Hit the <Run/Stop (F4)> touch key. The sampler should go to “STOP” mode.

9.6.2.12. Hit the <Data (F3)> touchkey. Observe and record the start time/date, total elapsed time, sample volume, and flow %CV.

9.6.2.13. Observe and record the minimum, average, and maximum ambient temperature, filter temperature, and pressure. Also record the average flow results. Record the local condition code.

9.6.2.14. Hit the <Pwr Data (F4)> touchkey to view and record any power interruption messages.

9.6.2.15. Hit the <ESC> touchkey twice to return to the Main Screen.

9.6.2.16. Record the date and time of filter removal from the sampler in the Chain-of-Custody section of the Filter Field Sample Report.

9.6.2.17. Pull the handle of the filter exchange mechanism out to access the sampled filter.

9.6.2.18. Visually check the filter while in the cassette for tears, pinholes, or any unusual appearance, then immediately install a metal cassette cover on the top of the filter cassette.

9.6.2.19. Remove the filter holder with cassette from the sampler and place it into the filter transport container. Do not allow the filters to be shaken, dropped, or touched by any foreign object.

9.6.2.20. Check the sampler for any obvious problems, such as a full water jar. Describe any obvious sampler problems on the monthly maintenance checksheet, and take corrective action before the next sample run. Note any anomalies on the Filter Field Sample Report.

9.6.3. Complete the Monthly Maintenance Checksheet and perform all required maintenance actions. Annotate the Monthly Maintenance Checksheet accordingly.

9.6.4. Loading new filter

9.6.4.1. Take the unsampled filter cassette from the filter cassette transport container and remove the top metal cassette cover from the filter cassette.

9.6.4.2. Place the cassette holder in position to collect a sample.

9.6.4.3. Ensure the cassette holder is seated properly on the alignment pins.

9.6.4.4. Push the handle of the filter exchange mechanism inward to lock the new filter cassette into place, being careful to ensure good alignment of the upper and lower cassette seals.

9.6.5. Program the Sampler for the next run

9.6.5.1. From the Main Screen, hit the <Filter Set (F1)> touchkey to reprogram for the new start and stop days. Hitting the <Next Day (F3)> touchkey will advance the program to the next day and default start time. Then hit the <+Day (F4)> touchkey until the correct scheduled start date is indicated. The start time/end time should not require adjustment, unless it is being changed from the default values.

9.6.5.2. Use the arrow keys to cursor down to “ID1”. Hit the <Edit (F1)> touchkey, and enter the barcode number of the new sample taken from the top of the Filter

Field Sample Report. Hit <ENTER> to program that number into the sampler's memory.

9.6.5.3. Hit <Escape (ESC)> to return to the Main Screen.

9.6.5.4. Ensure that the new programmed scheduled start date/time is indicated.

9.6.5.5. Hit <Run/Stop (F4)> to put the sampler in the "Wait" mode. It should display "0.0 Flow Rate", "0.0 Volume", and "000.00 Sample Time".

9.6.6. Post-sampling procedure

9.6.6.1. In the field office or a dust-free work environment, carefully remove the sampled filter from the filter holder and place a metal cassette cover on the bottom of the filter cassette.

9.6.6.2. Place the sampled filter in a cold shipping cylinder.

9.6.6.3. Remove the tabs and place a set of 5ºC and 25ºC heat sensing strips inside the shipping cylinder.

9.6.6.4. Document the date and time the samples are placed in the cooler or shipped to the lab on the Filter Field Sample Report. Note any problems in the comment section of the Filter Field Sample Report, and on the Monthly QC Checksheet.

9.6.6.5. Complete the information in the Chain-of- Custody section of the "Filter Field Sample Report" (Appendix D).

9.6.6.6. Place the report inside a zip-lock plastic bag to avoid condensation damage and attach the bag to the exterior of the shipping cylinder with a rubber band.

9.6.6.7. Place the shipping cylinder into the freezer or ship the cylinders as required.

9.6.7. Additional filter handling and shipping information

9.6.7.1. Some of the major differences between collection of $PM_{2.5}$ using the new FRM and the older dichotomous filter sampling for particulate matter are the additional time and temperature requirements (see *Filter Holding Times* presented in Appendix A).

9.6.7.1.1. The new FRM $PM_{2.5}$ filters must be used for sampling within 30 d of the date of preweighing by the lab.

9.6.7.1.2. Postweighing by the laboratory must be performed within 10 d of the end of the sampling if the sampled filters have been continuously stored at no more than 25°C since removal from the sampler.

9.6.7.1.3. If the sampled filters have been continuously stored at 4°C or less since removal from the sampler, the laboratory can conduct postweighing within 30 d of the end of sampling.

9.6.7.2. Since this latter (30 d at <4°C) requirement is preferred to give sufficient time for field, transport, and laboratory operations, additional equipment such as a freezer, insulated shipping containers, and chilled medium ("Blue Ice" or equivalent), is required.

9.6.7.2.1. Store the shipping cylinders (containing the unused, ready-to-sample filters, and the used filters) in the freezer, in such a way that the first received is the first sampled, and the first sampled is the first shipped.

9.6.7.2.2. To minimize the possibility of contaminating the sample filter prior to the sampling event, load the sample filter(s) at a time as close as practical to the start of the sampling event.

- 9.6.7.2.3. Although the sample cassette(s) may remain in the sampler up to 96 h (4 d) after the end of the sampling event, remove them from the sampler as soon as practical.
- 9.6.7.3. When traveling to a site, bring a chilled shipping cylinder, and a cooler with chilled medium inside.
  - 9.6.7.3.1. The shipping cylinder will be used to chill the sampled filters to less than 4°C during the transportation period to the operator's field office or shipping location.
  - 9.6.7.3.2. If a temperature threshold is exceeded during shipment, note this information in the affected sample filter's Filter Field Sample Report.
- 9.6.7.4. Prepare the filter samples for shipment.
  - 9.6.7.4.1. Remove the shipping cylinder(s) containing the oldest (earliest sample date) sample cassettes and attached Filter Field Sample Reports from the freezer.
  - 9.6.7.4.2. Open the shipping cylinder, and confirm that each sample cassette has a matching sample report.
  - 9.6.7.4.3. Orient the indicators in such a manner that the indicator window is clearly visible upon examination.
  - 9.6.7.4.4. Fill in the appropriate portions of the Chain-of-Custody sections of each Filter Field Sample Report.
  - 9.6.7.4.5. Close the shipping cylinder(s).
- 9.6.7.5. Place the shipping cylinder with its report in an insulated shipping container.
  - 9.6.7.5.1. The type of insulated shipping container needed and the amount of chilled medium used will depend on the transit time of shipping as well as the expected ambient temperatures during shipment.
  - 9.6.7.5.2. Close the shipping container and secure the lid or opening to prevent opening during shipment.
  - 9.6.7.5.3. Address the container to the analyzing laboratory and store the container in a cool place until pickup.
  - 9.6.7.5.4. Ship samples to the lab using a suitable service or carrier. Determine beforehand how long the transit time is between pick-up and arrival at the lab. Schedule the pick-up to avoid arrival on weekend or holiday dates.

9.7. Troubleshooting

- 9.7.1. If a problem is encountered as a result of the review of the sample summary data, which may affect the validity of the sample, download and store the 5-min averages.
- 9.7.2. Review the 5-min averages for operational parameters which may exceed limits of the measurement quality objectives (Appendix A).
- 9.7.3. Also, refer to Section 12 of the TEC Manual (2004, Rev. B): Resetting the Sampler for a probable cause and remedy.
- 9.7.4. If the perceived problem does not affect sample validity, continue to monitor the problem or correct it.
- 9.7.5. If the problem persists, contact the manufacturer. (Section 13.1).

9.8. Computer hardware and software

- 9.8.1. Data will be stored in the data acquisition computer in the site's on-farm instrument shelter (OFIS).
- 9.8.2. The daily summary reports of this data will be sent to the site's leader via e-mail.

9.8.3. Computer data can also be accessed and downloaded remotely via PCAnywhere® software.

10. Data and Records Management

10.1. Basic information about data acquisition and control hardware and software, raw data inspection, and management of barn data is contained in SOPs B1, B2, B3 and B5, respectively.

10.2. Introduction to data submittal

10.2.1. Once field personnel have retrieved sampling information either manually (off the sampler's display as described in Sections 7 and 8 of the Partisol-FRM 2000 Operation Manual) or electronically, the sample run information must be forwarded to the site's Principal Investigator.

10.2.2. If the sampling information was recorded manually, a Filter Field Sample Report(s) will accompany the sampled filter(s) to the laboratory.

10.2.3. If the sampling information was recorded electronically, the sampling information will be sent to the lab via file transfer protocol and an abbreviated Filter sample record, and additional sampling information will accompany the sampled filter(s) on the Filter Field Sample Report(s).

10.3. When QC checks are performed, the date, results, and any pertinent comments should be recorded onto the Monthly Quality Control Maintenance Checksheet for the FRM $PM_{2.5}$ Filter Sampler (QC Checksheet) presented in Appendix C. It is recommended that a copy be made by the operator and kept at the field site for later reference by the operator or a site visitor.

11. Quality Control and Quality Assurance

11.1. Schedules for calibration, maintenance, and other QA/QC-related activities for field-deployed equipment are included in Appendix B.

11.2. Laboratory Quality Control and Quality Assurance Checks are listed in Appendix F.

11.3. Trip blanks and field blanks are included in Section 9.4.4.8.

11.4. The field and laboratory procedures training will be evaluated using forms included in Appendix G and Appendix H.

12. References

12.1. USEPA. 1997. Reference Method for the Determination of Fine Particulate Matter as $PM_{2.5}$ in the Atmosphere. U.S. Environmental Protection Agency. 40 CFR Part 50, Appendix L.

12.2. USEPA. 1998. Quality Assurance Guidance Document 2.12. Available at http://www.epa.gov/ttn/amtic/files/ambient/pm25/qa/m212covd.pdf . Accessed on January 23, 2006.

12.3. USEPA. 2001. Guidance for Preparing Standard Operating Procedures (SOPs). US Environmental Protection Agency. Publication QA.G-6, EPA Quality Assurance Division, Washington, DC. November. Document EPA/240/B-01/004. Available at http://www.epa.gov/quality/qs-docs/g6-final.pdf. Accessed on September 2006.

12.4. Partisol –FRM Manual. 2004. Partisol-FRM Model 2000 PM-2.5 Air Sampler Operating Manual, Rev. B.” (TEC Part No. 42-004298).

12.5. State of California, Air Resources Board, Monitoring and Laboratory Division. 1999. “Air Monitoring Quality assurance Volume II, Standard Operating Procedures for Air Quality Monitoring, Appendix AJ, TEC Partisol-FRM MODEL 2000 PM-2.5 AIR SAMPLER”. Online at http://www.arb.ca.gov/aqdas/aqsbdocs1/v2apxaj.pdf. Accessed December 21, 2005.

12.6. USEPA. 1998. Quality Assurance Guidance Document: Model Quality Assurance Project Plan for the $PM_{2.5}$ Ambient Air Monitoring Program at state and Local Air Monitoring Stations (SLAMS), Document EPA-454/R-98-005, April, 1998.

12.7. USEPA. 1998. Quality Assurance Guidance Document; Method Compendium; Field Standard Operating Procedures for the $PM_{2.5}$ Performance evaluation Program. Available at http://www.epa.gov/ttn/amtic/pmqa.html accessed on 8/22/06.

12.8. SOP A9. 2006. Measurement of Airflow Rate or Calibration of Air Sampling Instruments with Gilibrator 2 Calibration Systems. Standard Operating Procedure A9. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Suppliers Contact Information

Partisol instrument: Thermo electron Corporation, TEC:

Senior Customer Support Lead, Air Quality Instruments (TEC Products)
Environmental Instruments Division, Thermo Electron Corporation
Phone: 518-452-0065 Ext. 2258, Fax: 518-452-0067
http://www.thermo.com/com/cda/product/detail/0,1055,10122676,00.html

Appendix A. Measurement Quality Objectives for FRM $PM_{2.5}$

Requirement	Frequency	Acceptance Criteria
Filter Holding Times:	All sample filters	
Pre-sampling		<30 d after preweighing. Store in the freezer.
Post-sampling (in sampler)		<96 h from end of sampling
Post-sampling (during storage and transport)		<10 d at 25°C from end of sampling or <30 d at 4°C from end of sampling
Sampling Period:	All data	1380 to 4380 min (one to three days)
Sampler:	Every 24 hrs (or every sampling period) of operation	
Flow rate	24 hrs	Average ±5% of 16.67 L/min
Flow rate variability	24 hrs	≤2% CV 5-min averages variation over 24 hr ≤(5% of 16.67 L/min=0.834 L/min)
Filter temp sensor	24 hrs	No excursions of >5°C lasting longer than 30 min
Data Completeness	Quarterly	75%
Filter:	All filters	Visual defect check
Monthly QC Check:	Monthly	
Flow rate		±4% of audit standard (One point verification)
Leak check		<5 in of Hg pd in 1 min 80 mL/min
Ambient temp sensor		±2°C of standard
Ambient press sensor		±10 mm of Hg of standard
Clock/timer		±10 min of corrected clock time
Multipoint Calibration:	Semiannually or when failed monthly check following major repair, or after sampler transport	
Flow rate		±2% of transfer (xfer) standard
Leak check		<5 in of Hg pd in 1 minute
Temperature Sensor		±2°C of xfer standard
Pressure Sensor		±10 min of corrected clock time
Monthly QC Standards:	Annually	
Flow rate standards		±2% of full scale @ 20 L/min
Temperature Standard		±0.1°C resolution ±0.5°C accuracy
Pressure standard		±1 mm Hg resolution ±5 mm Hg accuracy
Calibration Xfer Standards:		
Flow rate xfer standard	FTS meter annually Mass flow meter quarterly	±2% of NIST-traceable standard
Temperature xfer standard	Annually	±0.1°C resolution ±0.5°C accuracy
Pressure xfer standard	Annually	±1 mm Hg resolution ±5 mm Hg accuracy

Appendix B. Quality Control Maintenance and Calibration Schedule for Federal Reference Method $PM_{2.5}$ Sampling Using the TEC Partisol-FRM Model 2000

	*Daily	Every 5 Samples	Every Month	Every 14 Samples	Every 6 Months	Every 12 Months
Record and review run data summary	X					
Clean/inspect cassette & rubber seals	X					
Inspect or drain inlet water jar	X					
Service WINS impactor well		X				
Perform a leak test		X	X			
Clean interior of sampler			X			
Clean air intake filter and fan			X			
Inspect O-rings, gaskets and seals			X			
Verify sampler clock time			X			
Perform single-point flow check			X			
Check ambient temperature and pressure sensors			X			
Run field and trip blanks			X			
Transport samples with a temp-logger			X			
Disassemble and clean PM_{10} inlet, downtube and entire WINS				X		
Perform as-is three-point calibration/verification of flow rate, pressure and temperature sensors					X	
Verify as-is condition of sampler interior, inlet, WINS impactor & leak test					X	
Replace large in-line filter					X	
Check battery on main computer board					X	
Perform multi-point calibration of flow rate, pressure & temperature sensors					X	
Measure temp of station freezer	X					
Calibrate or re-certify flow rate, pressure and temperature QC check standards						X

*or each time sample cassettes are exchanged

Appendix C. Monthly Quality Control Maintenance Check Sheet TEC Partisol – FRM Model 2000 PM$_{2.5}$ Air Sampler Single Channel

Site Name ____MM/DD/YYYY___________________________________
Site Number ____Technician____
Sampler I.D. Number____

Operator Instructions:
Each Run: Record and review sample run date; inspect/clean water jar, cassette & rubber seals.
Run Dates:__________________ ___________________ ___________________ __________________ _________________

Every 5 Runs: Clean or change out WINS impactor well.
Dates WINS Serviced: ______________ _________________ ______________ _____________ _____________

Monthly: Clean interior of sampler, air intake filter and fan. Date Performed:____
Inspect o-rings, gaskets, seals; check sampler clock time (<±10 min):____________________
Perform single-point QC check of flow rate, ambient temperature and pressure. * (annotate below)
Run field and trip blanks, and temp-logger with samples during transport. Date:
Perform leak check –Date/Results: _____________/_____________/_____________/_____________/_____________
(<80mL/min for 1 min.: which is equal to <5” Hg change/min.)

Every 14 Runs: Disassemble and clean PM$_{10}$ Inlet, downtube and entire WINS. A leak test must be performed every time the WINS impactor is changed out or cleaned.

Semiannually: Perform multi-point calibration of flow rate, and single point calibration of temperature and pressure sensors.
Date Last Calibrated: ____
Perform Leak Test, Inspect sampler’s inlet, WINS, and interior conditions.
Replace large in-line filter. Date Last Performed:
Check Voltage Level on Main Computer Board Battery. Date Last Performed: ________________________

Annually: Re-certify QC check standards – Certification Date:_________________ __________________ _________________
(flow std) (temp std) (press std)

*Monthly Sampler Flow Rate, Ambient Temp and Pressure Check Results:

	Flow Rate Standard	Temperature Standard	Pressure Standard
Standard Name/Type:			
Identification Number:			
Correction Factor:			
Std’s Indicated Readings:			
Std’s Corrected Readings:			
Sampler’s Reading:			
Percent Difference:			
Acceptance Criteria:	15.84 to 17.50 L/min	<±2° C of standard	<±10 mm Hg of std

OperatorComments:____
____
____

Reviewed by:____ Date:__________________

Appendix D. Filter Field Sample Report and Chain-of-Custody Form for the TEC FRM Partisol-FRM Model 2000 $PM_{2.5}$ Sampler

Sample ID:____________________ ☐ Check if data electronically submitted to Laboratory
Site Name: ____________________ Cassette I. D. Number:____________
Site Number:____________________ Scheduled Sampling Date: __________
Field Technician: ____________________ Sampler Property #: ____________

SAMPLE SUMMARY

Start Date / Time: ________ / ______
Total Elapsed Time: __________Hr:min
Volume: ________________(m^3)
Flow CV ________________(%)

	MIN	AVG	MAX
Ambient Temp(C):			
Filter Temp (C):			
Pressure (mmHg):			
Flow (L/min):			

Local Condition Codes: ______________ Sampler Flag Codes:______________

A. No Unusual Conditions	E. Fire Nearby
B. Wind/Blown Sand/Dust	F. Sampler Malfunction
C. Construction Nearby	G. Rain
D. Farming Operation Nearby	H. Other (See Comments)

OK Good	T. Filter Temp
F. Flow Rate	I. Inst. Elec. Temp
X. Flow Cutoff	V. Power Outage
S. Ambient Temp.	E. Elapsed Sample Time
P. Ambient Pressure	C. Percent CV

Operator Comments: ______________________________

CHAIN OF CUSTODY

ACTION	DATE MM/DD/YYYY	TIME HH:mm	FILTER TEMP. (C)	NAME
Filter shipped to site				
Filter received at site				
Sample load				
Sample removal				
Sample placed in cooler				
Sample shipped **to** Lab				
Sample received **at** Lab				
Start post-conditioning				

FOR LABORATORY USE ONLY
Postweight by:

	Mass:	Dup Mass:	Date:	Analyst:
Preweight				
Postweight				

LabComments:______________________________

Appendix E. TEC $PM_{2.5}$ FRM Partisol-FRM Single Channel Sampler Calibration Datasheet

Site Name ______________Site Number__________________ Sampler Property Number_________________
Site Elevation ___________Ambient Temperature__________ Ambient Pressure________________________
Cassette I.D._________________________

Temperature Sensor Calibration

Temperature Standard ID Number ___________________________Certification Date__________________________
Ambient Temperature Sensor: Ambient Reading_________ Span ____________Offset___________
Filter Temperature Sensor: Ambient Reading _________Span ____________Offset___________

Pressure Sensor Calibration

Pressure Standard ID Number ________________________________Certification Date________________________
Standard Slope __________________ Standard Intercept____________________
Barometric Pressure ________________ Span ______________Offset__________________

Leak Test

External Leak Flow______________________ Time____________________
Internal Leak Flow_______________________ Time____________________

Flow Calibration

MFM Standard ID Number____________________ Certification Date_____________________
Standard Slope _____________________________Standard Intercept____________________

Nominal Flow	Sampler Flow	Standard Flow	Temperature
16.7	__________	___________	___________
17.5	__________	___________	___________
15.8	__________	___________	___________
18.3	__________	___________	___________
15.0	__________	___________	___________

Sampler Span________________________________ Offset____________________________________
Calibrated by_________________________________ Checked by________________________________

Temperature Calibration Verification

Temperature Standard ID Number__________________ Certification Date________________________
Ambient Temperature Sensor: Ambient Reading__________ Span__________ Offset__________
Filter Temperature Sensor: Ambient Reading__________ Span__________ Offset__________

Pressure Verification

Sampler Pressure ____________________________Pressure Standard____________________________

Flow Verification

Sampler Flow________________ MFM Standard Flow: Qstd____________________ Qact_____________________
Percent Difference___________________________

Time Verification

Time Standard Make__________ Model_______________ Certification Date________________ Bias____________
Sampler Time________________ Time Standard____________________ Time difference______________________

Final Time Set

Sampler Time________________ Time Standard _______________________Time Difference__________________
Calibrated by ___________________________________Checked by_______________________________________

Appendix F. Lab Quality Control Maintenance Schedule for Federal Reference Method $PM_{2.5}$ Sampling Using the TEC Partisol-FRM Model 2000

Requirement	**Frequency**	**Acceptance Criteria**	**CFR, 2.12 reference†**	**Information provided**
Blanks				
Lab blanks	Approximately 10% per weighing run	±15 µg difference	Part 50, App. L, Sec. 8.2 2.12, Sec. 7.7	Laboratory contamination
Calibration Verification				
Balance calibration	1/yr	Manufacturer's spec.	2.12, Sec. 7.2	Verification of equipment operation
Lab temp. calibration	3 mo	±2 °C	Quality assurance project plan (QAPP), Sec. 13/16	Verification of equipment operation
Lab humidity calibration	3 mo	±2%	QAPP, Sec. 13/16	Verification of equipment operation
Accuracy				
Balance audit	1/yr	±15 µg for unexposed filters	2.12, Sec. 10.2	Laboratory technician operation
Balance check	Beginning, every 10th sample, end	<3 µg	2.12, Sec. 7.14	Balance accuracy/stability
Calibration standards				
Working mass standards	3-6 mo	25 µg	2.12, Sec. 4.3 and 7.3	Standard verification
Primary mass standards	1/yr	25 µg	"	Primary standards verification
Temperature standard	1/yr	±0.1 °C resolution	2.12, Sec. 4.3.7 and 7.6	Standards verification
		±0.5 °C accuracy		(check of accuracy)
Relative Humidity std	1/yr	±2% RH accuracy,	2.12, Sec.4.3.7 and 7.6	Standard verification
		±0.5%RH resolution		
Precision				
Replicate filter weighing	1 per weighing session	±15 µg difference	2.12,	Weighing repeatability/filter stability
Primary flow meter calibration	1/yr	±2% of NIST-traceable Std.	Part 50, App. L, Sec.9.1 & 9.2	Standard verification

† 2.12 refers to the EPA's Quality Assurance Guidance Document 2.12, Monitoring $PM_{2.5}$ in Ambient Air Using Designated Reference or Class I Equivalent Methods. November 1998.

Appendix G. Training Certification Evaluation Form. Field Sampling Procedures.

Training Certification Evaluation Form
Field Sampling Procedures

Trainee: ____________________________ Date _________________

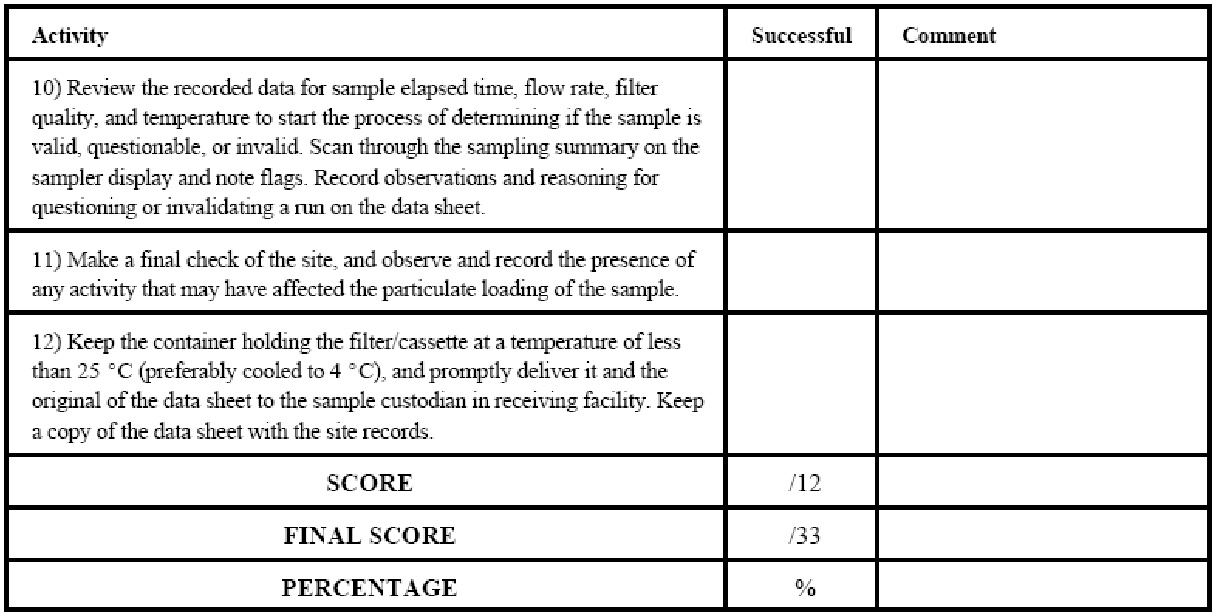
Evaluator: _________________________ Score: _________________

Activity	Successful	Comment
Prepare for Site Visit on Scheduled Date/time		
1) Preweighed sampling filter in cassette, packed in a labeled carrier. Also take spares.		
2) Three preweighed field blank filters in cassettes, packed in labeled carriers, if a field blank study is scheduled		
3) $PM_{2.5}$ Sampler Run Data Sheet for each sampler, site notebook; calculator		
4) Transfer standard for ambient temperature measurements		
5) Transfer standard for ambient atmospheric pressure measurements		
6) Transfer standard for volumetric flow-rate measurements		
7) Laptop computer and connecting cables to download sampler data		
8) Spare parts and tools to include O-rings, silicone grease, lab wipes, voltmeter, etc.		
9) Operator's manual for sampler(s) to be serviced		
SCORE	/9	
Fifth Day Maintenance Check		
1) Clean impactor well assembly or filter/lab wipes/diffusion oil to clean and service the one at the site		
2) Sample inlet adapter and flow rate measurement transfer standard		
3) Clean, unused flow check filter in its cassette		
4) Sampler Flow Check Data Sheet		
SCORE	/4	
Install Filter/Cassette and Begin Sampler Operations		
1) Remove the new filter/cassette from its protective case and visually inspect the filter/cassette for flaws. Verify that this is the correct filter for this sampler, site, and run date		
2) Be sure sampler is **not** operating.		
3) Fill in initial information on $PM_{2.5}$ Run Data Sheet.		

Appendix G Training Certification Evaluation Form. Field Sampling Procedures. (Cont.)

Activity	Successful	Comment
4) Remove the sampler's filter holder assembly (if required by the manufacturer's instructions). Inspect the O-rings inside the filter holder.		
5) Install the filter/cassette in the filter holder assembly, and then install the loaded filter holder assembly in the sampler per the manufacturer's instructions. If you touch or scratch the filter, void the filter and get another one from the set of extra filters brought to the site.		
6) Program the sampler to energize at the beginning of a sampling period (consult the instruction manual).		
7) Make independent measurements of ambient temperature (T_a) and ambient pressure (P_a) using transfer standards. Record these values and the T_a and P_a values indicated by the sampler on the data sheet		
8) Ensure that the sampler(s) begins operation at the designated time. Record the start time on the data sheet. 15 minutes after sampling begins, record the sampler's display value for the indicated flow rate, Q, in L/min on the data sheet.		
SCORE	/8	
Remove Filter/Cassette; End Sampling Operations		
1) Determine P_a and T_a using transfer standards. Enter on data sheet.		
2) When sampling ends, record stop time, total elapsed time, final Q, Q_{avg}, Q_{cv}, total volume sampled, T_a, P_a, etc, on data sheet		
3) After each completed run, download data from the sampler data port to a laptop or other computer storage disk.		
4) Open the filter holder assembly (consult the instruction manual); remove the used filter/cassette; visually inspect the filter for tears, oil, insects, moisture, etc; and record observations on the data sheet.		
5) Place the filter/cassette inside a properly labeled protective container. Verify the container's label versus the site name, date, etc.		
6) Place the container inside a cooled storage chest. Do not allow the metal container to come into contact with ice or water. Sealed cooling blocks are recommended. Protect the containers from condensed water.		
7) Inspect the interior of the filter housing. Note any abnormalities.		
8) Inspect the interior of the impactor housing and the exterior of the impactor well. Remove any moisture or dust with a lint-free wipe and make notes on the data sheet.		
9) Without opening the impactor well, inspect the well's interior. Note any abnormalities. Clean or replace the impactor well if necessary or if the recommended 5-day servicing is due. Reinstall the impactor assembly. (If another sampling run is to begin, insert a new filter/cassette in the filter holder assembly and set up the sampler for the next run.)		

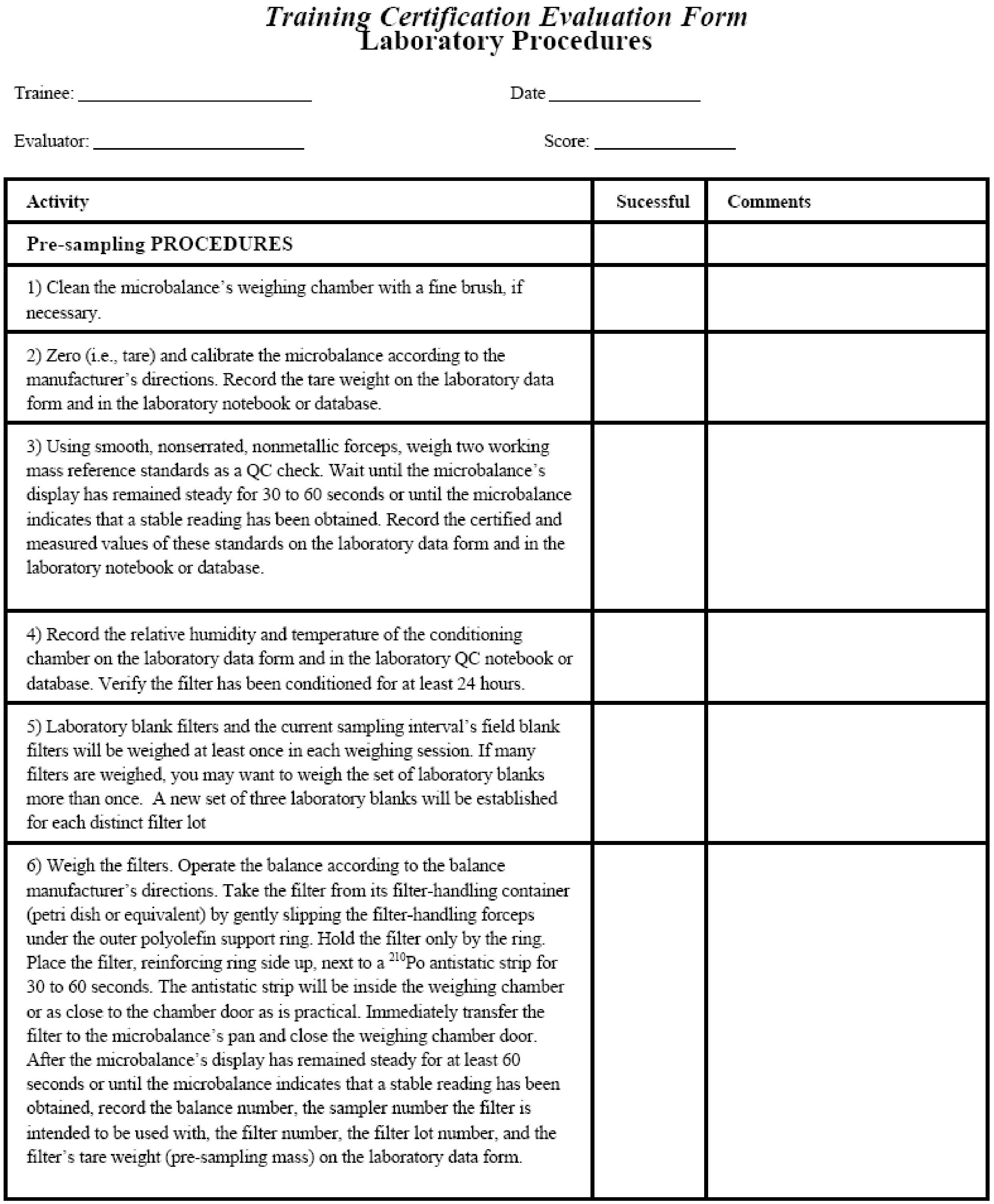
Appendix G Training Certification Evaluation Form. Field Sampling Procedures. (Cont.)



Activity	**Successful**	**Comment**
10) Review the recorded data for sample elapsed time, flow rate, filter quality, and temperature to start the process of determining if the sample is valid, questionable, or invalid. Scan through the sampling summary on the sampler display and note flags. Record observations and reasoning for questioning or invalidating a run on the data sheet.		
11) Make a final check of the site, and observe and record the presence of any activity that may have affected the particulate loading of the sample.		
12) Keep the container holding the filter/cassette at a temperature of less than 25 °C (preferably cooled to 4 °C), and promptly deliver it and the original of the data sheet to the sample custodian in receiving facility. Keep a copy of the data sheet with the site records.		
SCORE	/12	
FINAL SCORE	/33	
PERCENTAGE	%	

Training Certification Evaluation Form source: Quality Assurance Guidance Document: Model Quality Assurance Project Plan for the $PM_{2.5}$ Ambient Air Monitoring Program at state and Local Air Monitoring Stations (SLAMS), Document EPA-454/R-98-005, April, 1998.

Appendix H Training Certification Evaluation Form. Laboratory Procedures.



Training Certification Evaluation Form
Laboratory Procedures

Trainee: ________________________ Date ______________

Evaluator: ______________________ Score: _____________

Activity	Sucessful	Comments
Pre-sampling PROCEDURES		
1) Clean the microbalance's weighing chamber with a fine brush, if necessary.		
2) Zero (i.e., tare) and calibrate the microbalance according to the manufacturer's directions. Record the tare weight on the laboratory data form and in the laboratory notebook or database.		
3) Using smooth, nonserrated, nonmetallic forceps, weigh two working mass reference standards as a QC check. Wait until the microbalance's display has remained steady for 30 to 60 seconds or until the microbalance indicates that a stable reading has been obtained. Record the certified and measured values of these standards on the laboratory data form and in the laboratory notebook or database.		
4) Record the relative humidity and temperature of the conditioning chamber on the laboratory data form and in the laboratory QC notebook or database. Verify the filter has been conditioned for at least 24 hours.		
5) Laboratory blank filters and the current sampling interval's field blank filters will be weighed at least once in each weighing session. If many filters are weighed, you may want to weigh the set of laboratory blanks more than once. A new set of three laboratory blanks will be established for each distinct filter lot		
6) Weigh the filters. Operate the balance according to the balance manufacturer's directions. Take the filter from its filter-handling container (petri dish or equivalent) by gently slipping the filter-handling forceps under the outer polyolefin support ring. Hold the filter only by the ring. Place the filter, reinforcing ring side up, next to a ^{210}Po antistatic strip for 30 to 60 seconds. The antistatic strip will be inside the weighing chamber or as close to the chamber door as is practical. Immediately transfer the filter to the microbalance's pan and close the weighing chamber door. After the microbalance's display has remained steady for at least 60 seconds or until the microbalance indicates that a stable reading has been obtained, record the balance number, the sampler number the filter is intended to be used with, the filter number, the filter lot number, and the filter's tare weight (pre-sampling mass) on the laboratory data form.		

Appendix H Training Certification Evaluation Form. Laboratory Procedures (Cont.)

Activity	Sucessful	Comments
7) After every tenth filter weighing, the analyst will rezero the microbalance and reweigh one working standard. Record the zero and working standard measurements on the laboratory data form and the laboratory QC notebook or database. If the zero and working standard measurements disagree from the first measurements of the day by more than 3 μg (i.e., three times the microbalance's reproducibility), repeat the zeroing process and reweigh the working standards. If the two measurements still disagree, contact the laboratory's QA Officer, who may direct the analyst to (1) reweigh the previously weighed filters and/or (2) troubleshoot or repair the microbalance, re-zero and reweigh the two working standards and repeat the weighing session.		
8) Any unused filter whose weight is outside the normal range (i.e., 110 to 160 mg) must be investigated. If there is a consistent negative replication (>15 μg) for laboratory blank filters, it is usually a sign that the filters have not equilibrated long enough. In this case, notify the QA Officer.		
9) Return the filter to the filter-handling container, replace the lid, and return it to storage.		
10) Prior to filters beinge taken to the sites, install each filter in a filter cassette, and put the filter/cassette assembly into a protective container for transport to the sampler. Attach a label with the sampler number and the unique filter number to the outside of the protective container. This label will also be used to identify the upcoming sample run date. Record the sampler number, sample date, and filter number on the $PM_{2.5}$ Sampler Run Data Sheet. Double-check the entries in the laboratory data form. Prepare several extra filters in case a filter is invalidated during the installation process.		
SCORE	/10	
Post-sampling DOCUMENTATION/INSPECTION PROCEDURES		
1) Examine the field data sheet. Determine whether all data needed to verify sample validity and to calculate mass concentration (e.g., average flow rate, ambient temperature and barometric pressure, and elapsed time) are provided. If data are missing or unobtainable from a field operator or if a sampler malfunction is evident, flag the filter and record in the laboratory data form that the sample has been flagged and the reason. Notify the QA Officer		

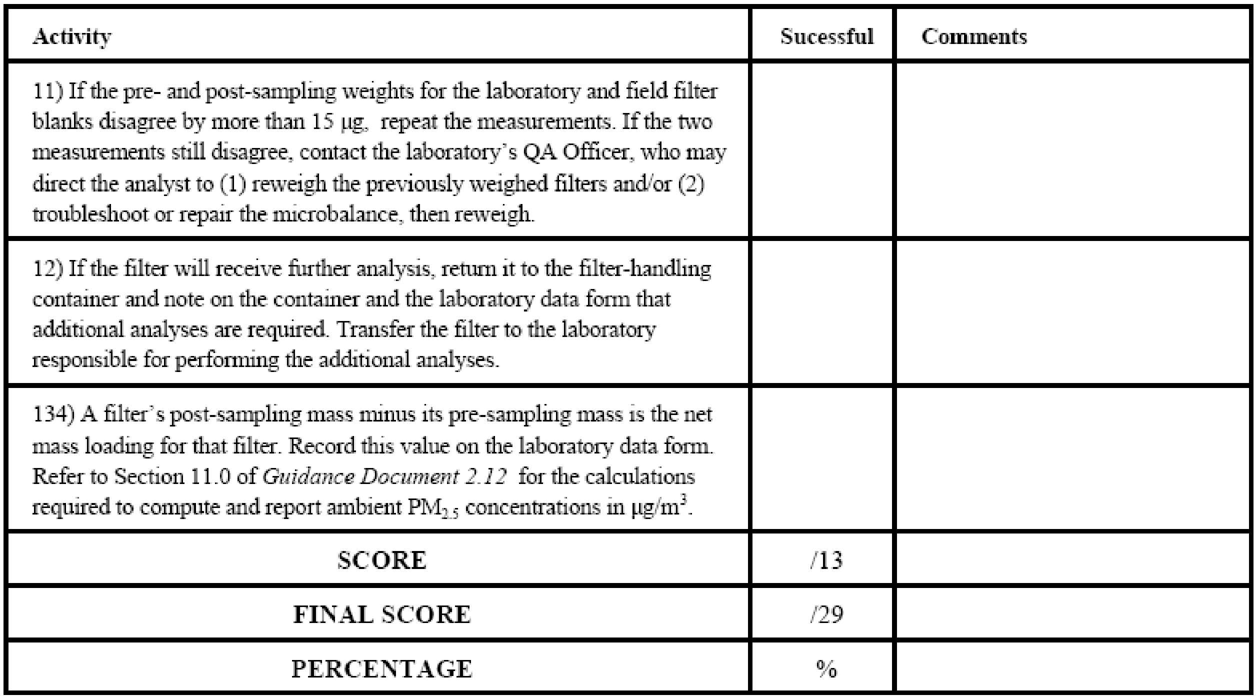
Appendix H Training Certification Evaluation Form. Laboratory Procedures (Cont.)

Activity	Sucessful	Comments
2) If the shipment was to be kept cold, verify that the temperature of the cooler's interior was maintained at the desired point, usually less than 4 °C. If the protective container is cold, allow it to warm to the filter conditioning environment's temperature before opening, to preclude water condensation on a cold filter. Remove the filter from its protective container and examine the container. If particulate matter or debris is found in the protective container after the filter has been removed, flag the filter and record notes on the laboratory data form that the sample has been flagged and the reason. Save the filter for inspection by the QA Officer.		
3) Match the sampler number with the correct laboratory data form on which the original microbalance number, filter number, pre-sampling filter weight, and other information were inscribed. Group filters according to the microbalance used to determine their initial tare weights. Initial separation of filters in this way will eliminate the risk of a measurement error that could result from the use of different microbalances for pre- and post-sampling weighings.		
4) Remove the filter from both the protective container and the filter cassette. Be careful not to touch or otherwise disturb the filter and its contents. Transfer the filter to a filter-handling container labeled with the corresponding filter number. Place the used filter in the container "dirty-side" up. Keep the particles from contact with the walls of the container. The filter must be handled with clean, smooth forceps and must not be touched by hands. Inspect the filter for any damage that may have occurred during sampling. If any damage is found, void the sample, and record on the laboratory data form that the sample has been voided and why. Retain the filter for inspection by the QA Officer.		
5) Transfer the filter in its filter-handling container to the conditioning chamber under the same conditions as pre-sampling (± 5% RH)		
6) Allow the filter to condition for not less than 24 hours		
SCORE	/6	
POST SAMPLING FILTER WEIGHING		
1) Group filters according to the microbalance used for pre-weighing and by their filter numbers. Reweigh each filter on the same microbalance on which its pre-sampling weight was obtained.		
2) Clean the microbalance's weighing chamber with a fine brush, if necessary.		
3) Zero (i.e., tare) and calibrate the microbalance according to the manufacturer's directions. Record the tare weight on the laboratory data form and in the laboratory notebook or database.		

Appendix H Training Certification Evaluation Form. Laboratory Procedures (Cont.)

Activity	Sucessful	Comments
4) Using smooth, nonserrated, nonmetallic forceps, weigh two working mass reference standards as a QC check. Wait until the microbalance's display has remained steady for 30 to 60 seconds or until the microbalance indicates that a stable reading has been obtained. Record the certified and measured values of these standards on the laboratory data form and in the laboratory notebook or database.		
5) Record the relative humidity and temperature of the conditioning chamber on the laboratory data form and in the laboratory QC notebook or database.		
6) Laboratory blank filters and the current sampling interval's field blank filters will be weighed at least once in each weighing session. If many filters are weighed, you may want to weigh the set of laboratory blanks more than once. A new set of three laboratory blanks will be established for each distinct filter lot		
7) Weigh the filters. Operate the balance according to the balance manufacturer's directions. Take the filter from its filter-handling container (petri dish or equivalent) by gently slipping the filter-handling forceps under the outer polyolefin support ring. Hold the filter only by the ring. Place the filter, reinforcing ring side up, on a ^{210}Po antistatic strip for 30 to 60 seconds. The antistatic strip will be inside the weighing chamber or as close to the chamber door as is practical. Immediately transfer the filter to the microbalance's pan and close the weighing chamber door. After the microbalance's display has remained steady for at least 60 seconds or until the microbalance indicates that a stable reading has been obtained, record the balance number, the sampler number the filter is intended to be used with, the filter number, the filter lot number, and the filter's tare weight (pre-sampling mass) on the laboratory data form.		
8) After every tenth filter weighing, the analyst will rezero the microbalance and reweigh the one working standard. Record the zero and working standard measurements on the laboratory data form and the laboratory QC notebook or database. If the zero and working standard measurements disagree from the first measurements of the day by more than 3 μg, repeat the zeroing process and reweigh the working standards. If the two measurements still disagree, contact the laboratory's QA Officer, who may direct the analyst to (1) reweigh the previously weighed filters and/or (2) troubleshoot or repair the microbalance, re-zero and reweigh the two working standards and repeat the weighing session.		
9) Any unused filter whose weight is outside the normal range (i.e., 110 to 160 mg) must be investigated. If there is a consistent negative replication (>15 μg) for laboratory blank filters, it is usually a sign that the filters have not equilibrated long enough. In this case, notify the QA Officer.		
10) Return the filter to the filter-handling container, replace the lid, and return it to storage.		

Appendix H Training Certification Evaluation Form. Laboratory Procedures (Cont.)



Activity	Sucessful	Comments
11) If the pre- and post-sampling weights for the laboratory and field filter blanks disagree by more than 15 µg, repeat the measurements. If the two measurements still disagree, contact the laboratory's QA Officer, who may direct the analyst to (1) reweigh the previously weighed filters and/or (2) troubleshoot or repair the microbalance, then reweigh.		
12) If the filter will receive further analysis, return it to the filter-handling container and note on the container and the laboratory data form that additional analyses are required. Transfer the filter to the laboratory responsible for performing the additional analyses.		
134) A filter's post-sampling mass minus its pre-sampling mass is the net mass loading for that filter. Record this value on the laboratory data form. Refer to Section 11.0 of *Guidance Document 2.12* for the calculations required to compute and report ambient $PM_{2.5}$ concentrations in µg/m^3.		
SCORE	/13	
FINAL SCORE	/29	
PERCENTAGE	%	

Training evaluation forms source: Quality Assurance Guidance Document: Model Quality Assurance Project Plan for the $PM_{2.5}$ Ambient Air Monitoring Program at state and Local Air Monitoring Stations (SLAMS), Document EPA-454/R-98-005, April, 1998.

CONTINUOUS MEASUREMENT OF PM_{10} PARTICULATE MATTER USING THE THERMO ELECTRON SERIES FH 62C14 (BETA) SAMPLER

Standard Operating Procedure (SOP) P4

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Standard Operating Procedure (SOP) P4

Prepared by
Juan Carlos Ramirez

Reviewed by
Ji-Qin Ni, Bill W. Bogan, and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

Thermo C-14 Beta Sampler Calibration Form

For Samplers Using Firmware V2.049

Site: ________________ Monitor S/N: ___________________ Date: _________________

Temperature Sensor Calibration

Article I. Allow unit to run, calibrate sensors at normal system operating temperatures.
Article II. Calibrtion Menu – unlock code 147
Article III. Sensors submenu – go through each item in turn and adjust as needed. Log the final results after adjustment.

T_1 ambient sensor _______ Reference Ambient Temp ______ Criteria: ± 6 °C

T_2 upper head sens. _______ Reference upper head ______

T_3 lower head sens._______ Reference lower head ______

T_4 heated tube sens._______ Reference heated tube ______

Pressure Sensor Calibration

P_3 ambient ___________ Ref. Barometer ___________ Criteria: ± 10 mmHg

Note: hPa = mm.Hg * 1.33 , mm.Hg = hPa * .75218 (@20^o C)

Flow Rate Calibration

Flow Device Type ________________________ S/N __________________

Sampler Flow _____________ Actual Flow ___________ Criteria: ± 2%

Note: L/m = L/hr / 60

High Voltage Automatic Set Process

2. Service Menu – unlock keypad - Mechanical Control – turn pump off
3. Perform Filter Change & Zero (FC+Z)
4. Watch for QLF figure to have "*" next to it
5. Calibrtion Menu – unlock code 147 – High Voltage & Thresholds – Start – allow 5 minutes until stable, log readings in chart provided here
6. Back up on screens and Save to EEPROM
7. Service Menu – Mech. Ctrl – pump on, zero tape, back up & lock keypad, exit menu.

New HV	S_{ref}	**Plateau Slope**

Mass Foil Calibration

1) Operations Menu – unlock keypad if locked – Temp Ctrl System screen – set heater control to Off
2) Let sampler run and wait for $T_2 = T_1$ although being within 2^0C seems to be sufficient
3) Service Menu – Mechanical Control screen – turn pump off.
4) Calibration Menu – Foil Calibration – follow screen prompts step by step
5) Note the Amp Values and log them in the chart to the right
6) Remove span foil and holder per prompt
7) Back up and Save to EEPROM
8) Operations Menu, Temp Ctrl – set heater control to On.
9) Service Menu, Mechanical Control – ensure that pump is On
10) Lock keypad

Foil Span Value $_u$g *	**Old Amp Value**	**New Amp Value**	**Bias % of FS**

** For reference only – from the span foil in the calibration kit used for this test.*

Values Archived to EEPROM? __________

Comments:

Operator:____ Date:_________________

QA Coordinator:______________________________________ Date:_________________

1. Scope and Applicability

1.1. The Thermo Electron Corporation (TEC) Series FH62C14 (Beta) Continuous Ambient Particulate Monitor (hereafter referred as C14 Beta) will be used for continuous monitoring of the particulate matter (PM_{10}) concentrations in ambient air outside of confined animal houses or barns. Specifically, the location of the instrument is on top of the on-farm instrument shelter (OFIS).

1.2. The C14 Beta instrument is designated by USEPA as an equivalent method (EPA Designation No. EQPM-1102-150) for PM_{10} (particles ≤ 10 µm in diameter).

1.2.1. The instrument can be configured to measure $PM_{2.5}$ and TSP (Total suspended particulates) as well, but this SOP does not address these applications.

1.3. The measurement range of the C14 Beta monitor is 0 to 5,000 $\mu g/m^3$ (default) and 0 to 10,000 $\mu g/m^3$, with a minimum detection limit of 1 $\mu g/m^3$ (24-h average) and 9 $\mu g/m^3$ (measured values). Maximum particulate load on the filter is typically 1,500 µg.

1.4. Use of the C14 Beta monitor is appropriate for air temperatures in the range of -20 to 40°C.

2. Summary of Method

The C14 Beta monitor (Fig. 1) works by drawing ambient air, including suspended particles, through the PM_{10} inlet head at a flow rate that is adjusted to 16.7 L/min (1 m^3/hr). The inlet head consists of a series of impaction plates, which segregate the suspended particulate matter by size. Air is deflected downwards into the acceleration jet of the impact unit. Because of their greater momentum, particles larger than the 10-µm cutoff impact out and are retained in the middle plenum impaction chamber. The particle fraction smaller than 10 µm is carried upward by the air flow, and down the vent tubes to the C14 Beta gauge sampler, where the PM_{10} particles are deposited on a glass fiber filter tape (Fig. 2). Low-level beta radiation is emitted from the Carbon-14 radioactive source, and passes through the filter tape and deposited particles. The increase of particles collected on the tape causes a lower beta-ray measurement in the measuring chamber (Fig. 2). This filter-spot position results in a continuous observation of the increasing particulate mass, which can be converted to continuous particulate concentration data. A compensation chamber receives an equal portion of the emitted beta rays, and includes a foil with the same absorptivity as clean filter tape. This, therefore, provides a reference point for comparison with the tape that includes accumulated sample. Because of this, the instrument is less sensitive to temperature, pressure, and humidity fluctuations than some other types of continuous PM monitors. By measuring the accumulated mass of particles on the tape and the volumetric flow rate of air through the instrument, the onboard computer can calculate the PM_{10} mass concentration in the air. Output from the C14 Beta monitor is sent to the data acquisition system located in the OFIS.

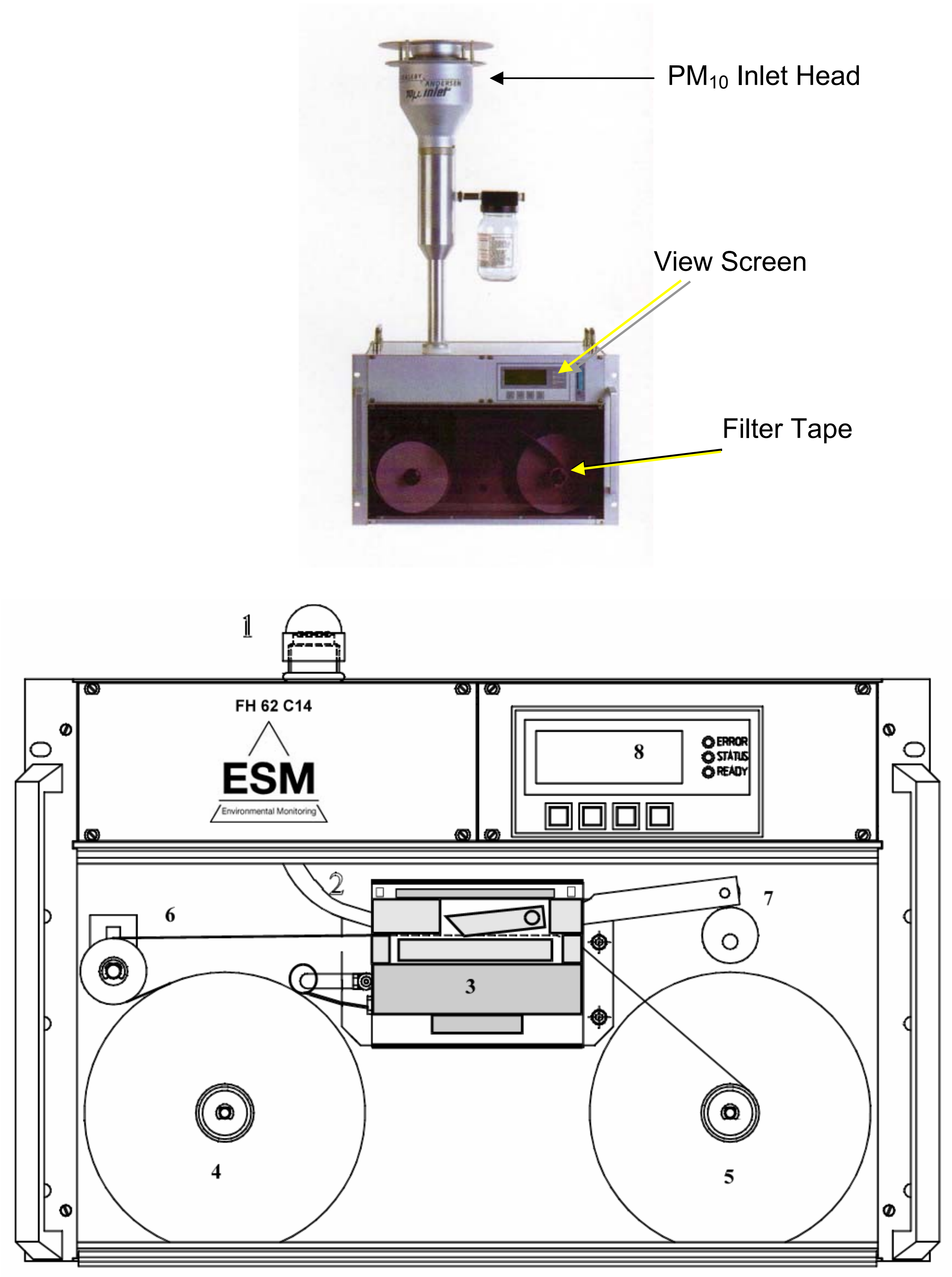


Figure 1. Thermo Electron Corporation C14 Beta Gauge (Pacwill Environmental, 2003 (photo), and Thermo Electron Corp. instrument manual (diagram)).

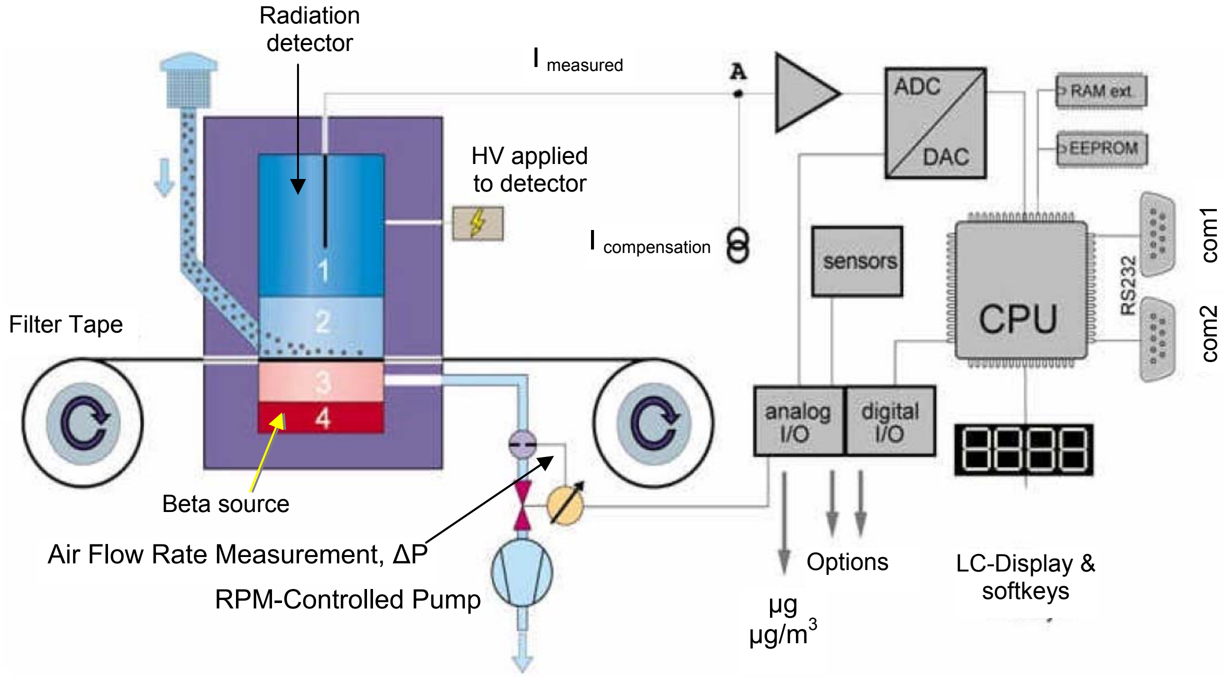


Figure 2. Thermo Electron Series FH62C14 (Beta) PM_{10} sampler schematic (Thermo Andersen, 2002).

3. Definitions & Acronyms

3.1.	AC	Alternating Current
3.2.	Beta radiation	A stream of beta particles (which can be either electrons or positrons, depending on the specific emitter) emitted at close to light speed by radioactive decay
3.3.	atm	atmosphere, 746 mBar
3.4.	CFR	Code of Federal Regulations
3.5.	C14	Carbon-14, a low level radioactive source of beta radiation.
3.6.	DAQ	Data acquisition
3.7.	FTS	Flow Transfer Standard
3.8.	HPa	Hecto Pascals (Pa*10^2)
3.9.	HV	High voltage
3.10.	IM	Instruction manual
3.11.	I/O	Input-output
3.12.	LR	Linear regression
3.13.	OFIS	On-farm instrument shelter
3.14.	Pa	Pascal
3.15.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.16.	PM	Particulate matter

3.17.	PM_{10}	PM of ≤ 10 μm diameter
3.18.	QAPP	Quality Assurance Project Plan
3.19.	RC	Digital filter time constant for mass signal (IM Section 3.4.1)
3.20.	STDEV	Standard deviation
3.21.	SOP	Standard Operating Procedure
3.22.	TEC	Thermo Electron Corporation

4. Health and Safety

4.1. Instrument repair should only be carried out by trained personnel, and in accordance with procedures detailed in the IM.

4.2. Switch off the power supply of the instrument and unplug the power cable before opening the instrument and removing the detector.

4.3. Use protective eyewear when opening the detection chamber for maintenance.

4.4. Carbon-14 Source: Only trained personnel with radiological authorization (e.g., the TEC service division) may work on the source (e.g., cleaning the measurement chambers). The source has been secured with tamper-proof hardware and may not be disassembled without authorization.

5. Cautions

5.1. Do not block the sample tube or inlet of the instrument. The instrument has very sensitive internal foils. These foils and the detector window can be damaged if the air inlet is blocked when the pump is running.

5.2. Be extremely careful when handling the calibration mass foil set. Contact Thermo Electron Corporation for cleaning instructions. Do not wipe the foil window. Do not touch the foil window with your fingers. See Section 9.4.2 for more details.

5.3. Power interruption can cause the instrument's display negative mass and concentration values as the instrument comes back on. To prevent this from occurring as the result of power interruption the following should be done.

5.3.1. Set switch 34 on the back of the instrument (Fig. 2 of the IM, page 13) to "HV buffer". This will maintain a voltage across the detector during any power outage, and minimize measurement loss.

5.3.2. Use an uninterruptible power supply with battery backup (SOP U6) to prevent damage and data loss in case of power failure.

5.3.3. Furthermore, a lightning arrestor will protect the entire on-farm instrument shelter (SOP U1) and secondary surge suppressors will protect the PC and the instruments from electrical surges.

5.4. If the heated sampling tube is being used, allow the instrument to equilibrate to room temperature (~ 1 h) before beginning the calibration procedure.

5.5. Store and transport the instrument at a temperature in the range -30° to 60°C.

5.6. Operate the instrument at a temperature in the range of -20° to 40°C.

5.7. Prevent condensation of water in and around the instrument. Avoid situations where the internal temperature is below the dew point of the incoming air. If the instrument is located inside a conditioned room and the PM_{10} head is outside, install the sampling tube heater that is available from the instrument manufacturer.

5.8. Protect the instrument from precipitation and abrupt changes in temperature.

5.9. Some internal components can be damaged by the discharge of static electricity. To avoid damaging internal components, follow these precautions when performing any service procedure:

  5.9.1. Wear an antistatic wrist strap that is properly connected to earth ground (note that when the analyzer is unplugged, the chassis is not grounded).

  5.9.2. If an antistatic wrist strap is not available, be sure to touch a grounded metal object before touching any internal components.

  5.9.3. Handle all printed circuit boards by the edges.

  5.9.4. Carefully observe any other instructions for each procedure in the IM.

5.10. Do not dismantle, remove or tamper with the C14 radioactive source. It will never be necessary for field personnel to adjust, replace or touch the C14 source. All C14 issues will be handled by the manufacturer.

  5.10.1. Maintenance work on the source (e.g. cleaning the measuring section) may only be carried out by an individual trained by Thermo Electron Corporation with suitable authorization.

6. Interferences

6.1. Water may collect on the filter tape in humid or rainy climates, causing artificially high mass readings. In hot, humid environments where the instrument is housed in an air-conditioned shelter, heat the inlet tube within the shelter to avoid condensation. In rainy climates, use the instrument's inlet tube heater to ensure that any water drawn into the unit is in the vapor phase as it passes through the filter.

  6.1.1. Set the heater at the lowest effective temperature to avoid volatilizing any semivolatile compounds in the PM_{10}. A brief accumulation of water on the filter tape that subsequently evaporates as drier air is pulled through the instrument will cause erroneous short-term readings, but will not adversely affect the 24-h average value

6.2. Because the instrument compensates for fluctuations in temperature, the ambient air stream does not need to be heated to a particular standard temperature, as long as it is within the operating range (-20° to 40°C), although heating may still be necessary for moisture control (Section 6.1). Heating the ambient air stream can also eliminate some semivolatile chemicals, leading to inaccurate mass measurements. .

7. Personnel Qualifications

7.1. Personnel must be trained in the use of the instrument before initiating the procedure. Training requires about four hours.

7.2. Each analyst must read and understand the entire IM and this SOP before operating the instrument.

7.3. Personnel should also be trained to interpret the analyzer output signal, set up the internal data logger, and interpret the selected logged parameters.

8. Equipment and Supplies

8.1. Method EQPM-1102-150 requires that the C-14 Beta monitor be installed with the following Thermo Electron hardware:
  8.1.1. C-14 Beta monitor (Series FH62C14 Continuous Ambient Particulate Monitor)
  8.1.2. 10µm omni-directional inlet operated at 16.67 L/min (e.g., Model SA246B or as specified in 40 CFR 50, Appendix L)
  8.1.3. Sample tube with optional heater
  8.1.4. Inlet to sample tube connector
  8.1.5. Vertical stabilization of sample tube (if necessary)
  8.1.6. Vacuum pump with hose and speed control harness
8.2. Keep the following tools, supplies, and spare parts at each remote site:
  8.2.1. Glass fiber filter sample tape GF#10, Part No. FH111
  8.2.2. Weatherproof silicone caulk or sealant
  8.2.3. Certified NIST-traceable flow meter capable of measuring 16.7 L/min
  8.2.4. Certified NIST-traceable temperature and pressure sensor
  8.2.5. Adhesive tape (necessary after calibration to fix the filter tape to the take-up reel)
8.3. Keep the following spare parts in a central stock at PAAQL:
  8.3.1. Glass fiber filter sample tape GF#10, Part No. FH111
  8.3.2. Pump, Part No. FH180.
8.4. Accessories for airflow check or audit:
  8.4.1. NIST-traceable volumetric Flow Transfer Standard (FTS)
  8.4.2. Unit Coupling: Part No.FH113
  8.4.3. 5″ Unit Downtube: Part No.FH10819.
  8.4.4. Sample Inlet Adapter: Part No.FH113C
  8.4.5. Tubing to connect the FTS to the sample inlet adapter

9. Procedure

9.1. Instrument setup
  9.1.1. Carefully check analyzer and converter for visible defects or damage.
  9.1.2. Analog output settings
    9.1.2.1. Verify or modify the configuration following the procedure in the IM (Section 2.2.1, page 20) which refers to the Main Circuit Board (Fig. 17 on page 128 of the IM). The same information about pin connections for voltage output or current loop is in Section 10.1.1 of the IM (page 126). Information about the Analog Output Instrument codes is in Table 1, Section 3.9.2 of the IM.
    9.1.2.2. The default analog output from the C14 Beta monitor is 0-10 V or 0-20 mA, provided by the status signals and analog output I/O connector (page 13 of the IM). Select between 0-10 V and 0-20 mA analog output according to the DAQ hardware configuration (SOP B1). A summary of the procedure for switching between the 0-10 V and 0-20 mA output options follows.
      9.1.2.2.1. Turn the power off, and unplug the instrument.
      9.1.2.2.2. Remove the upper, rear panel of the sampler prior to barn installation, so that the Main Circuit Board jumpers can be set or verified.

9.1.2.2.3. If there are dummy (temperature) sensor jumpers labeled T1 and T4 installed, remove them in favor of the 2 sensor cables from the rear plug labeled “sensors”.

9.1.2.2.4. Check the output configuration terminals, X24 and X10. One is for the rear 25-pin I/O port, and one is for the front face I/O port. These diagrams illustrate the voltage output and current output jumper settings. Both I/O ports should be set up alike, in the Volt Output setting. Note the correct jumper setting:

Correct

Incorrect

Figure 3. Jumpers installation for setting up the analog output.

9.1.3. Connections and startup

9.1.3.1. Refer to Section 2.2 of the IM (page 18) for connection and startup instructions, including steps to activate external temperature sensors and specify data collection output type.

9.1.3.2. Mount the sampler to a rack or shelf inside the OFIS, and attach the inlet tube, which will go through a specially designed flange or collar on the OFIS ceiling. Make sure that the vertical position of the sampler in the rack will allow the sample tube to fit within the ceiling flange once installed.

9.1.3.3. Install the waterproof flange on the roof at this time. Install the heated inlet carefully, so that that the bottom of the inlet tube just reaches the instrument inlet. When properly installed, the heated inlet tube will hang vertically over the top of, and perpendicular to, the top of the sampler at the inlet point, where a mating collar is then secured into place.

9.1.3.4. Pass the ambient temperature sensor, whose lead protrudes from the end of the heated inlet tube under the roof flange, through the roof flange, and mount it inside the sun shield, which is clamped onto the outside inlet tube that supports the PM_{10} head and cyclone.

9.1.3.5. Connect the 9-pin connection (attached to cables that protrude from the lower end of the inlet tube) to the rear panel of the sampler at the “Sensors” mating socket.

9.1.3.6. Connect the inlet tube heater power supply to the large, metallic clamps on the tube using Allen screws. Use only one screw per clamp for power lead connections. One heavy supply output lead goes to one clamp, and the other supply output lead goes to the other clamp. Connect the power supply input to the rear panel of the sampler, as marked.

9.1.3.7. Plug the pump directly to AC power, and to the marked electrical and pneumatic connections on the rear of the sampler.

9.1.3.8. Turn on instrument. The detector needs 3 to 4 h for stabilization, after the power is first turned on. The instrument will generally display negative mass and concentration values during this time.

9.1.3.9. If the filter tape is already installed, advance it to the next position (Section 9.2.4.1.3).

9.1.3.10. If not already installed, attach and install a roll of approved filter media, intended for this instrument, to the left side spindle, unwinding clockwise. Use the controls described under the Maintenance menu to open the filter head. Bring the sample media up and over the transport sensor wheel (resembling a tension roller), and pass the media through the sample head left to right. Use a piece of office or masking tape to secure the tape head to the take-up spool.

9.1.3.11. Data collection is accomplished by wiring a male 25-pin I/O connection as follows: Pin 12 = 10V+ out and Pin 13 = 10V- out. Run this data collection wire pair to an input channel of the DAQ system for real-time data collection.

9.2. Operation of the keypad or screen

9.2.1. Once the sampler has been set up, certain operating parameters will be set or verified for proper operation and data collection. It is important to understand the operation of the keypad or screen itself, to conduct these operations.

9.2.2. Verify that the C14 Beta monitor's parameters are set to the following values:

9.2.2.1. Operated for 24-h average measurements

9.2.2.2. Flow rate of 1000 L/hr (16.67 L/min)

9.2.2.3. Daily automatic filter change (1,440-min cycle time)

9.2.2.4. Automatic filter change when flow rate <950 L/h

9.2.2.5. Automatic filter change when sampled filter spot mass is > 1,500 mg

9.2.2.6. Factory default calculation mode settings (60 min LR time, 10% STDEV, 33 s RC mass filter)

9.2.3. The sampler has a view screen (Fig. 4), with options at the bottom of the screen which may be affected by the keypad immediately beneath it. The softkeys correspond to the functions just above them. Fig. 4 shows a different name for each of the two left soft keys. The first and second softkeys from the left correspond to one of the two functions shown above them, depending on which specific screen is selected.

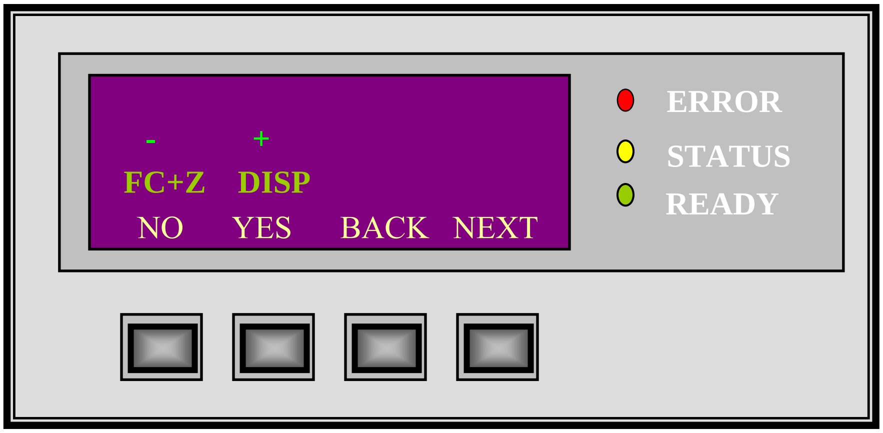


Figure 4. View screen for data readout and for input of operating parameters.

- 9.2.3.1. The “Next” key moves to the next screen in the rotation of selectable options. Executing this button saves the information present in the screen at that point.
- 9.2.3.2. The “Back” selection moves to the prior screen in the rotation of selectable options. NOTE – going “Back” will fail to save whatever parameters were changed on a given screen. Only going “Next” will save entries to the screen.
- 9.2.3.3. “Yes” moves to a sub-menu under a given heading, or executes actions which are described on the display, or switches on parameter flags (as appropriate).
- 9.2.3.4. “No” switches off parameter flags.
- 9.2.3.5. “+” and “-” change input values and parameter values.
- 9.2.3.6. These principles of value change apply to all areas of screen operation.

9.2.4. The Value Display is usually seen while the sampler is running. It shows the word “Normal”, a 4-digit status line, a 2-digit error code line, and the present active sample concentration in µg /m^3. Under normal running conditions, the three indicator lights to the right of the keypad/screen will show:

- 9.2.4.1. Green LED “Ready” is on.
- 9.2.4.2. Yellow LED “Status” is off.
- 9.2.4.3. Red LED “Status” is off.
- 9.2.4.4. **Pressing the “Next” key once** from this view will show concentration, mass, and airflow rate.
- 9.2.4.5. **Pressing “Next” a second time** will show the airflow rate at the sample inlet, and the flow rate adjusted for standard temp (25°C) and pressure (760 mm/Hg).
- 9.2.4.6. **Pressing “Next” a third time** will show 30-min, 3-h, and 24-h average PM concentrations.
- 9.2.4.7. **Pressing “Next” a fourth time** will show the Radon content in the current sample.
- 9.2.4.8. **Pressing “Next” a fifth** time will show status or error codes, with a “Text” option displayed; choosing “Text” will give information about the error.
- 9.2.4.9. **Continuing with “Next”** will offer the chance to set date and time.

9.2.5. Unlocking the screen

- 9.2.5.1. In order to make changes to menu items, the keyboard must be unlocked. To unlock the screen, **go to any one of the other view screens - Operations, Maintenance, or Calibration - by pressing the button under the word “Yes**”. Once there, the question “Keys Locked?” will be seen [“On Line = Yes” is displayed]. Press the “No” button to affirm that the keypad is not to remain locked [“On Line = No” is displayed]. The following becomes true when the keypad is unlocked under any menu screen:
  - 9.2.5.1.1. The yellow Status LED will come on as a reminder that the machine is not in normal operation.
  - 9.2.5.1.2. The keyboard is free, so that all parameters can be changed with the “+” and “-“ keys.
  - 9.2.5.1.3. A manual filter change can be initiated by pressing the “FC+Z” keys.
  - 9.2.5.1.4. Serial and parallel interfaces are disabled, though control signals and other electronic inputs are unaffected if such were to become in use.

9.2.6. Further explanations of how this instrument operates, in all following sections, will include references to the sampler view screen. Options at the bottom of the screen represent changes that may be affected by the keypad immediately beneath it.

9.2.7. The Operations Menu allows the operator to set chiefly interface issues, such as analog outputs, baud rates (if serial communications are used), etc.

- 9.2.7.1. Unlock the keypad, and then use the "Next" key to move through the following parameter choices, and make the selection or use the "+" or "-" or specific words presented, depending upon the choices available, to adjust the settings as needed.
  - 9.2.7.1.1. Press the button beneath the COM# displayed to toggle between COMM1 or COMM2. Press "Yes" to save and continue to the next option.
  - 9.2.7.1.2. This section of variables allows the user to specify a print format for the capture of near real-time data through the COMM port, and to specify output cycle intervals. The IM shows example formats on page 112.
- 9.2.7.2. The screens labeled Analog Outputs allow the operator to configure output signals to match parameters used by the data logger of choice at the installation location. Press "Yes" to check or change settings.
  - 9.2.7.2.1. The first option under this heading determines the voltage output seen by the logger under a zero reading on the instrument. Note that the instrument should have already been set up to deliver voltage output, not milliamp output; the screen will still show references to "mA' where 0 mA = 0 V, and 20 mA=10 V. For ESC data logger use, set the Output Zero to correspond to 0 mA.
  - 9.2.7.2.2. The second option selects which output will be chosen from Section 3.9, Table 1, on page 40 of the IM. Choose Selection 10 (mass concentration in μg/m^3).
  - 9.2.7.2.3. The third option under this heading allows setting of the span value desired for mass concentration. Again, the screen will read 20 mA for what is, in fact, a 10-V span output.
- 9.2.7.3. The Filter Change screen parameters which follow specifies under which conditions a filter change will occur. Press "Yes" to check or change settings.
  - 9.2.7.3.1. The first settable trigger is for mass concentration; set this for 1500 μg/m^3. If a sample should exceed this limit, an extra filter change will occur.
  - 9.2.7.3.2. The second variable is for airflow; if flow falls below this set level a filter change will occur. 950 L/h is the normal setting.
  - 9.2.7.3.3. The next setting will cause a filter change after a preset period of time since the last one. Set this cycle to 1440 min (one change per day).
  - 9.2.7.3.4. Finally, select the hour of the above filter change. For midnight, enter "24:00", since "00:00" represents NO regular filter change interval for this instrument.
- 9.2.7.4. The Heater and Air Flow rate screen determines the operating temperature of the condensation-preventing heated inlet tube, and the sample air flow rate. Press "Yes" to check or change settings.
  - 9.2.7.4.1. The first screen displayed upon entering this section shows the percent of heater regulator effort (i.e. 567 = 56.7%), the nominal set point in °C for the inlet, and the present, measured inlet temperature in °C. Enable the ability to change the set point by pressing the NOMIN key.

9.2.7.4.1.1. Use the "+" and "-" keys to select an appropriate operating temperature. A range around 40°C will be common. Press "NEXT" to save and continue.

9.2.7.4.2. The next screen will show Air Flow regulatory status. As with inlet temperature, this will display regulator effort percent (i.e. 638 = 63.8%), a nominal set point, and the actual flow as measured.

9.2.7.4.2.1. Enable the ability to change the set point by pressing the NOMIN key.

9.2.7.4.2.2. Use the "+" and "-" keys to select the standard air flow of 1000 L/h. Press "NEXT" to save and continue.

9.2.7.5. The Concentration Thresholds, labeled "Limits Concentration, is the next settable screen. Press "Yes" to check or change settings, and "Next" to save and go past.

9.2.7.5.1. Limit 1 is the level at which the yellow status LED will be activated and a display of STAT 0100 will be shown.

9.2.7.5.2. Limit 2 determines the level at which a display of STAT 0200 will be shown.

9.2.7.5.3. A display of STAT 0300 will be seen if both Limit 1 and Limit 2 are exceeded.

9.2.7.6. A language screen allows adjustment for operation in various countries.

9.3. Instrument operation

9.3.1. Routine operation of the instrument involves allowing the sampler to run in a stable temperature environment around 25°C, changing filter media approximately once per a year (depending upon consumption), periodic adjustment of inlet tube temperature as required, calibration, and following trends in sample data or a break in the usual pattern of collection for possible anomalies.

9.3.2. Tape handling and pump operation are operated through the Maintenance Menu. Unlock the keypad (Section 9.2.4), and use the "Next" key to move through the available options, and make the selection or use the "+" or "-" or specific words presented. Use "Next" to initiate actions and to go to the next step, as needed.

9.3.2.1. Pump operation is the first control available. It is necessary to start and stop the pump during various phases of use. DO NOT simply pull the pump control plug from the rear of the sampler to stop the pump.

9.3.2.2. The next three options allow one to open the sample head, move the filter strip manually, and close the head. The head is opened during set-up, and for calibrations. Closing the head will begin an automatic zero reference check.

9.3.2.3. Strictly follow the IM when performing any further functions under Maintenance, as they do not in any way reflect routine operation or maintenance of the instrument.

9.4. Instrument Calibration

9.4.1. Enable Calibration Mode. Follow procedure in Section 9.2.5.1 to access this mode.

```
CALIBRATION
*******************


     YES  BACK  NEXT
```

9.4.1.1. In this mode the particulate mass, the air flow rate, the temperature, and pressure sensors are calibrated. Correct calibration of these parameters is necessary to accurately record the particulate concentration

```
CALIBRATION
KEYS LOCKED ?
(ON LINE) NO NOYES
          BACK NEXT
```

9.4.1.2. If the keys are locked, the following parameters cannot be modified. Press NO to unlock the keys

```
CALIBRATION
CHANGE NO.: 12345
02-07-23 13:30
       BACK   NEXT
```

9.4.1.3. The running number (date + time) of the parameter change or recalibration is indicated. With each parameter or calibration change the change number and date (yy-dd-mm) are entered. Press NEXT.

```
CALIBRATION:
CALIB. CODE:
                0
-    + BACK NEXT
```

9.4.1.4. Enter the code "147" in this screen: This is necessary to protect sensitive calibration parameters. Other passwords are used for special setups.

9.4.1.5. Note: The calibration menu is locked if the calibration menu is inactive for 4 min.

Wrong code:

```
CALIBRATION
CALIBR. LOCKED !
12345
     -   +  BACK   NEXT
```

Valid code:

```
CALIBRATION
CALIBRATION FREE !
147
    -  +  BACK   NEXT
```

9.4.1.6. After the correct password is entered, the status bit "calibration enabled" is set.

```
CALIBRATION
AMPLIFICATION:
    7250 µg
-   + BACK NEXT
```

9.4.1.7. The mass calibration value is indicated, and can be entered. This mass - calibration factor [µg] is determined from the instrument during the reference-foil calibration. It converts the detector count rate into the mass value. The keys "-" and "+" appear only if the calibration is enabled, and these are only used for a fine tune adjustment of the Span (e.g., seasonal adjustments if necessary).

9.4.1.8. Record the calibration values of the temperature sensor, pressure sensor, flow rate, and mass foil calibration in the **"Thermo C-14 Beta Sampler Calibration Form"**. (Appendix A).

9.4.2. Mass Foil Calibration

9.4.2.1. The foil calibration procedure is a user-interactive mode, and should be performed annually, or as stated in the QAPP, or after service to the measurement chamber. Follow all instructions displayed on the screen. The complete process is automatically directed by the C14 BETA firmware. The complete procedure lasts approx. 20-30 min. If necessary, stop the procedure using the ABORT key.

9.4.2.2. **WARNING**: Take very good care of the calibration foil set. Contact Thermo Electron Corporation for cleaning instructions. Do not wipe the foil window. Do not touch the foil window with your fingers.

9.4.2.3. Perform calibration only with the heater off and the unit thermally equilibrated.

CALIBRATION
FOIL CALIBRATION
PROCEDURE ?
YES BACK NEXT

9.4.2.4. Press YES to access the calibration mode using the reference mass foils. Follow the instruction displayed on the screen.

CALIBRATION PROCEDURE
SPAN FOIL VALUE:
1442 µg
\- + BACK **NEXT**

9.4.2.5. Enter the SPAN foil value (choose the mid-range foil for 0-5,000 $\mu g/m^3$ range or maximum value foil for 0-10,000 $\mu g/m^3$ range) Mid-Range Span is to be used for USEPA Equivalency. Press NEXT

CALIBRATION PROCEDURE
HEAD OPENS !
PLEASE WAIT!
ABORT

9.4.2.6. The sample/measurement chamber opens. This screen is displayed while the measuring head opens (about 30 s).

CALIBRATION PROCEDURE
INSERT FOIL HOLDER !
ABORT **NEXT**

9.4.2.7. Cut filter tape from take-up reel and pull it out. Then insert the foil holder frame from the left into open gap. Note that the word “oben” on the foil holder should be facing “up”. (oben = up) Press NEXT.

CALIBRATION PROCEDURE
HEAD CLOSES
PLEASE WAIT!

9.4.2.8. This screen is displayed while the measuring head closes (~ 30 s).

```
CALIBRATION PROCEDURE
INSERT ZERO FOIL!

        ABORT   NEXT
```

9.4.2.9. Insert the zero foil (Nullfolie) with the word “unten” facing down. Close the front instrument cover. Press NEXT**.** The zero has now begun.

```
CALIBRATION PRO 27%
AUTOZERO ACTIVE
115 4 12*
ABORT TIMER:355
```

9.4.2.10. The offset and mass indication during the mass auto zero lasts ~ 7.5 min. Wait until the timer count down is ready. If offset is > +500 %, then the procedure stops. Contact Thermo Electron Corporation if this occurs.

```
CALIBRATION PRO
TAKE OUT FOIL

ABORT         NEXT
```

9.4.2.11. Once the Zero Foil calibration is complete, take out the zero foil and place in the protective case. Press NEXT.

```
CALIBRATION PRO
INSERT SPAN FOIL.

ABORT         NEXT
```

9.4.2.12. Insert the chosen SPAN foil with the word “unten” facing down. Close the front instrument cover. Press NEXT.

```
CALIBRATION PRO
CALIBRATION ACTIVE
79 1515 1451*
           ABORT
```

9.4.2.13. Wait until the calibration timer countdown has been completed (10-15 min).

```
CALIBRATION PRO
RATE 0 (1/s) mass(µg) 2 1515
1451*
           ABORT
```

9.4.2.14. This screen is displayed during the Span Calibration, and shows the count rate and mass value.

```
AMPLIFICATION
OLD: 7505 NEW: 7489
NEW VALUE ?
NO  YES  BACK   NEXT
```

9.4.2.15. The old and new amplification values are shown when completed. Press "YES" to accept the new calibration value

9.4.2.16. Press "NO" to decline the new calibration value

9.4.2.17. Press "BACK" to repeat the foil calibration procedure. Then Press NEXT.

```
CALIBRATION PRO
HEAD OPENS
PLEASE WAIT
```

9.4.2.18. By Pressing "ABORT" during the calibration procedure, this screen will be displayed.

```
CALIBRATION PRO
TAKE OUT FOIL
INSERT FILTER STRIP
          NEXT
```

9.4.2.19. At the end of the calibration, take out the foil and then the foil holder. Insert the filter tape and adhere it to the take-up reel. Press NEXT.

```
CALIBRATION PRO
WRITE PRESET VALUES
INTO EEPROM
    YES  BACK   NEXT
```

9.4.2.20. To write the new calibration values into memory, Press YES. The parameters and calibration data are now stored into the EEPROM. An automatic reload of this calibration parameter will happen after a cycling of the power.

9.4.3. Airflow Rate Verification

9.4.3.1. As per 40CFR, Part 50, Appendix L, Section 9.2.5, the flow rate of the Model C14 Beta should be verified. Check the flow rate at least quarterly, or as stated in the QAPP.

9.4.3.2. Complete the temperature and pressure verification tests conducting this Flow Rate Verification.

9.4.3.3. Prepare the equipment and parts listed in Section 8.4.

9.4.3.4. Attach the small sample tube adapter to the Model C14 Beta inlet.

9.4.3.5. Attach the inlet adapter to the sample tube. Depending upon what NIST-traceable volumetric flow transfer standard (FTS) is being used, the FTS may either be attached now, or a flow audit adapter may be added to accommodate any flexible tubing that the FTS may require.

9.4.3.6. Allow 60 s for flow to stabilize.

9.4.3.7. Section 9.2.4.5 describes the procedure to display the airflow rate at the inlet, and as the airflow rate corrected to standard conditions (25°C and 1 atm). Compare the value obtained with the audit flow meter with the air flow rate at the inlet value displayed by the monitor.

9.4.3.8. Record the Model C14 Beta Volumetric Flow Rate as Qm and the FTS flow rate as Qi. Use units of L/h for both.

9.4.3.9. Take three (3) readings each of Qm and Qi, and average the respective values.

9.4.3.10. Use the following equation to calculate the percent difference (%D):

$$\%D = (Q_i - Q_m)/Q_i * 100 \qquad (9.1)$$

9.4.3.11. If the %D is within ±4%, then the volumetric flow rate is acceptable.

9.4.3.12. If the %D of the volumetric flow rate is more than ±4%:
  - 9.4.3.12.1. If the test is an acceptance verification test conducted after unpacking a new instrument, contact Thermo Electron’s Technical Support, or your local sales representative.
  - 9.4.3.12.2. Conduct a calibration test (Section 9.4.4) if it is a test other than the initial verification test.

9.4.3.13. Volumetric flow rate calibration is covered in Section 9.4.4.

9.4.4. Air Flow Rate Calibration

9.4.4.1. For a flow rate calibration, use a NIST-traceable volumetric flow calibration device (e.g. flowmeter). Calibrate all temperature and barometric pressure sensors before conducting the air flow rate calibration. Perform calibration once per year, or as directed in the QAPP. Perform calibration after the instrument has been moved from its location, after any major repair or maintenance, or after poor audit results.

CALIBRATION
AIR FLOW:

YES BACK NEXT

9.4.4.2. Press YES to begin the airflow rate calibration.

CALIBRATION

AIR FLOW:
MEAS.: 999 l/h
CAL BACK **NEXT**

9.4.4.3. The volumetric flow rate is initially indicated as measured by the C14 BETA. Press CAL to change the air flow rate calibration coefficient. Thereafter, enter the actual air flow rate measured by a reference instrument and press NEXT. Allow 30 s between indicated airflow adjustments. Repeat as necessary until corresponding reference and C14 BETA flow rate values agree within 2%.

CALIBRATION
VOLUME REFEENCE
:OPERA
SET BACK NEXT

9.4.4.4. The conditions (temperature and pressure) of the air flow rate used for the calculation of the concentration can be set here. Press SET to toggle between the following options:

OPERA	volumetric conditions
273° K	273°K , 1013 hPa
293° K	293°K , 1013 hPa

9.4.5. Temperature and Pressure Sensor Calibration

9.4.5.1. The calibration of temperature and pressure sensors, indicated by a reference unit, is entered here. The instrument starts an automatic adjustment after each calibration entry. Values are stored in battery-buffered RAM with check sum.

```
CALIBRATION
TEMPERATURE- AND
PRESSURE SENSORS
     YES  BACK   NEXT
```

9.4.5.2. Press YES to access the submenu for calibrating the temperature and pressure sensors.

```
CALIBRATION OF SENS.

TEMP. PM 10 HEAD

MEAS.: 23 °C

     CAL  BACK   NEXT
```

9.4.5.3. The ambient temperature sensor (T1) is indicated in this screen. Press CAL to change its value. Enter the measured value of a reference thermometer using the ± keys.

```
CALIBRATION OF SENS.
TEMP. PM 10 HEAD
MEAS.: 23 °C
     -  +  BACK   NEXT
```

9.4.5.4. The adjustment procedure lasts about 5 to 30 s. During this time, a "K" flashes in the first line on the right.

9.4.5.5. When this procedure is finished one of the following texts appear on the screen:

```
CALIBRATION OF SENS.
CALIBRATION O.K.
MEAS.: 25 °C
       CAL BACK NEXT
```

```
CALIBRATION OF SENS.
CALIBR NOT POSSIBLE
MEAS.: 23 °C
           BACK NEXT
```

9.4.5.6. If the message "CALIBR NOT POSSIBLE" appears, then the new calibration value cannot be reached within the limits of the adjustment range. Check the entry that was made, check for a loose connection on the T sensor cable, or for a frayed wire.

9.4.5.7. Use the same calibration procedure for the following sensors:

```
CALIBRATION OF SENS.
TEMP. UPPER HEAD
MEAS.: 26 °C
       CAL BACK NEXT
```

9.4.5.8. T2: Temperature sensor over the filter tape

```
CALIBRATION OF SENS.
TEMP.LOWER HEAD
MEAS.: 25 °C
       CAL BACK NEXT
```

9.4.5.9. T3: Temperature sensor under the filter tape

```
CALIBRATION OF SENS.
TEMP.INLET HEATER
MEAS.: 40 °C
      CAL BACK NEXT
```

9.4.5.9.1. T4: Temperature sensor at the tube wall of the heated sample tube (optional)

```
CALIBRATION OF SENS.
AIR PRESS(ABSOLUTE)
           MEAS.: 958 hPa

      CAL BACK NEXT
```

9.4.5.10. The value of the ambient pressure sensor (P3) is indicated here. Press CAL to change its calibration (hPa = in Hg / 33.7685) Enter the value obtained from a reference barometer, using the + or - key. Press NEXT to finish the data input. Allow ~30 s for the adjustment procedure.

9.4.5.11. After calibrating the barometric pressure sensor (P3), it is usually not necessary to calibrate the P1 and P2 sensors. If these sensors are operating in the 3500-4500 Pa and 80-100 hPa range, respectively, then calibration is not needed. If annual calibration is needed, remove the top cover of the C14 BETA to access the pressure line upstream of the orifice.

```
CALIBRATION OF SENS.
ORIFICE PRES(ZERO)
MEAS.: 0 Pa
      CAL BACK NEXT
```

9.4.5.12. The value of the orifice pressure sensor (P1) is indicated here. Press CAL to change its calibration when the pump is switched off. Enter zero (0) with the unit at rest. Press NEXT to finish the data input. Allow ~30 s for the adjustment procedure.

```
CALIBRATION OF SENS.
ORIFICE PRESS(SPAN)
MEAS.: 5098 Pa

CAL BACK NEXT
```

9.4.5.13. The value of the orifice pressure sensor (P1) is indicated here. Apply a pressure of 50 hPa (5000 Pa) on the upstream orifice pressure line. Press CAL to change its calibration of the slope (SPAN). Measure the exact value using a reference instrument and enter this value using ± keys. Press NEXT to finish the data input.

```
CALIBRATION OF SENS.
HEAD(ZERO): MEAS.: 0
hPa
CAL BACK NEXT
```

9.4.5.14. The value of the vacuum/pressure (under filter tape) sensor (P2) is indicated here. Press CAL to change its offset (zero point). Switch off the pump and enter the zero value. Press NEXT to finish the data input. The adjustment procedure starts.

```
CALIBRATION OF SENS.
HEAD(SPAN): MEAS.: 210
hPa

CAL BACK NEXT
```

9.4.5.15. The value of the vacuum/pressure sensor (P2) is indicated here. Apply a vacuum of about 200 hPa on the upstream orifice pressure line. Measure the exact value using a reference instrument and enter this value using + or – key. Press CAL to change its calibration of the slope (SPAN).

WRITE PRESET VALUES
INTO EEPROM ?
YES BACK NEXT

9.4.5.16. All parameters, date of inserting the source and calibration data are written in the EEPROM. A reload of these data happens if the power is cycled and an error in the battery-buffered RAM is triggered or if through an explicit keypad command in the maintenance menu a successful writing or read command was applied.

EEPROM WRITE O.K.

BACK NEXT

EEPROM ERROR !

BACK NEXT

9.5. Calibration of the C14 BETA

9.5.1. Mass Calibration

9.5.1.1. Do not touch the calibration foil windows inside the holder.

9.5.1.2. Note: If the heated sampling tube is being used, the instrument should equilibrate to room temperature before the calibration procedure begins (~ 1 hr).

9.5.1.3. The C14 BETA has no front access to the filter tape. Therefore, the filter tape must be cut near the measuring head and removed from the side of the measurement head. After the calibration procedure, the filter tape must be inserted and fixed to the take-up reel using an adhesive tape.

9.5.1.4. The calibration procedure uses an internal menu operation. The menu operation is comprehensively described in Section 4.2.4.1 of the IM (Mass Foil Calibration Procedure, page 65),

9.5.1.4.1. Access the Calibration submenu KEYS LOCKED ? and confirm with key NO.

9.5.1.4.2. Access the Calibration submenu CALIBR. CODE and enter the release code 147.

9.5.1.4.3. Activate the foil calibration procedure via the Calibration, submenu FOIL CALIBRATION PROCEDURE ? and confirm with YES.

9.5.1.4.4. Enter SPAN Mass Foil Value (~ 1,400 µg, see the foil kit imprint), and press NEXT.

9.5.1.4.5. The measurement chamber will open. Remove the filter tape from the particulate sampling position and insert the guide bar into the filter gap on the left with the word “oben” facing up. Press NEXT.

9.5.1.4.6. Insert the zero foil from the left with the word “unten” facing down. Close the front monitor window.

9.5.1.4.7. Press NEXT. The filter spot is closed and a zero adjustment of the mass is initiated (3-5 min). Offset and mass value are indicated.

9.5.1.4.8. Next, the order appears in the display to take out the zero foil and to insert the SPAN foil. Confirm by pressing NEXT.

9.5.1.4.9. The SPAN adjustment runs approximately 5-10 min, until the measurement value stabilizes itself. The actual mass value, as well as the remaining measurement time, is indicated.

9.5.1.4.10. Next, the old and new calibration factors FCAL are indicated. Use the YES key to accept the new calibration factor is accepted, or NO to discard it.

9.5.1.4.11. The measurement value of the SPAN foil is indicated and can be compared with the imprinted value. Confirm with NEXT.

9.5.1.4.12. The measurement chamber is opened again. Take out SPAN foil and guide bar and insert filter tape and adhere it to the take-up reel. With the NEXT key, a filter change is triggered and the measurement operation starts again.

9.5.2. Mass Validation

9.5.2.1. Use the same or an independent set of mass transfer standard foils to conduct an audit or verification of the mass calibration. Validate using the following steps. It is best to understand the above mass calibration procedure first. Within the Maintenance Menu, perform the following steps:

9.5.2.1.1. Enable the keys, switch off pump, open the head, and remove the filter tape

9.5.2.1.2. Insert the foil holder. Carefully insert and align the null foil

9.5.2.1.3. In the Maintenance Menu → Close the Head and Zero.

9.5.2.1.4. Wait 8 min for the zeroing cycle to finish.

9.5.2.1.5. After zeroing cycle is complete (as seen on the front display), remove the null foil and insert the mid-range span foil.

9.5.2.1.6. From the Main Menu, press DISP to obtain a direct reading of the detected mass. Compare with the imprinted foil value; the two should be within 5% of each other. If not, redo the verification. If an error >5% persists, recalibrate.

9.5.3. Instrument configuration

9.5.3.1. A screen that reads “Configuration ETC” can be found following the Calibration Menu. A release code has to be entered to unlock this screen.

9.5.3.2. Do not change anything under this heading, unless it can be demonstrated that the values used are consistent with USEPA Equivalent Method Designation practices. Reconfiguration during the warranty period will void the instrument warranty.

9.5.3.3. Once the configuration screen has been entered, the following settings should remain as set. Advance to the following screen via “Next” button, in each case:

9.5.3.3.1. Calculation Mode = 0 [zero].

9.5.3.3.2. Regression Time = 60 min.

9.5.3.3.3. Standard Deviation = 10%.

9.5.3.3.4. Efficiency Ea2 = 20.3%.

9.5.3.3.5. Negative Concentration output = Yes.

9.5.3.3.6. RC-Filter for Mass = 33 s.

9.5.3.3.7. Comp. Factor F (R1/R2) = 360% [Do Not Change].

9.5.3.3.8. Version: 86,84,92,EPA = 0 [zero, for std. EPA]

9.5.3.4. If changes are made, a following screen prompts the operator to write preset values into the EEPROM. The usual answer will be “Yes”, in order to save such changes. Proceed to “Next” after doing so.

9.6. Maintenance

9.6.1. Maintenance schedule

Maintenance Schedule Recommended by Manufacturer	Maintenance Procedure	IM Section	SOP Section
1-3 mon.	Check air flow	4.2.4.2	9.4.3
3 mon.	Clean/inspect PM_{10} inlet head	5.6	9.6.3
3 mon.	Mass validation with foil set	5.11.3	9.5.2
6-9 mon.	Check/replacement of filter tape	4.2.3	9.6.5
12 mon.	Mass calibration with foil set	4.2.4.1 & 5.11.2	9.4.2
12 mon.	Air flow calibration	4.2.4.2	9.4.4
12 mon.	Replace pump carbon vanes	5.4	9.6.8
2 yrs	Cleaning measurement chamber	Contact: TEC	

9.6.2. Check airflow.

9.6.2.1. Use the procedure described in Section 9.4.3.

9.6.3. Clean and inspect PM_{10} sampler inlet head

9.6.3.1. Inspect the water collector bottle (located on the sampler inlet head tube) at least every five sampling days (Fig. 5). Remove any accumulated water, clean the interior of the bottle, inspect the seals, and replace the bottle in the holder.

9.6.3.2. Dismantle and clean the sampler inlet once a month, or as specified in the QAPP. Mark each assembly point of the sampler inlet with a pen or pencil to provide reference marks during reassembly.

9.6.3.2.1. Disassemble the sample inlet unit. If the assembly screws are frozen, apply penetrating oil or commercial lubricant to make removal easier. Clean all interior surfaces and the bug screen with a general purpose cleaner or compressed air, paying particular attention to small openings and cracks. Cotton swabs and/or a small brush are helpful. Completely dry all components.

9.6.3.2.2. Check the O-rings for distortion, cracks, fraying, or other problems, and replace as necessary. Apply small amounts of grease to the rings before assembling the unit. Reassemble the unit in accordance with the previously scribed match marks. Take particular care to ensure that all O-rings seals are properly seated, and that all screws are uniformly tightened.

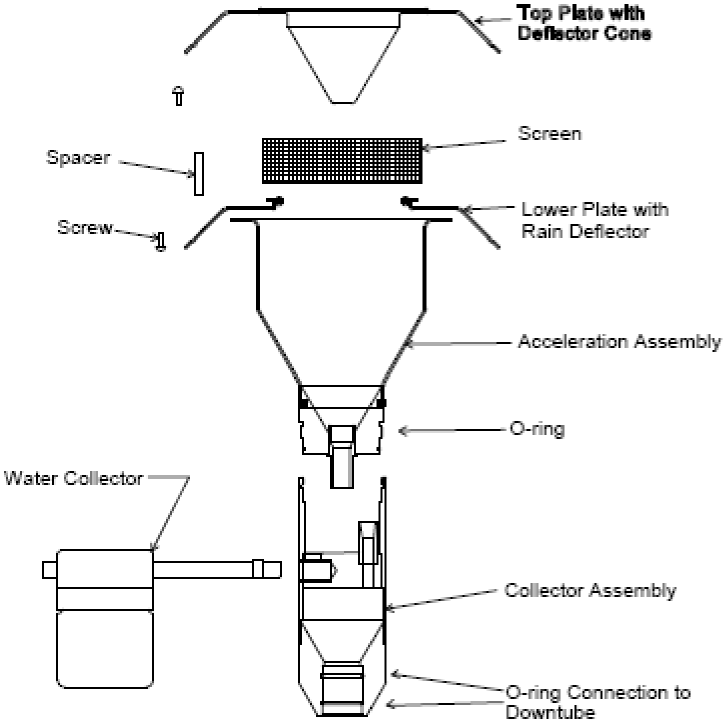


Figure 5. PM$_{10}$ sampler head.

9.6.4. Mass validation with foil set.
  9.6.4.1. Follow the procedure described in Section 9.5.2.
9.6.5. Check/replacement of the Filter Tape
  9.6.5.1. As soon as the filter tape on the filter roll is empty, replace the roll.
  9.6.5.2. The filter tape is usually replaced annually, but this can also depend on the non-standard operational parameters chosen by the user or the loading per filter spot. In high-concentration areas, more frequent filter changes can occur due to higher loading. As a basis for estimation, note that 42 m of tape per roll is sufficient for approximately 800-900 single measurements. Due to the uncertainty of filter tape life in high-concentration areas, check the filter tape every 6-9 mos.
  9.6.5.3. To change the filter tape, follow the instructions in Section 4.2.3 of the IM, under the Maintenance Menu, and Section 9.1.3.10 of this SOP.
9.6.6. Mass calibration with foil set
  9.6.6.1. Follow procedure in Section 9.4.2.
9.6.7. Air flow calibration
  9.6.7.1. Follow procedure in Section 9.4.4.
9.6.8. Carbon Pump Vane Replacement
  9.6.8.1. Vane replacement must be done outdoors. Failure to do so may introduce carbon particles into the air and damage electronic equipment.
  9.6.8.2. Before servicing, the vacuum pump must be switched off and secured from any accidental start-up.

9.6.8.3. In order to replace the vanes, remove the silencer housing (1), the silencer diaphragms (2), the distance ring (3), and the cylinder cover (4) (Fig. 6).

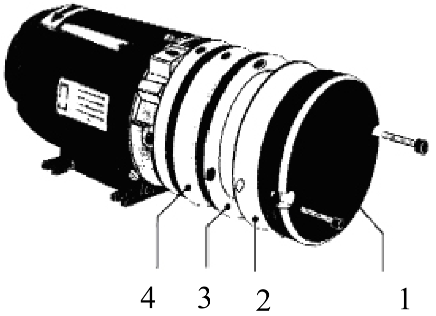


Figure 6. Pump Parts Location.

9.6.8.4. Blow carbon particulate from vane cavity (Fig. 7) with an air hose.
9.6.8.5. **WARNING**: Avoid breathing in carbon particulate. Used an approved particle filter or respirator.
9.6.8.6. When installing new vanes, be sure that the beveled side points outwards.
9.6.8.7. Reassemble the parts in the reverse order.

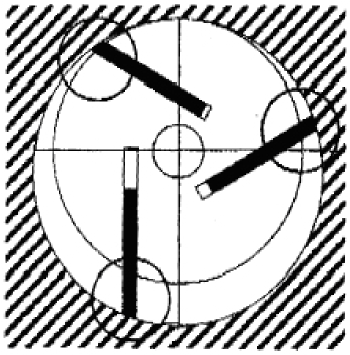


Figure 7. Carbon Vane Installation.

9.6.9. Clean the measurement chamber. Contact TEC service department.

9.7. Record all maintenance on the “Monthly Maintenance Checks” form (Appendix B of this SOP).

9.8. Troubleshooting: Section 12 of the IM (page 132) presents a list of errors, potential causes, and appropriate corrective actions.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet that is designated for this method. Supplement this electronic record with a bound record book designated for the method, which should also contain bound copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and site logbooks with permanent ink, or in electronic field notes.

10.4. Overstrike errors in writing with a single line; initial and date any correction on the hard copy notes.

10.5. Use the “Thermo C14 Beta Sampler Calibration Form” (Appendix A) to record the calibration values before transferring them to the electronic form in the daily notes.

10.6. Use the “Monthly Maintenance Checks – Thermo Electron FH 62C14 (Beta) Continuous Ambient Particulate Monitor” form (Appendix B), to record the monthly maintenance activities before transferring the information to the electronic form in the daily notes. Store all monthly maintenance forms on-site, in a three-ring binder that is labeled for this instrument.

11. Quality Control and Quality Assurance

11.1. Calibration of mass , temperature, pressure and air flow rate, is performed periodically as described in this SOP (Sections 9.4.2, 9.4.4, 9.4.4, and 9.4.3 respectively), and according to the QAPP.

  11.1.1. PM mass: The mass measurements of the C14 BETA instruments are calibrated to a mass transfer standard foil set (Section 9.4.2). These foil sets are calibrated against quartz particulate (SiO_2), in comparison to a calibrated gravimetric mass measurement. The original calibration values are listed in the factory test papers delivered with the instrument.

    11.1.1.1. Validate mass calibrations quarterly (Section 9.5.2).

    11.1.1.2. Re-calibrate mass measurements annually (Section 9.4.2).

    11.1.1.3. Re-calibrate mass measurements (Section 9.4.2) after intrusive maintenance and repair work, and to validate the mass span setting.

  11.1.2. Airflow rate

    11.1.2.1. Check the measurement at least quarterly (Section 9.6.2).

    11.1.2.2. Calibrate (Section 9.4.3) annually with a NIST-traceable volumetric flow transfer standard that is accurate within ±2%.

  11.1.3. Temperature

    11.1.3.1. Calibrate (Section 9.4.5) at least quarterly. Use a NIST-traceable temperature standard accurate within ±0.5°C.

  11.1.4. Barometric pressure

    11.1.4.1. Calibrate pressure sensors (Sections 9.4.5.10-9.4.5.15) at least quarterly. Use a NIST-traceable pressure standard accurate within ±2 mmHg.

11.2. The manufacturer has not developed any recommended leak checking procedures. Do not put the system under high positive or negative pressure; damage to the measurement system could result.

11.3. All the NIST traceable calibration standards certifications are to be kept up-to-date.

11.4. All AC powered Transfer Standard equipment will be allowed to equilibrate for at least one hour to ambient conditions.

11.5. Daily data will be inspected within three days for completeness. Any anomaly will be investigated, first by contacting the site engineer, and then by contacting the site Principal Investigator.

12. References

12.1. FH62C14 Instruction Manual.. 2004. Series FH62C14- Continuous Ambient Particulate Monitor Instruction Manual. P/N 100230-00. Thermo Electron Corporation, Franklin, MA. Revision of March 2005.
12.2. Delaware Department of Natural Resources and Environmental Control (DNREC). 2003. Standard Operating Procedure C-14 (Beta) sampler for continuous 2.5µg Particulate Monitoring. Word document, 23 pp. October 9.
12.3. USEPA. 1999. Compendium Method IO-1.1. Determination of PM_{10} in Ambient Air using the Andersen Continuous Beta Attenuation Monitor. Document No. EPA/625/R-96/010a. June 1999. Available at www.epa.gov/ttn/amtic/files/ambient/inorganic/mthd-1-1.pdf . Accessed 7/20/2006.
12.4. Thermo Andersen. 2002. FH62C14- Continuous Ambient Particulate Monitor catalog. Version 18 April 2002.
12.5. Pacwill Environmental. 2003. FH62I-N Beta Attenuation Monitor. Available at http://www.pacwill.ca/betagauge.html. Accessed on 7/20/2006. Page last updated on October 27, 2003.
12.6. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.
12.7. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.8. SOP U1. 2006. On-farm Instrument Shelters for Barn Sources. Standard Operating Procedure U1. Purdue Ag Air Quality Lab.
12.9. SOP U6. 2006. The Powerware 9125 Uninterruptible Power Supply. Standard Operating Procedure U6. Purdue Ag Air Quality Lab.

13. Contact Information

13.1. Manufacturer: Thermo Electron Corporation, 26 Tech Valley Drive, East Greenbush, NY 12061.
  13.1.1. Technical Support: 1- 866-282-0430 or 518-452-0065.

13.2. PAAQL: odor@purdue.edu, heber@purdue.edu, http://www.AgAirQuality.com.

Appendix A

Thermo C-14 Beta Sampler Calibration Form

For Samplers Using Firmware V2.049

Site: ________________ Monitor S/N: ___________________ Date: _________________

Temperature Sensor Calibration

Article I. Allow unit to run, calibrate sensors at normal system operating temperatures.
Article II. Calibrtion Menu – unlock code 147
Article III. Sensors submenu – go through each item in turn and adjust as needed. Log the final results after adjustment.

T_1 ambient sensor _______ Reference Ambient Temp ______ Criteria: ± 6 °C

T_2 upper head sens. _______ Reference upper head ______

T_3 lower head sens._______ Reference lower head ______

T_4 heated tube sens._______ Reference heated tube ______

Pressure Sensor Calibration

P_3 ambient ___________ Ref. Barometer ___________ Criteria: ± 10 mmHg

Note: hPa = mm.Hg * 1.33 , mm.Hg = hPa * .75218 (@20^o C)

Flow Rate Calibration

Flow Device Type _______________________ S/N _________________

Sampler Flow _____________ Actual Flow ___________ Criteria: ± 2%

Note: L/m = L/hr / 60

High Voltage Automatic Set Process

2. Service Menu – unlock keypad - Mechanical Control – turn pump off
3. Perform Filter Change & Zero (FC+Z)
4. Watch for QLF figure to have "*" next to it
5. Calibrtion Menu – unlock code 147 – High Voltage & Thresholds – Start – allow 5 minutes until stable, log readings in chart provided here
6. Back up on screens and Save to EEPROM
7. Service Menu – Mech. Ctrl – pump on, zero tape, back up & lock keypad, exit menu.

New HV	**S_{ref}**	**Plateau Slope**

Mass Foil Calibration

1) Operations Menu – unlock keypad if locked – Temp Ctrl System screen – set heater control to Off
2) Let sampler run and wait for $T_2 = T_1$ although being within 2^0C seems to be sufficient
3) Service Menu – Mechanical Control screen – turn pump off.
4) Calibration Menu – Foil Calibration – follow screen prompts step by step
5) Note the Amp Values and log them in the chart to the right
6) Remove span foil and holder per prompt
7) Back up and Save to EEPROM
8) Operations Menu, Temp Ctrl – set heater control to On.
9) Service Menu, Mechanical Control – ensure that pump is On
10) Lock keypad

Foil Span Value $_u$g *	**Old Amp Value**	**New Amp Value**	**Bias % of FS**

** For reference only – from the span foil in the calibration kit used for this test.*

Values Archived to EEPROM? __________

Comments:

Operator:____ Date:_________________

QA Coordinator:___________________________________ Date:_________________

Appendix B. Monthly Maintenance Checks – Thermo Electron FH 62C14 (Beta) Continuous Ambient Particulate Monitor

Site _________________ S/N _______________________ MM/YYYY____________________

Date		Clean PM_{10}	Check Filter Tape	Clean inlet

Flow, Temp, and Press Checks

Date	Parameter (Flow, Temp, or Press)	Ref. Device Value	Beta C-14 Value	Diff.

Criteria : Flow check ± _____% Conversions: Pressure: mmHg = hPa x 0.75218
(From QAPP) Temp check ± _____°C hPa = mmHg x 1.33
Press check ± _____ mmHg Flow: L/m = L/h / 60

Comments: ____

USE OF CONTROL CHARTS FOR PERFORMANCE MONITORING OF GAS ANALYZERS AND ANALYTICAL INSTRUMENTS

Standard Operating Procedure (SOP) Q1

USE OF CONTROL CHARTS FOR PERFORMANCE MONITORING OF GAS ANALYZERS AND ANALYTICAL INSTRUMENTS

Standard Operating Procedure (SOP) Q1

Prepared by
Bill W. Bogan and Claude A. Diehl

Reviewed by
Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Control charts provide a real-time graphical representation of the performance of a gas analyzer or other analytical instrument, which can be used to assess data quality and to spot long-term trends in the instrument's performance. The purposes of control charts are as follows:
  1.1.1. Visual presentation of the quality control of the analyzers and other instruments
  1.1.2. Real-time assessment of the data quality of the analyzers or measurement devices
  1.1.3. To monitor the long-term performance of the instrument
  1.1.4. To determine when a corrective action must be done
1.2. The control charts described in this SOP can be applied to gas analyzers, and to any other type of measurement device (e.g. temperature, relative humidity, and pressure sensors).
1.3. A control chart plotting the standard deviation is beyond the scope of this SOP.

2. Summary of Method

Control Charts are generated by plotting data from the zero-precision checks (SOP G9) with known reference standards (control sample). After the zero-precision check is conducted, the control chart must immediately update to give real-time assessment of the instrument's performance. A control sample is used to check the instrument's performance. The instrument's response to a control sample is an indication of the instrument's deviation from the true value that is a result of intrinsic instrumental measurement error. Control limits are established to maintain statistical control of the data quality. If the reference standard results in a measurement outside the control limits, the control chart is a tool used to alert the analyst / researcher to increased uncertainty in the instrument's measurements. Other Control Chart parameters include the mean and standard deviation of the last *n* samples, where *n* may be from 5 to 20.

3. Definitions

AirDAC	Air data acquisition and control program
Control Limits	The bounds of the range (above and below the true value) that denote acceptable performance of the analyzer or sensor.
Control Sample	A known reference standard
PAAQL	Purdue Agricultural Air Quality Laboratory
QAPP	Quality Assurance Project Plan

4. Cautions

4.1. Use the correct range for the analyzer or sensor, and for AirDAC. A range that is too small will cause the analyzer or sensor's analog output to be pegged in response to the reference standard.
4.2. The control sample applied to check the analyzer or sensor must be consistent over time. In the case of gas analyzers, for example, use the same concentration for the reference gas for the zero-precision check (SOP G9).

4.3. The control sample should be representative of the range of measurements which the analyzer or sensor is expected to measure. In the case of gas analyzers, verify that the concentration of the reference gas is similar to that in the gas samples being analyzed.

5. Personnel Qualifications

5.1. Personnel must be trained in the use of control charts before working with any analyzer or sensor for which a control chart is used.
5.2. Each analyst must also read and understand this SOP before conducting a multipoint calibration (SOP G8) and zero-precision check (SOP G9).

6. Equipment and Supplies

6.1. Computer and AirDAC software program (SOP B2)
6.2. Microsoft Excel software

7. Procedures

7.1. Setup of the Control Chart
  7.1.1. A template of the Control Chart will be supplied by PAAQL to each site, and will be located in the Instrument Performance Record spreadsheet of each individual instrument. Each instrument (analyzer or sensor) will have its own Control Chart.
  7.1.2. General formatting and style (Fig. 1)
    7.1.2.1. Use Microsoft Excel’s x-y plot function for all Control Charts.
    7.1.2.2. Use SI units.
    7.1.2.3. The ratio of the width to height of the chart should be 1.62. This ratio is known as the Golden Ratio, and is related to the Golden Rectangle. A template is in the Instrument Performance Record File.
    7.1.2.4. Use Arial font in graphs and do not bold.
    7.1.2.5. Use 14-point font for the title.
    7.1.2.6. Use 12-point font for all other notations (axes, labels, comments, and numbering).
    7.1.2.7. Place the tic marks on the outside of the graph.
    7.1.2.8. Format each tic label with fixed decimal places.
    7.1.2.9. The x-axis is time (Date). Include one tic mark per week (every 7 d), and label every so many weeks with mm/dd such that the labels fit on the axis.
    7.1.2.10. Don’t use vertical labeling on the x-axis.
    7.1.2.11. Put the legend of the graph on the inside of the chart box, not outside.
    7.1.2.12. Place captions outside the chart.
    7.1.2.13. Avoid redundancies in graph labeling. For example, there is no need for a title, since a caption covers it.
    7.1.2.14. Label the control limits.
    7.1.2.15. Multiple baselines can be used for one instrument.
      7.1.2.15.1. Simultaneous baselines for the precision check gas standard and the zero reference gas can be plotted on the same chart.

7.1.2.16. Ancillary data can be plotted on the control chart (e.g. reaction chamber pressure for a chemiluminescence ammonia analyzer).

7.1.2.17. Include the serial number of the instrument in the control chart.

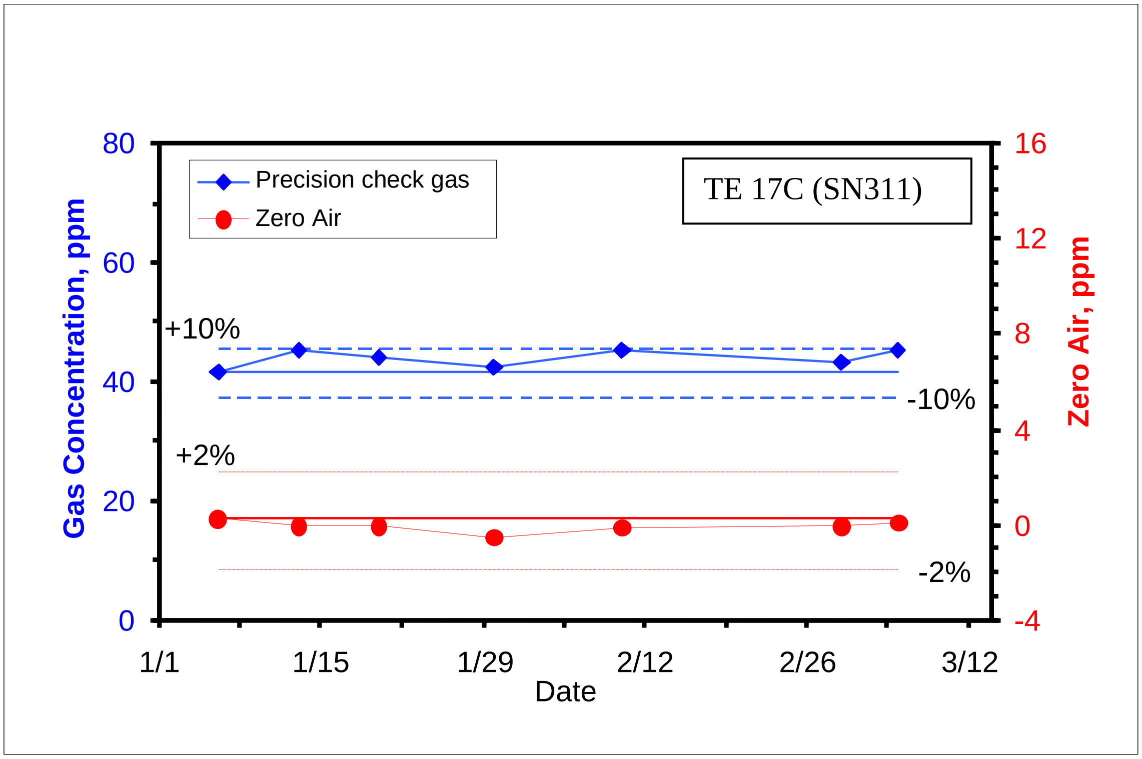


Figure 1. An example of a Control Chart, in this case for a TE 17C Ammonia Analyzer. Two baselines (both components of the zero/precision check) are included, along with their control limits (± 2% for the zero gas and ± 10% for the precision check gas).

7.2. Updating the control chart

7.2.1. Before updating, save the current control chart in the Instrument Performance Record File's "Zero – Precision Record" worksheet to keep a record of past control charts.

7.2.2. The control chart is updated from the zero-precision check data that is tabulated in the Instrument Performance Record File's "Zero – Precision Check" worksheet. This data is entered as described in SOP G9.

7.2.3. The baseline measurement is the first zero-precision check after a multipoint calibration (SOP G8) that is the target value.

7.2.3.1. The baseline measurement is established using a standard reference, the value of which is chosen to be consistent with values that are expected to be measured.

7.2.4. Save the updated control chart in the Instrument Performance Record File's "Zero – Precision Check" worksheet, as described in SOP G9.

7.2.5. Control limits

7.2.5.1. Control limits are used to determine whether the analyzer or sensor has drifted out of calibration.

7.2.5.1.1. Do the following when data points fall outside the control limits:

7.2.5.1.1.1. Access the analyzer's or sensor's operation to determine if the equipment is operating properly or is in need of repair.

7.2.5.1.1.2. Recalibrate the analyzer or sensor, and establish a calibration curve and new control chart

7.2.5.2. The controls limits are set to a ± percentage of the baseline measurement. This percentage is dependent upon the Data Quality Objectives (DQO's) in the QAPP for the gas analyzer or sensor that the Control Chart is monitoring.

7.2.5.3. The control limits can be set in the Instrument Performance Record File's "Zero – Precision Check" worksheet. The percentage is entered into the boxes labeled "Control Limit %" for both the precision control limit and the zero control limit.

8. Data and Records Management

8.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

8.2. Manage all data according to SOP B5.

8.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all corrections.

9. Quality Control and Quality Assurance

9.1. Maintain a control chart for all gas analyzers or sensors specified in the QAPP for the project in question.

9.2. Update the Control Chart immediately after performing a zero/precision check of a gas analyzer (SOP G9) or other sensor.

9.3. Review the Control Chart to assess data quality and instrument performance every time it is updated.

9.4. E-mail the Control Charts to the research leaders (PI, QC Manager, Gas Analyzer Manager, etc.) in a timely manner. The exact list of persons who should receive Control Charts, and the frequency, will be specified in the QAPP for the particular project.

9.5. Keep a printout of the most recent Control Chart for each analyzer or sensor in the on-farm instrument shelter (OFIS). Keep these copies available for site audits, either by PAAQL personnel or outside QA auditors.

10. References

10.1. Taylor, J.K. 1987. Quality Assurance of Chemical Measurements. CRC Press LLC, Boca Raton, FL.

10.2. Ingersoll, W.S. 2001. Environmental Analytical Measurement Uncertainty Estimation – Nested Hierarchical Approach. Defense Technical Information Center # ADA396946. Online at http://www.stormingmedia.us/00/0037/A003793.html. Accessed 6/23/2006.
10.3. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
10.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
10.5. SOP G1. 2006. The PAAQL Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.
10.6. SOP G3. 2006. Measurement of Carbon Dioxide (CO_2) with the MSA Model 3600 Infrared Gas Monitor. Standard Operating Procedure G3. Purdue Ag Air Quality Lab.
10.7. SOP G4. 2006. Measurement of Ammonia (NH_3) Using the TEI Model 17C Chemiluminescence Analyzer. Standard Operating Procedure G4. Purdue Ag Air Quality Lab.
10.8. SOP G5. 2006. Measurement of Hydrogen Sulfide (H_2S) with the Thermo Electron Corporation Model 45C Pulsed-Fluorescence Analyzer. Standard Operating Procedure G5. Purdue Ag Air Quality Lab.
10.9. SOP G6. 2006. Measurement of Methane and Non-Methane Hydrocarbons with the Thermo Electron Corporation Model 55C Analyzer. Standard Operating Procedure G6. Purdue Ag Air Quality Lab.
10.10. SOP G7. 2006. Use of the INNOVA 1412 Photoacoustic Multi-Gas Monitor. Standard Operating Procedure G7. Purdue Ag Air Quality Lab.
10.11. SOP G9. 2006. Zero and Precision Checks of Gas Analyzers. Standard Operating Procedure G9. Purdue Ag Air Quality Lab.
10.12. SOP G10. 2006. Measurement of Ammonia Using the MSA Photoacoustic Infrared (IR) Analyzer. Standard Operating Procedure G10. Purdue Ag Air Quality Lab.
10.13. SOP G11. 2006. Operation of the Environics® Computerized Gas Dilution System. Standard Operating Procedure G11. Purdue Ag Air Quality Lab.

PRODUCER COLLABORATIONS AT BARN MONITORING SITES

Standard Operating Procedure (SOP) S1

PRODUCER COLLABORATIONS AT BARN MONITORING SITES

Standard Operating Procedure (SOP) S1

Prepared by

Albert J. Heber and Bill W. Bogan

Reviewed by

Juan Carlos Ramirez and Lingying Zhao (Ohio State Univ.)

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

The success of on-farm air-quality studies depends on communication and collaboration between the research staff, who are vitally interested in collecting high-quality air emission data from the site, and the livestock producer, whose main interest is to operate his/her facility for profit. The livestock producer and his/her staff may or may not have an intense interest in the data. This SOP, therefore, establishes procedures to optimize collaboration between the researcher and the producer, describes research-related information that must be collected from producers, delineates certain expectations, and outlines possible modifications to farm operations that may be needed to accommodate the study.

2. Summary of Method

The facility design and operational information of the farm must be provided by the producer to the researcher. In addition, the researcher must communicate to the producer those requirements which he/she must meet in order to conduct a successful study. The research team must be guided in effective communication with a livestock production entity. The collaboration and communication will include email messages, phone calls, face-to-face meetings, reports, data forms, presentations, data monitoring, and project documentation such as the Quality Assurance Project Plan.

3. Definitions

3.1.	SOP	Standard Operating Procedure
3.2.	Biosecurity	Preventing spread of disease to or from livestock or poultry.
3.3.	QAPP	Quality Assurance Project Plan

4. Health and Safety

4.1. Beware of and do not interrupt worker traffic. Research personnel may request a slight delay or interruption in normal activities during set up and disassembly of instrumentation, but must always defer to the decisions and activities of the farm staff.

4.2. Watch out for vehicular traffic such as litter, feed, animal, milk, and egg trucks, loaders, cars, and other vehicles.

4.3. The farm’s licensed electrician must conduct or approve all electrical work associated with the study. An example is connecting power to the instrument shelter.

4.4. Be careful around animals and birds to prevent personal injury.

4.5. Beware of moving apparatus such as manure scrapers, manure belts, feed delivery augers and belts, ventilation fans, etc. When working in close proximity to moving equipment, belts, or fans, avoid loose-fitting clothing or dangling jewelry which could become caught in the equipment. Put up or secure long hair.

4.6. Ensure that power is disconnected to fans when installing ventilation measurement equipment.

4.7. Stay out of confined spaces such as covered manure pits to avoid exposure to potentially dangerous levels of gases. Stay out of the barn when liquid manure in underfloor pits is agitated because manure agitation releases dangerous levels of hydrogen sulfide.

4.8. Wear protective clothing to prevent exposure to manure, dust particles, and noxious and toxic gases. Ammonia typically rises above the 35-ppm OSHA short-term exposure threshold.

  4.8.1. Research personnel should wear clean gloves when handling the the Producer Event Forms, or any other paperwork, to avoid exposure to potential contamination transferred by farm personnel who may have filled out the form in the barn with contaminated hands.

4.9. Emergency evacuation procedures at each measurement location will be those established by the livestock producer.

4.10. Post the phone number for medical emergency personnel and directions (map) to the nearest hospital in the instrument shelter close to the entrance.

4.11. Maintain a first aid kit in the instrument shelter.

5. Cautions

5.1. Notify the producer before any “preliminary” visits (for example, when visiting a site to assess its suitability), or when beginning site setup. Once research has been “established” at the site, it will most likely not be necessary to provide notification of routine weekly site visits, etc. Nonetheless, ascertain and follow the individual producer’s policy in this regard.

5.2. Take steps to overcome language barriers (e.g. Spanish vs. English). For example, if the majority of the workers are of Hispanic origin, distribute a pamphlet in Spanish indicating the objectives of the study and the importance of the taking care of the instrumentation. The pamphlet can be complemented with a video in Spanish (possible a PowerPoint presentation with audio in Spanish, or any language needed) that can be distributed to all the research sites, and can be included in a periodic (quarterly) refreshing session (considering that the rotation of workers in the farms can be high).

5.3. Post signs or labels by sensitive test equipment that indicates it must not be touched unless authorized by study personnel. Make sure that these are also written in the primary language(s) of the farm workers.

5.4. Research personnel must follow all biosecurity protocols and guidelines requested by individual producers. At minimum, these can be expected to include:

  5.4.1. Use of disposable boot covers and overalls (Section 8.1)

  5.4.2. Cleaning research vehicles and equipment entering the farm according to the producer’s specific protocol

  5.4.3. Accessing only areas or barns that are directly involved in the study, and avoiding contact with livestock and areas that the farmer has designated as off-limits

  5.4.4. Avoiding contact with dead animals

  5.4.5. Avoiding driving across feed delivery lanes to reach the pile or lagoon, or when leaving the pile or lagoon

  5.4.6. Ensuring that study personnel coming onto the farm have not exceeded producer-specified limits on foreign travel and/or visits to other poultry or livestock farms

5.5. To the greatest extent possible, solicit input and suggestions from the producer as to safe locations for equipment, possible hazards which might occur, and appropriate precautions which might best protect equipment and staff.

5.6. Remember that the producer's involvement and time commitment to the project is less than that of the research staff. The amount of time required for the livestock producer or his/her staff to execute their commitments to the study is a major factor influencing current and future involvement. Take care not to use more of the producer's and/or staff's time than is absolutely required for the study.

6. Interferences

6.1. Farm should operate with typical management, as though there were no study.
  6.1.1. Producers should notify researchers if research equipment is interfering with farm operations and needs to be moved or modified. Producers must agree not to move or modify study equipment themselves, unless failure to immediately move the equipment would result in its damage, or harm to persons or animals.
6.2. Tours of the study site must not be given without producer permission. Establish a policy about tours prior to set up of the instrumentation on the farm.
6.3. Any add-on research projects at the farm must be approved by the producer.

7. Personnel Qualifications and Training

7.1. All producer and research personnel involved in the study must read and understand this SOP.
7.2. A pre-study training and orientation session will be conducted by the research team and will include time for the producer to explain the farm operation. The training session will be conducted also in the primary language(s) of the farm workers. Translate any supporting documents or media which are included in the presentation (e.g. pamphlets or videos – Section 5.2) into the primary language(s) of the farm workers.

8. Utilities, Equipment and Supplies Provided at Farm

8.1. Personal protective clothing/equipment
  8.1.1. Levels of protective clothing will likely vary at a given facility, depending upon the season, current ventilation rate of the barn, and other factors.
  8.1.2. Protective clothing may be provided by the researchers, or by the producers, depending, for example, on the preferences of the producer. Reach an agreement on this point with each producer at the beginning of the study.
    8.1.2.1. For example, if producers wish to supply their own boots as part of their biosecurity program, researchers will abide by this preference.
8.2. Electric power (see SOP U1 Barn Instrument Shelter).
8.3. Phone line in instrument shelter
8.4. Internet service
8.5. A garden hose with a nozzle at the instrument shelter
8.6. Restroom and shower facilities, if available
8.7. All-weather (e.g. gravel) access to the instrument shelter
8.8. Mowing of grass, and/or other weed-abatement measures as necessary, in the vicinity of the instrument shelter

9. Procedures

9.1. Detailed information about the farm will be collected for each participating site as part of the site selection process. The site selection criteria and the characteristics of the test site and the barns are in Appendix A.

9.2. Producers will allow free access to farm by project staff.

9.3. Research staff will obtain photos of the site, preferably from several directions, documenting the locations of buildings and (if applicable) lagoons, topography of site, and placement location of the on-farm instruments shelter(s), Fig. 1.

9.4. Producers will be made aware of all necessary structural modifications (e.g. access holes into barns for sensor wires and gas sampling lines). See SOP U2 for Installation of Barn Measurements.

- 9.4.1. Provide a project schedule and QAPP to the producer at least 90 days prior to beginning any data monitoring.
- 9.4.2. Set up a monthly phone call with farm management to solve problems, provide updates and facilitate collaboration.
- 9.4.3. During the course of the study, each collaborating producer is requested to provide the university the following information for each barn (Table A2 in Appendix A):
  - 9.4.3.1. Animal inventory, average weight and average age
  - 9.4.3.2. Animal diet (feed composition, including nitrogen and sulfur levels, and feed consumption)
  - 9.4.3.3. Production (quantity and weight) of marketed animals, birds, eggs, milk, etc.
  - 9.4.3.4. Record of manure removals (for indoor manure storage)
  - 9.4.3.5. Record of cleaning operations
  - 9.4.3.6. Record of animal movements in and out of the barn
  - 9.4.3.7. Record of water consumption
  - 9.4.3.8. Advance notification of any alteration in production schedules and methods

9.5. Make sure that the producer understands that placement of equipment may in some cases require that some spaces, cages, or enclosures currently occupied by animals or birds be emptied or modified to include protective structures. Work with the producer to ensure that both the equipment and animals are well-protected.

- 9.5.1. Trailers which are placed in lots accessible to animals will likely need to be enclosed with protective fencing.
- 9.5.2. Tiers of layer cages may need to be emptied for placement of sensors (e.g. relative humidity sensors), so that the birds neither damage the sensors nor injure themselves.
- 9.5.3. Equipment placed in areas which may occasionally be accessed by animals (e.g. alleys in swine barns) may need protective enclosures.
- 9.5.4. Manure walls may in some cases need to be added to protect equipment.

9.6. Livestock producer or his/her staff should contact the PM/PI whenever there are any questions or concerns relating to measurement operations, or if there is catastrophic damage to farm operations.

9.7. Computer hardware & software

- 9.7.1. Data from the Producer Event Form (Appendix B) will be entered into an Excel spreadsheet.
- 9.7.2. PCAnywhere will be used by the research team to remotely access the data acquisition computer.

10. Data and Records Management

10.1. Site Identification. Each site will be labeled in a standard format to denote site type (in this case, area component), location and number. For example, the finisher swine barn site in Indiana is "IN3B". This format is described in more detail in SOP B5. Producers shall not be identified in each site plan.

10.2. Keep a bound notebook at each site that will include a log of farm visits, original copies of Producer Event Forms, and all other written documentation pertaining to the site. Write all entries in indelible ink. Overstrike all errors in writing with a single line; initial and date all such corrections.

10.3. The producer will maintain a log sheet (Producer Event Form – Appendix B) of non-monitored farm activities that affect emissions. Examples of pertinent events to record on the Producer Event Form include:

  10.3.1. Fan failures, maintenance, or cleaning
  10.3.2. Barn cleaning
  10.3.3. Major water leaks
  10.3.4. Power interruptions
  10.3.5. Manure removals
  10.3.6. Diet changes (composition or feeding rate)
  10.3.7. Molting of birds, or any other change in condition or activity which might influence particulate levels

11. Quality Control and Quality Assurance

11.1. Each research team member must maintain a log listing all of his/her exposures to animals at other farms. This will be used to document adherence to the farm's biosecurity protocol, and to provide information to track infections should any occur.

11.2. Monthly conference calls ensure communication between researchers and producer.

11.3. During each site visit, verify that farm staff are filling out the Producer Event Form, because they do not normally record such data during daily or weekly activities.

11.4. Document all decisions and action items on paper in ink during all planning and status meetings so that it can be confirmed that all parties are in agreement.. Keep copies of these in the bound site notebook (Section 10.2).

11.5. Be sure producer has a hard copy of this SOP, the relevant Site Monitoring Plan, and the project management chapter of the QAPP (which will include project management, the rationale for the study and project schedule), and access to the full QAPP on the internet.

11.6. The training sessions will include a verification of understanding of the basic aspects of the project, importance of the instrumentation and effects of farm operation on the study. Each attending producer or staff member will be directly engaged in a question and answer session, which may be supplemented with a questionnaire.

11.7. Producer should designate a responsible staff member (liaison between the farm and the research team) for collecting and transmitting operational information, and also provide the name of his or her substitute when he or she is not available in the plant. This person should attend all the informational meetings.

11.8. Scan all producer event forms, and keep them, both in electronic form (Word or Excel format) and in paper form at the site. Summarize the electronic copy on a weekly or monthly basis, and send this summary to the research leader.

12. References

12.1. SOP U1. 2005. On-farm Instrument Shelters for Barn Sources. Standard Operating Procedure. Purdue Ag Air Quality Lab.
12.2. SOP B5. 2005. Standard Operating Procedure for Data Management for Barns. Purdue Ag Air Quality Lab.

Figure 1. Typical barn monitoring site with instrument shelter between two monitored barns.

Appendix A: Barn Site Information Forms

Table A1. Site Selection Criteria

Category	Information
Farm name	
Address, phone	
Producer	Willing to provide production information?
	Cooperative and enthusiastic?
	Willing to make some inconsequential changes to system for the test?
	Willing to train herdsmen or flock managers about importance of test?
	Able to provide information about feed and water consumption?
	Willing to test abatement technologies after the NAEMS?
	Describe management style
Convenience	All weather access?
	Cell phone signal?
	Phone line available for instrument shelter?
	Internet available?
	Lodging nearby for research team?
	Electric power available for trailer?
Barn	Generally describe rations (pelleted, fat added, etc.)
	Describe feed delivery system
	Describe waste collection, handling and treatment system
	Rate barn hygiene from 1 to 5 (1 is cleanest)
Surroundings	Describe surrounding landscape
	Describe other pollution sources (for example, other farms or industrial operations) within one mile of site
Farm	Describe all barns on the site (# hd, size, age)
	Describe land application sites
	List any other animal species on site
	Distance from public road? Type of road (gravel or paved)?

Table A2. Characteristics of test site and barns*.

Descriptive parameters.	Barn 1	Barn 2	Barn 3
Livestock type (layers, etc.)			
Inventory (number of animals)†			
# barns at site			
Year(s) of construction			
Barn type			
Barn orientation			
Distance to site from university, miles			
Age of animals/birds on 1/1/06			
Type of animals/birds (genetics)			
Average mass, lb			
Animal occupation, d			
Number of tiers of pens			
Shower in/out?			
Barn width, ft			
Barn length, ft			
Barn area, ft^2			
Ridge height, ft			
Sidewall height, ft			
Barn spacing, ft			
Basement depth, ft			
Manure collection			
Manure storage in barn, d			
Number of pit circulation fans			
Number of room circulation fans			
External storage			
Duration of external storage, d			
Number of air inlets†			
Inlet type			
Inlet adjustment method			
Inlet control basis			
Controls vendor			
Number of exhaust fans†			
# variable speed fans			
Largest fan dia., in.			
Smallest fan dia., in.			
Fan spacing, in,			
Fan manufacturer			
# ventilation stages‡			
# temperature sensors†			
Emergency ventilation			
Artificial heating			
Summer cooling			
Internet service type			

*including the manure storage section, †per barn or room, ††one sampling probe located between the barns represents inlet air for both barns.

Appendix B. Producer Event Form

In order for the Purdue Air Quality group to do it's job, they need to know about changes around the barns that affect airflow, air emissions and other data. A few jotted notes here will help them not make mistakes when analyzing data. Thank you! Examples of events are: molting, fan failures, barn cleaning operations, major water leaks, power interruptions, generator tests, manure removals, and diet changes.

Description of Event	Start time/date	End time/date	Contact person

Researcher contact information:
Name(s):____
Office phone:_________________________
Cell phone:_________________________

RECORDING AND TRACKING ANIMAL INVENTORY AT LIVESTOCK BARNS

Standard Operating Procedure (SOP) S2

RECORDING AND TRACKING ANIMAL INVENTORY AT LIVESTOCK BARNS

Standard Operating Procedure (SOP) S2

Prepared by

Sam M. Hanni and Bill W. Bogan

Reviewed by

Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. The number, age, and size (life cycle stage) of animals housed in a facility are key factors in determining air emission factors for the facility.
1.2. This SOP describes a protocol for collecting information on each of these parameters for use in agricultural air quality monitoring and modeling studies.
1.3. This SOP spells out in greater detail the data that individual producers are expected to provide (SOP S1) regarding the animal inventory at their facilities.

2. Summary of Method

The barn inventory for cattle and swine will be determined by counting each animal. For caged layer birds, a selected number or percentage of the cages in each house (as specified in the QAPP) will be counted to obtain a per-pen average, which will then be multiplied by the known number of pens in the house. Since boilers are not housed in cages, an estimate of the total inventory will be obtained by counting the number of cages that hold the birds during transportation and multiplying by the average population in those cages (again, determined by averaging the counts in a prespecified number of cages). The total weight for barns housing swine layers, broilers and cattle will be determined by weighing a percentage of the animals in each barn that is being sampled, averaging the weights, and multiplying by the total inventory.

3. Definitions

3.1. **Growth Period:** The duration of time that an animal is in a facility
3.2. **Closeout:** The end of a growth period, at which time the barn is emptied
3.3. **Portable livestock scale:** A certified scale that is compact and easily moved by two individuals. The scale's range should correspond to that of the animals' beginning and ending weights.

4. Health and Safety

4.1. Wear a dust mask and ear plugs while weighing animals.
4.2. Use proper lifting technique when lifting or moving animals or scales.
4.3. Cattle can become frightened if they are approached too closely, and can cause injury to the individual taking the count. See Section 9.3.1 for procedures for counting cattle.

5. Cautions

5.1. Take steps to make sure a correct inventory was taken by the producer.
  5.1.1. Collect all inventory records before they are removed from the barn or are lost at the end of a growth period.
5.2. Animals that are removed from a cage or pen to be counted or weighed should be returned to the same pen.
5.3. Do not startle the animals or chase the animals in a pen.

5.4. Make sure that all scales have been properly calibrated (Section 11.1).

6. Interferences

6.1. Farm workers may need to interrupt counts to conduct operations. Try to schedule counts so they will not conflict with normal farm procedures.

6.2. The movement of animals from one location in a pen to another location in the pen could result in an inaccurate count. When manually counting livestock, verify the numbers by repeating the count.

6.3. Make sure that scales are level and free of dirt or manure.

7. Personnel Qualifications

7.1. All producer and research personnel involved in the study should read and understand this SOP.

7.2. A pre-study training and orientation session will be conducted by the research team and will include time for the producer to explain the farm's operation. The training session will also be conducted in the primary language of the farm workers with help of the translated video or PowerPoint presentation.

7.3. Individuals should gain experience in handling animals before moving animals without experienced supervision. Persons who do not have experience catching and handling livestock of the particular species at a site must work with, or be supervised by, farm personnel when directly handling the animals.

7.4. Each individual involved in the weighing of livestock must read and understand the manufacturer's manual for each scale used at that site. See Section 11.1.

8. Equipment and Supplies

8.1. Clipboard
8.2. Inventory worksheet
8.3. Pencils
8.4. Livestock marker
8.5. Portable livestock scale
8.6. On-farm livestock scale
8.7. Livestock tags
8.8. Sorting board

9. Procedures

9.1. General procedures
  9.1.1. Before data collection begins, collaborate with the producer or site manager.
    9.1.1.1. Request access to inventory worksheets.
    9.1.1.2. Learn how the producer inventories the livestock in each barn.
    9.1.1.3. Obtain copies of the inventory worksheet at the beginning of each growth period after a barn has been filled, and at closeout.

    - 9.1.1.4. Determine the type(s) of scale used by the farm to weigh livestock. Obtain a copy of the manufacturer's manual for that model of scale (Section 11.1).
    - 9.1.1.5. The QAPP will specify how often inventories should be taken in each barn.
  - 9.1.2. Weigh all livestock before it enters the barn and after it has left the barn.
  - 9.1.3. Before livestock enter the barn, take an average weight of all animals.
    - 9.1.3.1. Weigh trucks carrying animals to or from the barn (both empty and full weights).
      - 9.1.3.1.1. Weigh each truck immediately before it is filled and immediately after it has been filled.
      - 9.1.3.1.2. If possible, the truck weights should be taken on scales that have been calibrated by the Department of Transportation, or other responsible state agency. If the scale is located at the farm, refer to Section 11.1. The scale must be able to hold both the tractor and the trailer.
    - 9.1.3.2. Obtain all weights by retrieving copies of scale sheets from the producer.
    - 9.1.3.3. To obtain the average animal weight, subtract the empty weight of the truck from the full weight, and divide by the total number of animals on the truck
  - 9.1.4. Count the number of animals or birds in each barn.
    - 9.1.4.1. Preferably, two people should work together when counting livestock.
    - 9.1.4.2. Individually count each animal in a pen or cage.
    - 9.1.4.3. Confer and reach agreement on the count before moving to the next pen or cage.
    - 9.1.4.4. Record the count of the pen or cage on the inventory worksheet. If it helps, take pictures of the animals.
    - 9.1.4.5. Calculate the barn inventory.
- 9.2. Swine
  - 9.2.1. For finishers or nurseries:
    - 9.2.1.1. Count pigs on a per-pen basis.
      - 9.2.1.1.1. If possible, stand in the middle of the pen so that the entire pen can be seen.
      - 9.2.1.1.2. With producer permission, mark each animal with a livestock marker to ensure that each animal is counted. One person should do all marking; both should count.
        - 9.2.1.1.2.1. If the pen needs to be recounted, use a different color marker.
      - 9.2.1.1.3. Confer with the individual assisting in the counting.
        - 9.2.1.1.3.1. If the two counts are not the same, immediately recount the pen.
      - 9.2.1.1.4. If the count is correct, record the value and move to the next pen.
      - 9.2.1.1.5. After counting the last pen, add up the total number of pigs.
    - 9.2.1.2. To obtain an average weight of the barn, randomly select pig(s) from a pen, tag them with a livestock tag, and obtain individual weights.
      - 9.2.1.2.1. The total number of pigs which must be weighed to determine the barn average will be specified by the QAPP.
      - 9.2.1.2.2. Use tags to ensure that the same pigs are weighed each time.
      - 9.2.1.2.3. Moving from pen to pen, weigh each tagged pig with a portable scale.
        - 9.2.1.2.3.1. Move each selected pig onto the scale using a sorting board.
        - 9.2.1.2.3.2. Once the pig stops moving, and the weight does not fluctuate, the second person should write down the animal's tag number and weight.
      - 9.2.1.2.4. Mark each pig that is weighed with a livestock marker before it is returned to the pen that it came from.

        9.2.1.2.5. After all tagged pigs in a pen are weighed, move to the next pen.
    9.2.2. For gestation, breeding, or farrowing barns:
      9.2.2.1. Count the total sows and gilts located in each barn that is being sampled.
      9.2.2.2. Obtain an average weight for the barn by weighing individual animals.
        9.2.2.2.1. The QAPP will specify the percentage of animals to be weighed during the study, as well as the required frequency.
        9.2.2.2.2. Moving from crate to crate or pen to pen, weigh each sow or gilt on a portable livestock scale.
        9.2.2.2.3. Record the sow or gilt number, so that it can be identified for future weighing periods.

9.3. Dairy cattle in corrals or free stalls
  9.3.1. Counting procedures
    9.3.1.1. Do not mark or approach cattle. Cattle can become frightened if they are approached too closely, and could cause injury.
      9.3.1.1.1. Counters lacking experience around cattle should consult the site manager.
    9.3.1.2. Enter the pen, keeping a 10- to 15-ft space between yourself and the animal(s).
    9.3.1.3. Both counters should walk from one end of a pen to the other, counting each animal as they pass.
    9.3.1.4. If the animals become crowded, walk around the group, making sure that every animal can be seen and counted.
    9.3.1.5. Upon completing the count, confer with the individual assisting in the counting.
      9.3.1.5.1. If the two counts are not the same, immediately recount the pen.
  9.3.2. Weighing procedures
    9.3.2.1. Randomly weigh dairy cattle located in the barn or corral where the sampling is taking place. This should be done throughout the study.
      9.3.2.1.1. The total number of cows that must be weighed to determine the average, as well as the frequency of weighings, will be specified by the QAPP.
      9.3.2.1.2. If the scale is large enough, several cattle can be weighed at once and the average weight can be calculated for each animal.
      9.3.2.1.3. If the farm does not have a scale, weigh animals that are being moved onto or off of the farm using a truck scale.
        9.3.2.1.3.1. Copy and store all truck scale weigh scale sheets according to SOP B5.
    9.3.2.2. Calculate animal weights according to Section 9.1.3.3.

9.4. Caged layers
  9.4.1. Count layers on a per-cage basis.
    9.4.1.1. Contact the site manager to ensure that all cages are in use.
    9.4.1.2. Randomly select cages throughout the barn.
      9.4.1.2.1. The total number of cages that must be counted, as well as the frequency, will be specified in the QAPP.
    9.4.1.3. Both counters should look through the cage and visually count each bird.
    9.4.1.4. Upon completing the count, confer with the individual assisting in the counting.
    9.4.1.5. If the two counts are not the same, immediately recount the cage.
    9.4.1.6. Write down the total number of birds in the cage before moving to the next cage.
    9.4.1.7. After all of the required cages have been counted, add up the total number of birds that were counted.

      - 9.4.1.8. Divide the number of birds counted by the total number of cages counted to obtain average number of birds per cage.
      - 9.4.1.9. Multiply the average number of birds per cage by the total number of cages to obtain an estimate of the total number of birds per barn.
    - 9.4.2. To obtain an average weight of the barn, weigh individual birds from each cage.
      - 9.4.2.1. Moving from cage to cage, weigh all the birds in the cage on a portable livestock scale.
      - 9.4.2.2. Mark each bird before it is returned to the cage, so birds are not weighed twice.
      - 9.4.2.3. After all the birds in the cage have been weighed, move to the next cage.
      - 9.4.2.4. Record all cage numbers so that they can be identified for future weighings.
- 9.5. Broilers
    - 9.5.1. Count broilers as they enter the barn.
      - 9.5.1.1. Randomly select boxes of new chicks and count each bird in the box.
        - 9.5.1.1.1. The total number of boxes required will be specified by the QAPP.
      - 9.5.1.2. Count the total number of boxes that are unloaded, and multiply by the average number of chicks in the counted boxes to obtain an estimate of the total number of chicks entering the barn.
      - 9.5.1.3. Verify the all counts (# of boxes, # of chicks in each box) with a partner to ensure accuracy.
      - 9.5.1.4. Compare the number with the total count from the hatchery.
        - 9.5.1.4.1. If the two counts disagree by more than 1%, take the hatchery count as the actual count, as it is more likely to be accurate.
    - 9.5.2. Count broilers as they are loaded into cages for shipment to the slaughtering plant.
      - 9.5.2.1. Randomly select cages as they are being loaded, and count the total number of birds entering the cages.
      - 9.5.2.2. Count the total number of cages that are loaded, and multiply by the average number of birds in the counted cages to obtain an estimate of the total number of birds leaving the barn.
      - 9.5.2.3. Verify all counts (# of cages, # of birds in each cage) with a partner to ensure accuracy.
      - 9.5.2.4. Compare this count with the count at the slaughtering plant.
        - 9.5.2.4.1. If the two counts disagree by more than 1%, take the slaughtering plant count as the actual count, as it is more likely to be accurate.
    - 9.5.3. To obtain an average weight of the barn, catch randomly selected birds throughout the barn.
      - 9.5.3.1. Weigh the birds on a portable livestock scale.
      - 9.5.3.2. The total number of birds which must be weighed will be specified in the QAPP.

10. Data and Records Management

- 10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
- 10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

11. Quality Control and Quality Assurance

11.1. Properly calibrate all truck scales and livestock scales before use.
  11.1.1. Livestock scales that are provided by the farm will be calibrated according to the manufacturer's specifications for the particular model of the scale.
    11.1.1.1. If the farm cannot provide a manual for the scale, contact the manufacturer directly to obtain a manual.
    11.1.1.2. Calibration frequency should be that specified in the manual or every three months, whichever is less.
  11.1.2. Truck scales
    11.1.2.1. If possible, use truck scales that have been calibrated, maintained, and certified by a state governmental agency.
    11.1.2.2. If using a truck scale on a farm, follow the same procedure outlined in Section 11.1.1.
11.2. To add up the total livestock count, use a calculator or excel spreadsheet.
11.3. If possible, have two people making counts, so that the count can be verified before moving to the next pen, box, or cage.

12. References

12.1. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.2. SOP S1. 2006. Producer Collaborations at Barn Monitoring Sites. Standard Operating Procedure S1. Purdue Ag Air Quality Lab.

ACTIVITY MEASUREMENTS

Standard Operating Procedure (SOP) S3

ACTIVITY MEASUREMENTS

Standard Operating Procedure (SOP) S3

Prepared by

Juan Carlos Ramirez

Reviewed by

Ji-Qin Ni, Albert J. Heber, Bill W. Bogan,

and Matt J. Darr (Ohio State Univ.)

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

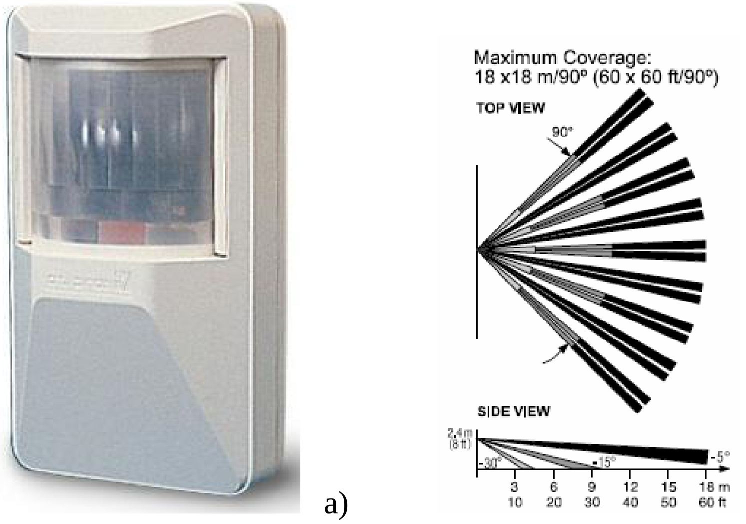
1. Scope and Applicability

1.1. This procedure refers to the equipment and methods to monitor the activity of animals (dairy cows, pigs, and broiler and layer chickens) and farm workers in confined animal feeding operations (CAFOs) using the Visonic SRN 2000 detector (Figure 1a). It is also applicable to project workers in the on-farm instrument shelter.

1.2. Activity data allow correlations to be drawn between animal activity and pollution generation patterns, especially those of the particulate matter (PM), ammonia and carbon dioxide. They also allow for tracking and recording the time(s) when maintenance is conducted in certain areas of the barns, and when site visits are made to the instrument shelter. The activity information for animals and workers helps to interpret aerial pollution data, and to improve quality assurance (QA) and quality control (QC).

1.3. This method detects activity which occurs within 18 m of the sensor, depending on detector configuration and mounting. With the standard lens, which has three layers and 38 beams, and a 90° monitoring angle, the maximum coverage is 18 m x 18 m (Figure 1b).

1.4. One limitation of the detector, when it is used as an activity sensor, is that the intensity of the output signal also depends on the distance of the infrared emission body. A small movement of a body close to the detector can generate an output signal equivalent to a larger movement of a body farther away from the detector.



a) b)

Figure 1. Visonic SRN 2000 detector (a), and its layered beams (b) (Visonic, 2002).

2. Summary of Method

2.1. Live animals and workers emit infrared radiation. When animals or workers are active, the infrared sources move. These infrared source movements can be detected by a passive infrared (PIR) detector operating according to the pyroelectric principle.

2.2. The pyroelectric sensor inside the PIR detector is made of a crystalline material that generates a surface electric charge when exposed to infrared radiation. The sensor elements are sensitive to radiation over a wide range, so a filter window is needed to establish an incoming range that is most sensitive to animal and human body thermal radiation. The pyroelectric sensor has two sensing elements. A radiation source passing in front of the sensor will activate the first element and then the other. The radiation source must pass across the detector in a horizontal direction if the detector is vertically installed (Glolab, 2006).

2.3. This method utilizes the SRN-2000 PIR detector because it provides analog output signals and has a wide detection range. The detector output is proportional to the temperature difference between the object and the background (Pederson and Pederson, 1995), as well as the angular velocity of the object.

2.4. The 0-4 VDC sensor output signals are sampled at 1 Hz, converted to 0-2 VDC proportional to motion strength (but inversely proportional to body distance), averaged over 15 s and 1 min, and saved in two data files, respectively, together with other measurement data by the DAQ system.

3. Definitions

3.1.	CAFO	Confined Animal Feeding Operation
3.2.	PIR	Passive Infrared Detector
3.3.	LED	Light-Emitting Diode
3.4.	DAQ	Data acquisition
3.5.	AirDAC	Air quality data acquisition and control program
3.6.	OFIS	On-farm instrument shelter

4. Health and Safety

4.1. The sensor will collect dust and fly specks; wear gloves when cleaning and/or maintaining the sensors.

4.2. When installing the sensor and lining up the signal cables on the barn ceiling, use the proper ladder height for safe and comfortable installation.

4.3. When using an electric drill to install the sensor and its bracket on the barn ceiling or wall, follow safety procedures for routing the electric cable from the electric outlet to the location of the sensor. Install warning signs to alert the farm workers to the location of cable, so as to prevent a tripping hazard.

5. Cautions

5.1. When servicing any of the wire connections to the sensor, shut off the exciting power (12 VDC) supply inside the instrument shelter to avoid short-circuits and damage of the sensor and the DAQ system.
5.2. Schedule a periodic cleanup of the sensor lens depending on the environment. A dirty lens reduces the sensitivity of the sensor.
5.3. When sealing the opening of the sensor for protection, avoid covering the lens.

6. Interferences

6.1. There are two small holes (about 3 mm diameter) on the enclosure of the sensor. They may allow dust to enter into the sensor. Place short pieces (about 1 cm long) of electric tape over these holes to seal them.
6.2. The orientation of the sensor is of great importance for optimal performance. This orientation needs to be permanently fixed, so that all signals can be compared. Fix the sensor cable so that it will not pull the sensor and change its orientation.
6.3. To minimize false activity readings, avoid aiming the sensor at heaters, bright lights, or windows with incident sunlight.
6.4. Avoid running the sensor cable close to high voltage electrical power cords.
6.5. Avoid running the sensor cable through areas accessible to animals. Animals may chew or otherwise damage cables.
6.6. When monitoring animal activity, worker activity will interfere. Locate the sensor to minimize such interferences.
6.7. When monitoring worker activity, locate the sensor so that it does not pick up animal activity.

7. Personnel Qualifications

7.1. The installer must have some experience with electronic sensors, or have received specific training in the installation of these activity sensors.
7.2. The installer and operator(s) must read this SOP and the Visonic Installation Instructions (Visonic, 2002) before installing or operating the instrument.

8. Equipment and Supplies

8.1. Passive Infrared Detector (SRN-2000N, Visonic, Ltd., Bloomfield, CT). Vendor Information: ADI, 9745 Industrial Dr, Unit 2, Bridgeview, IL 60455. Phone#: (708) 599-1390, Fax #: (708) 599-1525.
8.2. A metallic strip to hold the sensor. This should be approximately 0.5 in.wide and a minimum 7 in. long, flexible enough to be bent by hand, but stiff enough to hold its shape under the weight of the sensor. Such strips are generally available at local hardware stores.

8.3. Suitable cable to connect the sensor to the exciting voltage, and to relay signals to the instrument shelter. Use 3-conductor, 22-gage shielded cable for maximum wiring lengths of 230 m, or 20-gage for wiring lengths up to 330 m.
8.4. Machine screws to fix the metallic strip to the sensor
8.5. Sheet screws or wood screws to fix the metallic strip to the wall or ceiling
8.6. Cable ties to secure the cable
8.7. Labels to identify the instrument, the objective of the sensor, and a caution to the barn operator(s) to not disturb the sensor. The label also needs to convey the same information in the primary language of the farm workers. It should indicate the name of the farm contact person if any question arises (such as the need to move the sensor(s) because of maintenance or other work).
8.8. Electrical tape to close small openings in the sensor body
8.9. Phillips or flat screwdriver
8.10. Electric or battery operated drill
8.11. DC voltmeter (20K ohms/volt) or multimeter to verify the integrity of the sensor if necessary
8.12. Protractor or similar instrument to help in positioning the sensor
8.13. Sensor power supply (9-16 VDC, 20 mA each sensor) from the OFIS
8.14. DAQ hardware and software, and a computer located in the OFIS

9. Procedures

9.1. Verify that the lens is correctly selected and has the required coverage and number of beams. Refer to Sections 3.2 “Lens Selection” and 4.4 “Adjusting the Coverage Area” of the Visonic Installation Instructions (Visonic, 2002).
9.2. Verify that the lens is properly seated against the sensor body without leaving any visible openings. If there is an opening between the lens and the sensor body, the lens should be re-installed. Refer to Section 3.5 “Change Lenses” and Figs. 7 and 8 of the Visonic Installation Instructions (Visonic, 2002).
9.3. Prepare the sensors for field installation. This can include drilling through one of the wiring knockouts (Figure 2) for the cable and one or two mounting knockouts for inserting the screws to fix the sensor to the metallic strip.
9.4. Attach the sensor to the metallic strip holder using the machine screws.
9.5. Set the Coverage Range Control inside the sensor (Figure 2) to MAX to maximize its detection sensitivity.
9.6. Identify and select monitoring locations that allow maximum exposure of target creatures to the sensor’s beams. Monitoring locations may be specified in the project QAPP.
9.7. For barn sensors, contact the farm-project liaison to coordinate an installation schedule, and to get authorization to drill at the required locations.
9.8. Find electronic outlets for electric tools, if necessary. Ask the farm electrician where to connect the electric tools, if a battery-operated tool set is not available.
9.9. Install the sensor cable from the instrument shelter to the monitoring location. Use plastic cable ties to attach the cable to the barn wall or ceiling. Be careful to locate the cable beyond the reach of the animals and away from power lines.

9.10. Connect the “T.P.” terminal inside the sensor to the signal conductor that goes to the DAQ analog input channel. Connect the “12 VDC–” and “12 VDC+” to the exciting voltage “–” and “+,” respectively (Figure 2).

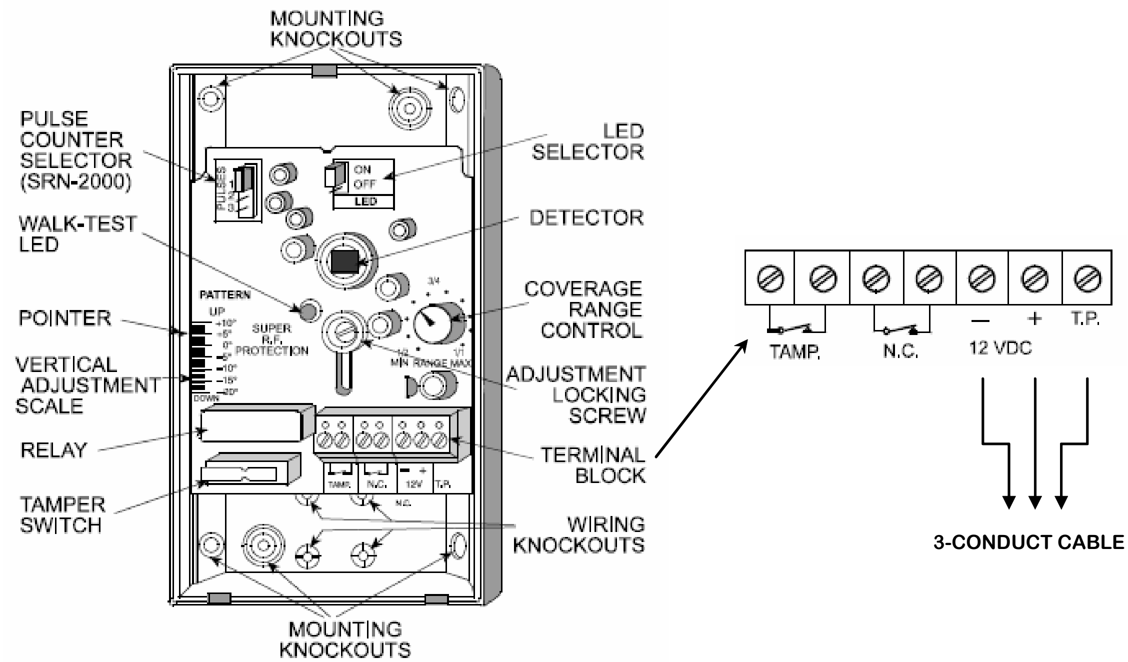


Figure 2. Open-cover view of the sensor and cable connections (adapted from Visonic, 2002).

9.11. Verify that the sensor enclosure is tightly closed. Seal the small hole openings to prevent entrance of dust into the sensor using short pieces of electrical tape (Section 6.1).

9.12. Fix the metallic holder strip of the sensor to the wall or ceiling. Use two screws so the sensor cannot rotate.

9.13. If the sensor is used to monitor animal activities, verify that it is facing the maximum number of animals, yet avoids picking up the activity of workers and/or equipment. See Figure 3 for the installation of the sensor in a layer barn. When installing the sensor in cattle or swine barns, follow the same criteria.

9.14. If the sensor is for workers, verify that it covers the maximum area of activities, while avoiding picking up animal activity.

9.15. If the sensor is used to monitor activities in the instrument shelter, install it on the end wall to maximize its coverage (Figure 4).

9.16. After installation, verify that all connections are correct. Power up sensor by turning on the 12 VDC power supply. Wait for about 5 min to let sensor stabilize.

9.17. Test the sensor by moving a hand about 0.5 m in front of it. The “Walk-test” LED (usually a red colored LED) should light up during hand movement. Be sure that the LED selector is set to the ON position (Figure 2). Otherwise, the LED does not light up, even if the sensor is working properly. Refer to Sections 9.19.1 through 9.19.5 for troubleshooting.

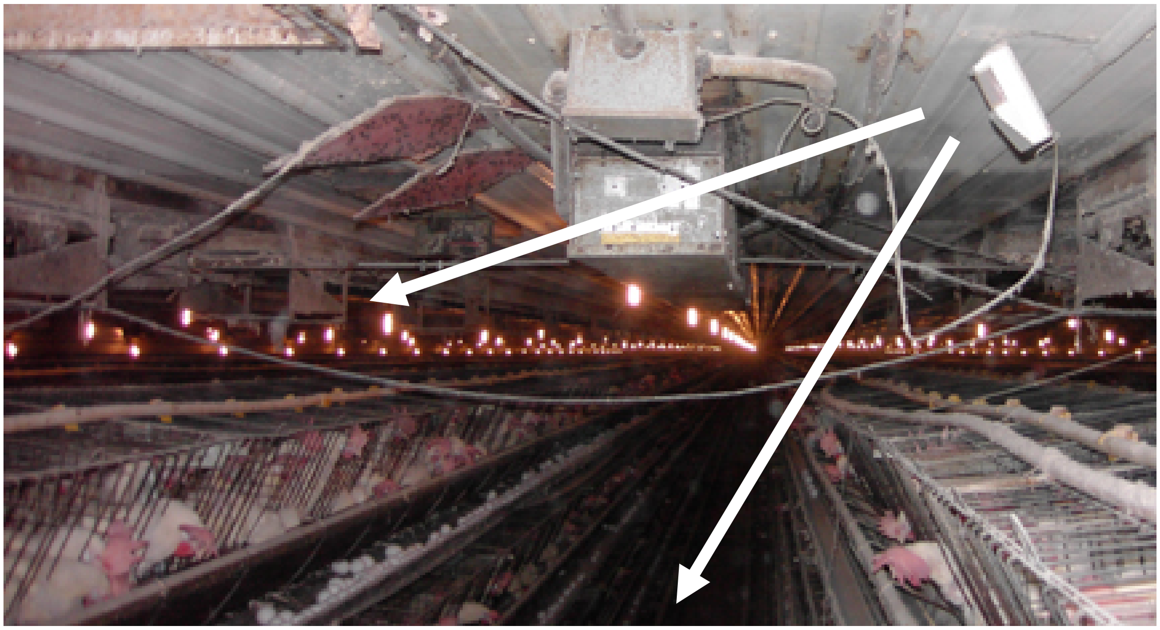


Figure 3. Activity sensor location in an egg layer barn, such that the sensor is aimed at multiple tiers of layer cages.

Figure 4. Activity sensor installed at the end wall inside an instrument shelter.

9.17.1. Verify the signals at the DAQ computer. The history display in AirDAC program (Figure 5. Example activity signals displayed in the AirDAC signal history graphs

(Left: 2-h display. Right: 18-min display). Signals such as those from R5 and R8 are optimal, and represent sensors detecting normal animal activities. Signals such as those from R4 (< 1.0 VDC) indicate that the sensor should be checked. Occasional signals from Door S confirm the presence of workers in the barn.

9.17.2.) should show about 0 VDC when the sensor does not detect activity and between 1 -2 VDC when it does. Refer to Sections 9.19.7 through 9.19.11 for troubleshooting if the signals are abnormal.

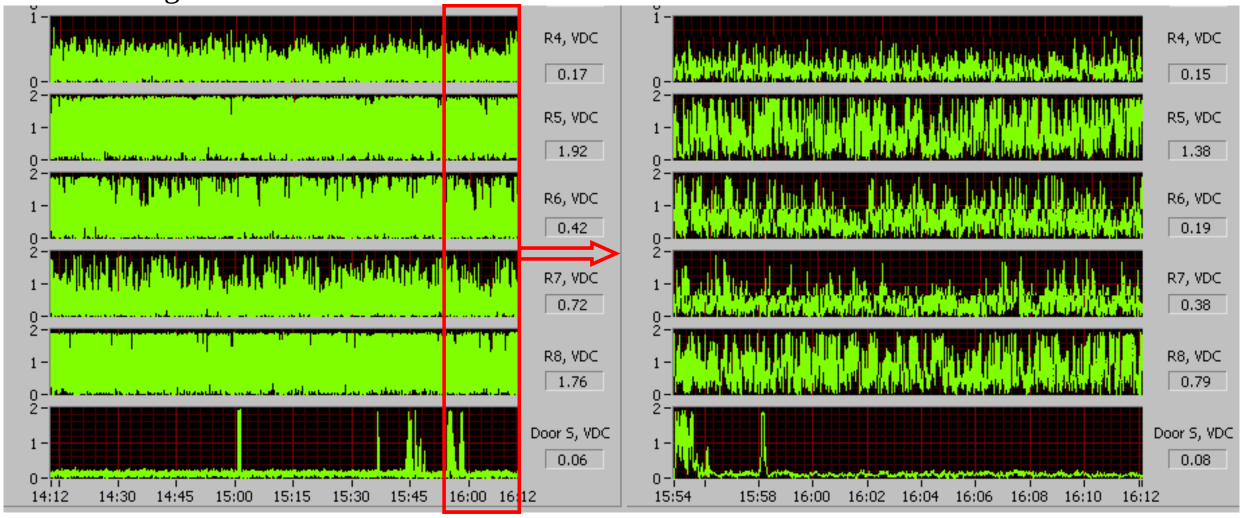


Figure 5. Example activity signals displayed in the AirDAC signal history graphs (Left: 2-h display. Right: 18-min display). Signals such as those from R5 and R8 are optimal, and represent sensors detecting normal animal activities. Signals such as those from R4 (< 1.0 VDC) indicate that the sensor should be checked. Occasional signals from Door S confirm the presence of workers in the barn.

9.18. Instrument calibration

9.18.1. No information is available for sensor calibration or standardization.

9.18.2. A simple method to test the working condition and output signal strength is:

9.18.2.1. To test the background signal when no activity is detected, cover the lens array with a piece of cardboard, so that motion cannot be detected. The output signal should be approximately 2.0 VDC. Refer to Section 4.7 “Test Point” in the Visonic Installation Instructions (Visonic, 2002) for more information. The output signal at the AirDAC should be about 0.0 V.

9.18.2.2. To test an active signal, wave one bare hand about 50 cm in front of the lens. The signals displayed by AirDAC should register the maximum strength of about 2.0 V (Figure 5. Example activity signals displayed in the AirDAC signal history graphs (Left: 2-h display. Right: 18-min display). Signals such as those from R5 and R8 are optimal, and represent sensors detecting normal animal activities. Signals such as those from R4 (< 1.0 VDC) indicate that the sensor should be checked. Occasional signals from Door S confirm the presence of workers in the barn.

9.19. Troubleshooting

9.19.1. If the LED still does not light when moving the hand (when the LED selector is set to the ON) there is no sensor signal, open the sensor cover and verify that the exciting voltage is within the required range (9-16 VDC).

9.19.2. If no voltage is detected, check the exciting voltage supply at the instrument shelter.

9.19.3. If the power supply at the instrument shelter is normal but the sensor does not receive exciting voltage, check cable continuity. Disconnect cable from power supply and DAQ system. Then disconnect it from the sensor terminals. Join all three conductors of the cable together at either the sensor end or the instrument shelter end. Measure the resistance among the cable conductors at the other end using a multimeter to verify continuity.

9.19.4. If the cable is abnormal, change it or fix the broken part.

9.19.5. If the power supply to the sensor is normal, verify that the sensor lens is clean, outside and inside, and that its orientation is correct.

9.19.6. Verify the integrity of the instrument, following the “Test Point” procedure in Section 4.7 of the Installation Instructions (Visonic, 2002).

9.19.7. If the sensor signals are not similar to those shown in Figure 5. Example activity signals displayed in the AirDAC signal history graphs (Left: 2-h display. Right: 18-min display). Signals such as those from R5 and R8 are optimal, and represent sensors detecting normal animal activities. Signals such as those from R4 (< 1.0 VDC) indicate that the sensor should be checked. Occasional signals from Door S confirm the presence of workers in the barn.

9.19.8. , first verify the DAC page in AirDAC (SOP B2). The DAC page should show about 2 VDC at “15. Sensor sgnl (S)” and about 0 VDC at “17. Adjusted (Y)” for the sensor when it is not detecting activity.

9.19.9. The sensor’s setting in the DAC page should be: SL = 2, SH = 3, RL = 0, RH = 1, A = 1, B = 0, and abs = 1.

9.19.10. If the sensor displays about 0 VDC in “15. Sensor sgnl (S),” this means AirDAC is not detecting a signal. Measure the voltage of the sensor signal connected to the DAQ hardware terminals using a multimeter. If it is about 2 VDC, the problem is with the DAQ hardware and software. Refer to SOPs B1 and B2 to solve the problem.

9.19.11. If the measured sensor signal at the DAQ hardware terminals is about 0 VDC, check the signal wire for continuity.

9.19.12. If the wire is normal, check the signal output inside the sensor between terminal 12 VDC – and T.P. (Figure 2). The output signal at the sensor T.P. terminal relative to the ground (-12 VDC) is a voltage, ranging from 0 to 4 VDC. The sensor has an offset of 2 VDC when there is no activity detected. If the sensor signals are more than 2.3 VDC or less than 1.7 VDC when the lens is covered, the unit should be replaced.

9.20. Data acquisition, calculations & data reduction requirements

9.20.1. The sensor output signal is acquired with an analog DAQ channel. The signal is sampled every second and calculated in the AirDAC program.

9.20.2. The calculated data is averaged every 15 or 60 s, and saved into two separate data files every minute. Refer to SOP B2 for more details.

10. Data and Records Management

10.1. Make a record in the test notes after the sensor installation that should at least include: date of installation, location and orientation of the sensor, wiring color code, DAQ channel number to which it is connected, the time the sensor starts collecting signals, and the name(s) of the person(s) who installed the sensor.

10.2. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.3. Manage all data according to SOPB5.

10.4. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Verify the sensor orientation periodically, at intervals specified by the QAPP. Document orientation with picture.

11.2. Clean the lens surface at a frequency specified by the QAPP.

11.3. Correlate the readings from the activity sensor with information provided by the farm liaison and investigate any discrepancy.

12. References

12.1. Visonic. 2002. Installation Instructions of Professional All Purpose PIR Detectors SRN 2000 Series. Revision 4 (Jan. 2002), Visonic Inc., Tel Aviv, Israel. Online at http://www.visonic.com/VisonicHomePage.nsf/sysAllDocuments/64DA845F3663E91EC2256BFD002104E0/$FILE/SRN-000%20series%20installation%20instructions.pdf. Accessed on 01/02/2006.

12.2. Glolab. 2006. How Infrared Motion Detector Components Work. Glolab Corporation, Wappingers Falls, NY. Online at http://www.glolab.com/pirparts/infrared.html. Accessed on 02/17/2006.

12.3. Pedersen, S. and C.B. Pedersen. 1995. Animal activity measured by infrared detectors. *Journal of Agricultural Engineering Research* 61(4): 239-246.

12.4. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.

12.5. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

CONTACTOR RELAY MONITORING

Standard Operating Procedure (SOP) S4

CONTACTOR RELAY MONITORING

Standard Operating Procedure (SOP) S4

Prepared by

Lingying Zhao (Ohio State Univ.) and Matthew J. Darr (Ohio State Univ.)

Reviewed by

Ji-Qin Ni, Albert J. Heber and Bill W. Bogan

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

Process monitoring is critical for analyzing air emission data from livestock facilities. Knowledge of when fans, lights, feeders, manure-removal belts, or other mechanized devices are operating can help interpret changes in air emissions from a barn. This SOP describes the procedures for monitoring production process control at livestock facilities based on the operation of electro-mechanical contactor relays. By utilizing a spare or “dry” contact on the standard contactor relay that controls a device or a group of devices, the data acquisition system can monitor and record the operational status of the devices.

This method usually monitors groups of devices that are collectively controlled by the process control system that the facility uses. For example, if the Stage 2 ventilation for a barn contains five ventilation fans, this method only monitors the on/off signals of the Stage control, and not the individual fans, which can be monitored using the vibration sensor method (SOP A7).

2. Summary of Method

An electrical loop with 5 VDC excitation voltage is created between the data acquisition system and the desired contactor relay. The loop goes through a spare contact in the contactor relay, or an auxiliary relay if no spare contact is available. The loop’s open/closed state is therefore controlled by the spare contact or the auxiliary relay, which depends on the current state of the contactor relay. The loop signals are acquired by the digital input (DI) channels of the data acquisition system every second. The 1-Hz signals are averaged every 15 s and 60 s, and are saved in two separate data files, along with other data acquired from the measurement system (SOPs B1 and B2). The DI signal in the data files are recorded as % of time; for example, if a specific DI channel receives a “closed” signal for 15 s, and an “open” signal for 45 s during one min, the saved datum for this min is “25% of time.”

3. Definitions

3.1.	DAQ	Data acquisition
3.2.	DI	Digital input
3.3.	OFIS	On-farm instrument shelter
3.4.	QAPP	Quality Assurance Project Plan
3.5.	SMP	Site monitoring plan
3.6.	SOP	Standard operating procedure

4. Health and Safety

4.1. Only allow certified electricians to connect data acquisition signal cables to the contactor relays.

4.2. The signal cable may pass high voltage (120 -240 V) during setup from the facility control system to the OFIS and damage the DAQ system. Do not connect the signal cable to the DAQ system in the OFIS until all setup inside the facility is complete.

5. Cautions

5.1. Prevent data acquisition errors caused by corrosion in the monitoring wire by tightly wrapping any exposed portion of wire with electrical tape.
5.2. If failures occur from faulty wiring or wiring corrosion, replace the entire loop from the data acquisition system to the process control system.
5.3. Coordinate with the farm electrician before working at the electrical control panel to install the signal cable for contactor relay control.
5.4. Check the contact terminals before connecting the signal cable. If the terminals are not clean, take out the terminal screws and scratch the dirt off the contacts by a knife or a piece of sand paper to ensure proper wire connection.
5.5. Use appropriate size wiring – as specified by the contactor relay manufacturer – to ensure a proper wire/terminal connection.
5.6. When running the signal cable(s) from the OFIS to the facility controller, lay the cable(s) properly to avoid tripping hazards to people or animals, and to prevent damage by rodents.

6. Interferences

6.1. Manually stopped devices (e.g. a fan is manually unplugged for maintenance) will introduce errors into the monitoring signals. Obtain maintenance records from the facility manager to identify periods when monitored devices may have been shut off, and correct such errors during data processing.
6.2. Bad contact connections will cause signal error. Make redundant connections to reduce this type of errors. For example, if there are multiple contactor relays in the same control group, connect two or three contactor relay signals in parallel for this group.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of contactor relays and their operation before initiating this procedure.
7.2. Personnel working with or near the main process control system must have a sufficient understanding of high-voltage control systems, and the precautions that should be taken in such situations.
7.3. Personnel should understand the data acquisition system and read SOPs B1 and B2 for cable connection and setup verification.

8. Equipment and Supplies

8.1. Multi-conductor 22-gage (shielded or non-shielded) signal cables for the circuit loop between the data acquisition and the process controller. Refer to Section 9.1.1 for the conductor numbers of the cables.
8.2. Data acquisition hardware and software in the OFIS for collecting and recording data, as specified in SOPs B1 and B2
8.3. Electrical tape

8.4. Cable ties
8.5. Multimeter and other electrical tools, e.g. cable cutter
8.6. Auxiliary relays if applicable (refer to the SMP in the QAPP for details)

9. Procedures

9.1. Prepare for setup
  9.1.1. Determine the DAQ signal cable conductor number by referring to the SMP and the design table for DAC measurement and control described in SOP B1. The minimum number of conductors for one barn is the total number of signals (or groups of contactor relays) in that barn plus one for +5 VDC.
  9.1.2. Estimate the length of the cables needed to connect the signals from the process controller to the OFIS.
  9.1.3. Specify connection requirements, and make a clear wiring diagram, including wire color codes, for the electrician to follow when connecting signal cables to the contactor relays.
  9.1.4. Coordinate with the facility manager and the electrician for the cable connection to the contactor relays in the facility.
9.2. Run the signal cables
  9.2.1. Use a multimeter to check the continuity of the cables to check for defects.
  9.2.2. Run the signal cables from the OFIS to near the enclosure(s) of the controller contactor relays. Leave sufficient cable lengths for connecting the contactor relays inside the enclosure by the electrician.
9.3. Connecting cables to contactor relays
  9.3.1. Identify the spare contacts in contactor relays that can be used for monitoring (Fig. 1).
    9.3.1.1. Connect the signal cable wires to the spare contacts in contactor relays according to the wiring diagram.
  9.3.2. If spare contactors are unavailable, install auxiliary relays to monitor the system control (Fig. 2).
    9.3.2.1. Connect the auxiliary relay actuation coil to the normally open contacts of the contactor relay according to the wiring diagram.
    9.3.2.2. Connect the contacts of the auxiliary relays to the signal cables.
9.4. Connect the cables to the DAQ system and test DAQ
  9.4.1. Use a multimeter to check the signal cable inside the OFIS to verify that no voltage is detected in the cable relative to the ground.
  9.4.2. Use a multimeter to check whether a signal wire is closed to the 5 VDC wire when the contactor relay to which they are connected is turned on. The signal wire should be open to the 5 VDC wire when the contactor relay is turned off.
  9.4.3. Connect the signal wires of the signal cables to the DI hardware terminals of the data acquisition system according to the wiring diagram and the design table for DAC measurement and control (SOP B1).
  9.4.4. Verify the connections to make sure that they are all correct.
  9.4.5. Connect the +5 VDC power supply to the exciting voltage (5 VDC) wires of the signal cables.
  9.4.6. Power up the DAQ hardware and start the AirDAC software (SOP B2).

9.4.7. Verify that the DI channel configurations for these signals are correct in the DAC page of AirDAC. The configuration for these channels should be: Signal low=0, Signal high=1, Range low=0, Range high=1, abs=0, Slope=1, and Intercept=0.

9.4.8. Verify that data displayed in the AirDAC and saved in the data files correctly reflect the operational status of the devices.

10. Data and Records Management

10.1. Document and maintain the setup records in a workbook of the electronic field notes designated for this method. Supplement this electronic record by a bound record book designated for the method with permanent ink, which should contain copies of the electronic record. Overstrike all errors in writing with a single line; initial and date all such corrections.

10.2. Manage all data according to SOP B5.

11. Quality Control and Quality Assurance

11.1. Visually inspect data for potential problems according to SOP B3.

11.1.1. Operations of certain devices such as feeders, manure belts, ventilation, and lights are routine. Non-routine behavior should trigger troubleshooting.

11.1.2. Erratic signals (unusual frequency) should trigger troubleshooting.

11.2. Verify that signals are correct by observing the process and comparing its status with recorded data.

11.3. Verify the fan stage data recorded using this method with the fan monitoring data recorded using vibration sensors (SOP A7). They should agree if both methods are working properly.

11.4. For troubleshooting, first study the signals. Specific problems with the DI signals are usually reflected in the data patterns.

11.4.1. If there are no “closed” signals for any DI channel, check the 5 VDC exciting voltage supply. Restore the voltage supply if it is off or disconnected. Check the data acquisition hardware and software to verify that they are working properly.

11.4.2. If there are no “closed” signals for some DI channels connected to a certain cable, check the cable’s continuity. If the cable is disconnected or broken, reconnect it or replace it.

11.4.3. If there are irregular signals for certain DI channels, check the data acquisition hardware for any defect with the specific relevant channels. Replace the defective channel, or replace the DI board.

11.4.4. If the DAQ system is not recording data correctly after the verifications described in Sections 11.2 and 11.3, check the wire connection to the contactor relays for any changes. Also, check with the facility manager for any changes in the production control system or its configuration (e.g. fan stage changes).

12. References

12.1. SOP A7. Fan Status Monitoring Using Vibration Sensors. Standard Operating Procedure. Purdue Ag Air Quality Lab.
12.2. SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure. Purdue Ag Air Quality Lab.
12.3. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure. Purdue Ag Air Quality Lab
12.4. SOP B3. 2006. Air Data Pre-Processing software. Purdue Ag Air Quality Lab.
12.5. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure. Purdue Ag Air Quality Lab.

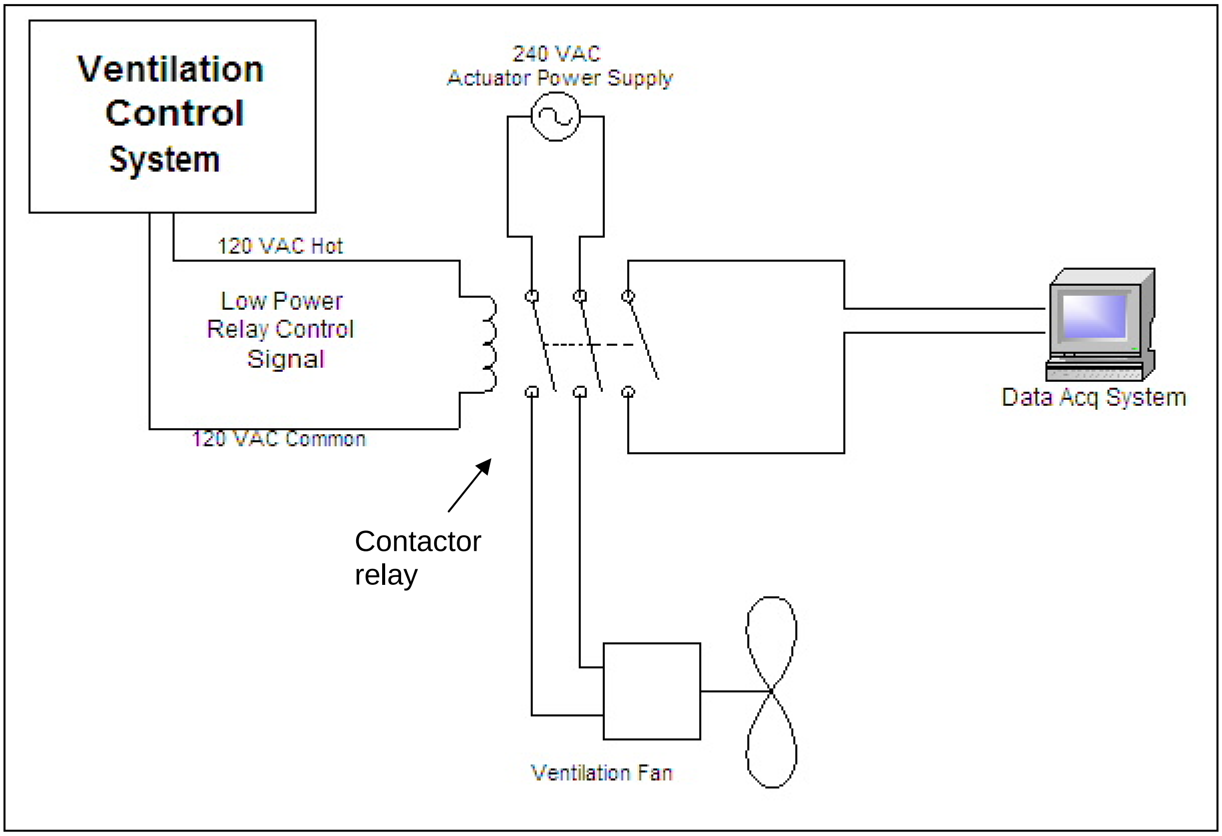

Figure 1. Connection of signal wire to the spare contact in the contactor relay monitor.

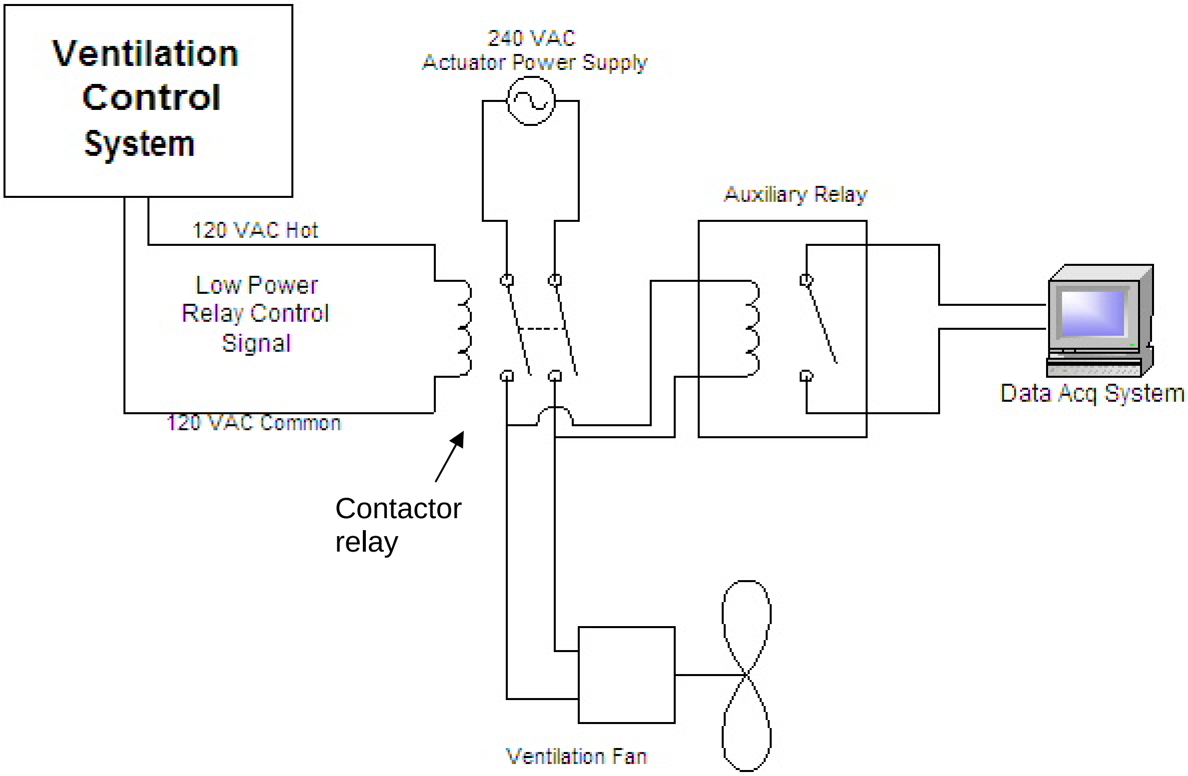

Figure 2. Connection of signal wire to the contactor relay via an auxiliary relay.

DETERMINING NITROGEN BALANCES FROM LIVESTOCK BARNS

Standard Operating Procedure (SOP) S5

DETERMINING NITROGEN BALANCES FROM LIVESTOCK BARNS

Standard Operating Procedure (SOP) S5

Prepared by

Bill W. Bogan and Curt A. Gooch (Cornell Univ.)

Reviewed by

Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)

Agricultural and Biological Engineering, Purdue University

West Lafayette, IN 47907

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1. Scope and Applicability

1.1. An ammonia-nitrogen (NH_3-N) balance for a livestock housing facility can provide a check for airborne ammonia emissions that are calculated based on measured air NH_3-N concentrations and the building's air exchange.

1.2. An NH_3-N budget makes use of information from several sources including data collected by this project and information available from the literature.

1.2.1. Data for key items such as feed composition, feed consumption, animal inventory, and average animal weight is supplied by the farmers and/or their nutritionists.

1.2.2. Chemical analysis of feed, bedding, manure, milk, and eggs provides additional data.

2. Summary of Method

NH_3-N losses will be estimated using a mass balance approach (Keener et al., 2002). Nitrogen concentrations of all materials, including animal flesh and production (milk and eggs for dairy and egg layers, respectively) entering and leaving the monitored housing facility will be determined or estimated. Feed, fresh bedding, manure (or manure/bedding mixture), milk and eggs (as applicable for each species) will be chemically analyzed for total nitrogen (SOP M4). Literature sources for meat composition for the various species will be used to make assumptions on the N composition of livestock biomass, and biomass gains will be determined based on producer-supplied data (SOP S1) and data from animal inventories conducted by study personnel (SOP S2). Finally, data on feed-consumption quantities and amounts of bedding used will be obtained from the producer (SOP S1). All of these quantities will be determined on a per-unit basis. The QAPP with its site monitoring plans and standard operating procedures will identify sampling locations, times, frequencies, preservation and analysis methods. The sample-collection methods described in SOP M1 will depend on the type of manure handling and storage used at the facility.

3. Definitions of Terms and Acronyms

3.1.	NH_3-N	Ammonia nitrogen
3.2.	QAPP	Quality Assurance Project Plan
3.3.	SOP	Standard operating procedure
3.4.	Total N	Total nitrogen as determined by the Kjeldahl or other method.
3.5.	NF	Nitrogen flux
3.6.	ζ	Animal-specific production efficiency, e.g., eggs per hen per day

4. Cautions

4.1. To develop an accurate model using the equations in Sections 7.3 and 7.4, the manure sample must represent the average holding time encountered by the manure in the monitored housing unit, as well as any manure treatments that occur within the housing unit that may affect the form of N and/or its release to the air. For example, with respect to holding time prior to land application, if only manure that has been stored the maximum time is sampled, its N content will be lower than average, and NH_3 emissions will be overestimated. Conversely, if the manure sample is fresher than the average storage time, N content will be overestimated, and emissions underestimated. In order to achieve this, it is necessary that the manure be well-mixed prior to or during sampling.

4.1.1. If manure is being sampled from inside storage units (either associated with the barn or separate), mix the manure using one of the methods described in SOP M1 prior to collecting the sample.

4.1.2. If samples are taken as the manure exits the barn, take similar steps to ensure that a representative sample is obtained.

4.2. Some loss of N may occur through routes that are not evaluated under this procedure.

4.2.1. Nitrate losses through surface water runoff or infiltration into soil can occur if manure is outside (and not stored in an appropriate long-term storage) for a period of time (Kohn et al, 1997). However, this may only occur at an outdoor site (such as a dairy corral), and should not be of concern for other dairy sites or other species.

4.2.2. Feed that is stored outside for a period of time may lose some of its N before or when it is being is fed to the animal. If feed is stored outside, the N analysis on feed will be conducted as it is provided to the animals, rather than as it is prior to storage.

5. Interferences

5.1. Manure transferred from the manure collection systems of another facility will complicate the nitrogen balance estimation.

5.2. Any nitrogen entering or leaving the facility (for example, by the routes listed in Section 4.2.1) that cannot be measured or estimated is an interference to the nitrogen balance calculation.

6. Personnel Qualifications

6.1. This SOP assumes a familiarity with the use of personal computers, general spreadsheet software (e.g. Microsoft Excel), and/or other data storage and analysis software.

7. Procedures

7.1. Data collected under several other SOPs will be used in the calculations which are conducted to determine the nitrogen balance. Because emissions are to be calculated on a per-barn basis, the data for the mass-balance “check” also need to be collected for each individual barn. These data are shown in Table 1.

7.2. Calculate the daily N fluxes in inputs (feed) and outputs (eggs, milk) as follows:

7.2.1. Daily nitrogen flux (NF) in feed (kg/animal-day):

$$NF_{D:feed} = R_{Nfeed} * m'_{feed} / n_b$$

7.2.2. Daily N flux in eggs (mg/hen-d):

$$NF_{D:egg} = m_{egg} * \zeta_{egg} * R_{Negg}$$

7.2.3. Daily N flux in milk (mg/cow-d):

$$NF_{D:milk} = \zeta_{milk} * R_{Nmilk}$$

7.3. Manure

7.3.1. The manure storage duration (the total time manure is stored in the animal housing unit) will most likely not coincide with growing period timeframes, nor will it be correlated to milk production. To avoid the errors described in Section 4.1, manure will be sampled at the end of a storage period (in the cases when manure is stored in the housing unit) or when it is about to exit the barn (in the case when no manure storage is present in the barn), in order to accurately estimate the manure and its nitrogen constituents produced by the housed animals. Thus, the other input and output fluxes will be normalized to the in barn manure storage period (Section 7.4).

7.3.2. Determine total nitrogen flux in manure (mg/animal-day) according to:

$$NF_{man} = R_{N:man} * w_{man}$$

Table 1. Data required for a nitrogen balance.

Quantity	**Units**	**Notation**	**Reference**
(All Species)			
Daily feed consumption rate	kg/barn or group	m'_{feed}	SOP S1
Number of animals	animals/barn or group	n_b	SOP S2
TKN content of feed	mg/kg per ration	R_{Nfeed}	SOP M4
Weight gain (or loss)	kg/animal/growing period	w	SOP S1 & S2
Manure production rate	kg/animal-day	w_{man}	SOP S1
Total N content of manure	mg/kg	R_{Nman}	SOP M4
Bedding addition rate	kg/animal-day	w_{bed}	SOP S1
Total N content of bedding	mg/kg	R_{Nbed}	SOP M4
(Layers)			
Average egg mass	kg	m_{egg}	SOP S1 & S2
Production efficiency, eggs	eggs/hen-day	ζ_{egg}	SOP S1
Total N content of eggs	mg/kg per egg	R_{Negg}	SOP M4
(Dairy)			
Production efficiency, milk	kg/cow-day	ζ_{milk}	SOP S1
Total N content of milk	mg/kg	R_{Nmilk}	SOP M4
(Dairy, Swine, Broilers)			
Total N content of biomass	mg/kg	$R_{Nbiomass}$	Literature

7.4. Calculate the average per-animal total N flux over the period of time corresponding to the duration of manure storage according to the following equations:

7.4.1. Total N flux in feed:

$$NF_{feed} = \sum_{D=1}^{n} NF_{D:feed}$$

Where *n* is the total number of number of days in the manure storage period

7.4.2. Total N flux in eggs:

$$NF_{eggs} = \sum_{D=1}^{n} NF_{D:eggs}$$

Where *n* is the total number of number of days in the manure storage period

7.4.3. Total N flux in milk:

$$NF_{milk} = \sum_{D=1}^{n} NF_{D:milk}$$

Where *n* is the total number of number of days in the manure storage period.

7.4.4. Total N flux in bedding:

$$NF_{bed} = \sum_{1}^{n} w_{bed} \times R_{N:bed}$$

Where *n* equals the number of bedding additions made during a manure-management period, <u>if</u> that bedding is removed to the manure-management system during that period

7.4.5. Total N flux in animal weight gain:

$$NF_{weight\ gain} = R_{N:biomass} * w$$

Note that it may be necessary to sum biomass gains over more than one growth period.

7.5. Use the following as a check on the N flux determined in Section 7.3.2:

7.6. NFman = NFfeed + NFbed – NFegg – NFmilk – NFweight gain

7.7. Using the NFman values from Section 7.3.2 (not Section 7.5), calculate NH_3 emissions ($EMNH_3$) per manure storage period or in barn manure residence time, in units of $kgNH_3$/animal, as follows, where 1.2143 is used to convert molar mass of N to molar mass of NH3:

7.7.1. For layers:

$$EM_{NH3} = (NF_{feed} - NF_{egg} - NF_{man}) * 1.2143$$

7.7.2. For broilers:

$$EM_{NH3} = (NF_{feed} + NF_{bed} - NF_{egg} - NF_{weight\ gain} - NF_{man}) * 1.2143$$

7.7.3. For dairy cows:

$$EM_{NH3} = (NF_{feed} + NF_{bed} - NF_{milk} - NF_{weight\ gain} - NF_{man}) * 1.2143$$

7.7.4. For swine:

$$EM_{NH3} = (NF_{feed} + NF_{bed} - NF_{weight\ gain} - NF_{man}) * 1.2143$$

8. Data and Records Management

8.1. Establish a Microsoft Excel spreadsheet which is used specifically for these calculations.

8.2. Analytical results for N contents of manure and other materials will be supplied in electronic version by the contract lab(s). Transfer data electronically from these files to the calculation spreadsheet to eliminate errors associated with manual data entry.

8.3. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record. Automatically back up electronic records electronically.

8.4. Manage all data according to SOP B5.

8.5. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line. Initial and date all corrections.

9. Quality Control and Quality Assurance

9.1. Producer should designate a responsible staff member (liaison between the farm and the research team) for collecting and transmitting operational information, and also provide the name of his or her substitute when he or she is not available in the plant. This person must understand the importance of informing research personnel as to any changes in farm operations which might affect the facility's N budget, including (but not limited to) changes in feed or bedding composition, changes in manure handling practices, changes in manure storage times, etc.

10. References

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10.7. SOP S2. 2006. Recording and Tracking Animal Inventory at Livestock Barns. Standard Operating Procedure S2. Purdue Ag Air Quality Lab.
10.8. SOP S6. 2006. Determining Total Kjeldahl Nitrogen (TKN) Contents of Feed, Bedding, Milk and Eggs. Standard Operating Procedure S6. Purdue Ag Air Quality Lab.

DETERMINING TOTAL KJELDAHL NITROGEN (TKN) CONTENTS OF FEED, BEDDING, MILK AND EGGS

Standard Operating Procedure (SOP) S6

DETERMINING TOTAL KJELDAHL NITROGEN (TKN) CONTENTS OF FEED, BEDDING, MILK AND EGGS

Standard Operating Procedure (SOP) S6

Prepared by

Alan Sutton, Brian Richert, Scott Radcliffe, Dan Kelly and Bill W. Bogan

Reviewed by

Albert J. Heber and Jerome J. King (Midwest Laboratories, Inc)

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Calculating a nitrogen (N) balance for a farm requires a method for determining the N contents of feed, bedding, milk and eggs at a particular barn or facility (Keener et al 2002).
1.2. This method determines the total Kjeldahl nitrogen (TKN) content of samples of these materials. Kjeldahl nitrogen is defined as the sum of ammoniacal nitrogen and nitrogen present in organic compounds.
1.3. The digestion method described in this SOP is taken from USEPA Method 1687 (2001 draft version), and is therefore also applicable to wastewaters, drinking water or groundwater, and industrial and other wastes.
1.4. The distillation and titrimetric procedures are described in USEPA Method 351.3.
  1.4.1. This method has a working range of approximately 0.5-10 mg N/gram of sample (wet weight basis).

2. Summary of Method

Feed, bedding, milk and egg samples are collected on the farm for off-site analysis in the laboratory. This method will determine the nitrogen contents of these materials using the Kjeldahl TKN (total Kjeldahl nitrogen) method (SOP M4). Liquid materials (milk and eggs) will be analyzed like slurry manure samples. Dry feed and bedding will be analyzed similar to a dry manure sample. All samples will be subjected to a metal-catalyzed acid digestion to convert the organic nitrogen in the sample to NH_3. The NH_3 in the digested sample (the sum of nitrogen originally present in the ammoniacal form, plus that which is liberated from organic compounds) is distilled from the rest of the sample, at which point it is captured in a dilute sulfuric acid/boric acid solution which contains a bromocresol green methyl red indicator. The NH_3 concentration of the distillate is then determined by automated titration with sulfuric acid.

3. Definitions

3.1.	COD	Chemical oxygen demand
3.2.	CV	Calibration verification
3.3.	IPR	Initial precision and recovery
3.4.	MDL	Method detection limit
3.5.	MgO	Magnesium oxide
3.6.	MS	Matrix spike
3.7.	NaOH	Sodium hydroxide
3.8.	OPR	Ongoing precision and recovery
3.9.	OSHA	Occupational Safety and Health Administration
3.10.	PR	Precision and recovery
3.11.	QA/QC	Quality assurance/quality control

3.12.	Sample batch	A group of samples which are analyzed at the same time, up to a maximum of twenty (20). If more than 20 samples are analyzed together, they must be split into more than one batch for the purposes of including QA/QC samples (Section 11).
3.13.	SOP	Standard operating procedure
3.14.	TKN	Total Kjeldahl nitrogen

4. Health and Safety

4.1. Use gloves, tongs, and/or suitable sample holders when handling/moving hot samples.

4.2. Treat each chemical compound as a potential health hazard, and reduce exposure to chemicals to the lowest possible level.

4.2.1. Wear protective clothing (gloves, lab coats, eyewear) when working with chemicals.

4.2.2. Conduct all sample digestions in properly ventilated fume hoods. Use a manifold to remove acid fumes.

4.2.3. Keep analytical balances and other work areas clean; deal with spills promptly.

4.2.4. When using concentrated acids and bases, keep a fully-stocked spill kit (including suitable neutralizers and absorbents) in the work area at all times.

4.3. Maintain a current awareness file of OSHA regulations regarding safe handling of the chemicals specified in this method.

4.4. Maintain a reference file of material safety data sheets (MSDS), which will be available to all personnel involved in these analyses.

4.5. Sulfuric acid digest is classified as a hazardous waste. Dispose of accordingly.

5. Cautions

5.1. Considerable heat is generated when dissolving sodium hydroxide (NaOH) in water, or by mixing acids in water. Cool the container in an ice bath when preparing NaOH solutions or mixing acids in water.

5.2. Excessive foaming during distillation can cause foam to pass into the condenser, which can contaminate the receiving flask and condenser with alkaline salts. Treat heavily-foaming samples with an anti-foaming agent.

6. Interferences

6.1. Keep samples at or below 4°C after collection and during shipping (SOP M1), and prior to analysis, to minimize microbial degradation of sample solids. Analyze all samples within 7 d of collection. Frozen (archived) samples can be maintained indefinitely.

6.2. When determining moisture content of wet samples, weigh as quickly as possible after transferring to crucibles, so evaporative water losses do not cause erroneous readings.

6.3. Unless extended drying times are required due to crusting of samples, do not exceed the specified drying times. Overdrying can result in negative errors due to volatilization of certain salts and/or organic matter, or heat-induced chemical decompositions, or to positive errors from weight gain through sample oxidation.

6.4. If samples form a crust during the drying stage, this can inhibit further evaporation (either of water or volatile solids), and must be dealt with through special handling (either extended drying times or careful physical disruption of the crust).

6.5. Following the initial drying step for total solids determination, some samples may retain small amounts of bound water, water of crystallization or interstitial water in crystals. Loss of this water is very slow; these samples may take longer to reach constant weight.

6.6. Some samples may exhibit loss of CO_2 as bicarbonate is converted to carbonate. Loss of ammonium carbonate may also occur.

6.7. Samples with high levels of oil and grease may require particularly long drying times to reach a constant weight; it may therefore be difficult to obtain incontrovertible results for these samples.

6.8. Some dried samples may be highly hygroscopic, containing stronger desiccants than the desiccators themselves. Follow the procedure outlined in Section 5.3 of SOP M3.

6.9. Minimize the time that desiccators containing dried samples are open, as samples can adsorb moisture from the air. If strong desiccants are present in the sample (i.e. if weight gain occurs while samples are in the desiccator), use a vacuum desiccator. Do not remove samples from desiccators until immediately prior to weighing.

6.10. Use the same balance for all weighing steps involving a particular batch of samples.

6.11. Use only NH_3-free water, which can be prepared by passing reagent water through an ion-exchange column that is packed with a mixture of both strongly acidic cation- and strongly basic anion-exchange resins. Regenerate this column periodically according to the manufacturer’s instructions.

6.12. NH_3 gas in the lab can deposit into the sample. Minimize exposure of samples to air.

6.13. Nitrate in large quantities (>10 mg/L) will oxidize NH_3 produced by the digestion and can introduce a substantial negative error. Although this interference cannot be prevented, its effect can be predicted and accounted for on the basis of preliminary nitrate determination of the sample. Whenever high nitrate levels are a potential issue, nitrate analyses of the sample should be conducted first.

6.14. Inorganic salts or solids will increase digestion temperature; however, conducting digestion at temperatures in excess of 400°C will cause pyrolytic loss of nitrogen. If high levels of salts and/or solids are suspected, adding extra H_2SO_4 can partially circumvent this problem. Approximately 1 mL H_2SO_4 per g of salt/solid will preserve the proper ratio, and allow digestion to proceed at the target temperature. Monitoring of digestion temperature will indicate if problems are occurring.

6.15. Large amounts of organic matter can consume the acid in the digestion reagent, causing digestion temperature to rise above 400°C. Adding 10 mL H_2SO_4 per 3000 mg COD will prevent this. Monitor digestion temperature and pH if this correction is used.

6.16. Nitrogen occurring in certain organic compounds will not be measured by this method. These compounds include those in which the nitrogen occurs in the following forms:

- azide
- azine
- azo
- hydrazone
- nitrate
- nitrite
- nitrile
- nitro
- nitroso
- oxime
- semicarbazone

6.16.1. In general, the levels of these classes of compounds in manure samples are not expected to be significant.

6.16.2.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the equipment before initiating the procedure.

7.2. Each analyst must read and understand this SOP before initiating these procedures, and must show the ability to generate acceptable data accuracy and precision. Each analyst must also have read and understood PAAQL SOPs M3 and M4, as well as USEPA Methods 351.3 and 1687, as the methods described in this SOP are derived closely from these.

8. Equipment and Supplies

8.1. Copies of PAAQL SOPs M3 and M4, as well as USEPA Methods 351.3 and 1687
8.2. Total solids determination (SOP M3)
  8.2.1. Drying oven
  8.2.2. Muffle furnace
  8.2.3. 15-100-mL crucibles or evaporating dishes made of porcelain or high-silica glass
  8.2.4. Watch glasses of suitable size to cover the crucibles/evaporating dishes
  8.2.5. Analytical balance: Sartorius Model CP124S (Capacity = 120 g; Accuracy = 0.0001g), Sartorius AG, Goettingen, Germany), or equivalent.
    8.2.5.1. Reference masses: 2-mg, 1000-mg, and 50-g class “S” weights
  8.2.6. Magnetic stirrer
  8.2.7. Spatulas
  8.2.8. Desiccator and desiccant (Drierite, Anhydrous Calcium Sulfate)
8.3. Total N determination (SOP M4)
  8.3.1. Tecator Instrument Model 2020 digestor block and aspirator for sample digestion
  8.3.2. Foss Kjeltec Model 2300 automated distillation and titration analyzer (FOSS Analytical, Hilleroed, Denmark), or equivalent
  8.3.3. Flasks: 100-mL Kjeldahl and 50-mL Erlenmeyer flasks
  8.3.4. Reagents
    8.3.4.1. Sulfuric acid: Concentrated, 0.020N & 0.25N H_2SO_4, certified (Midland Scientific, Omaha, NE)
    8.3.4.2. Sodium hydroxide: 40% NaOH solution, certified (Midland Scientific, Omaha, NE)
    8.3.4.3. Digestion reagent: TT-43 Pro Pac Kjeldahl digestion tablets (Alfie packers, Inc, Omaha, NE)
    8.3.4.4. Boric acid indicator
      8.3.4.4.1. Add 0.10 g bromocresol green, 0.10 g methyl red, 100 g .boric acid, and 20 mL of 0.10N NaOH to a 2-L flask that is half-full of NH_3-free water and dissolve all reagents
      8.3.4.4.2. Add NH_3-free water to the 2-L mark on the flask.

8.3.4.4.3. Quantitatively transfer contents of the flask to the receiving solution reservoir below the Foss Kjeltech Model 2300.

8.3.4.4.4. Add 8 more L of NH_3-free water to the reservoir, for a total of 10 L of solution.

8.3.5. Standards

8.3.5.1. Nicotinic acid standard (Contains 100 mg/L organic N): Dissolve 21.637 g nicotinic acid ($C_6H_5NO_2$) in ~ 150 mL NH_3-free water. Dilute to 200 mL with NH_3-free water.

8.3.5.2. Calibration standards

8.3.5.2.1. Prepare calibration standards by spiking 5-g aliquots of blank sand or diatomaceous earth (Section 8.3.6) directly with nicotinic acid standard solution (Section 8.3.5.1).

8.3.5.2.2. Prepare a minimum of five calibration standards, at five different concentrations, to produce a calibration curve with at least five points.

8.3.5.2.3. At least one of the calibration standards should have an analyte concentration at or below that necessary to meet the data quality objectives of the project. This concentration will be defined in the QAPP for the particular project.

8.3.5.2.4. The remaining standards should correspond to the range of concentrations found in actual samples, but should not exceed the working range of the titration-based system.

8.3.5.3. Calibration Verification (CV) standard

8.3.5.3.1. Prepare the CV standard so its N concentration approximates the midpoint of the calibration curve.

8.3.5.3.2. Use a different source (a different bottle of the same compound, or a different compound altogether) to prepare the CV standard than that used to prepare the calibration standards.

8.3.5.3.3. If a different ammonium compound is used for the CV stock, adjust the amount weighed according to the ratio of NH_3-N atomic weight to the molecular weight. See Section 8.9.4.3 of SOP M4 for an example of such a calculation.

8.3.5.4. Quality Control Sample (QCS): Standard Reference Material 1570a (Spinach Leaf). National Institute of Standards & Technology, Gaithersburg, MD.

8.3.6. Blank sand and diatomaceous earth

8.3.6.1. Bake 500 g diatomaceous earth or clean sand at 400°C for 8 h. Cool and store in a glass container with a sealing lid.

9. Procedures

9.1. Total and non-volatile solids contents

9.1.1. Preparation

9.1.1.1. As only total solids are to be determined, heat crucibles/evaporating dishes and watch glasses to 103ºC to 105ºC for 1 h.

9.1.1.2. Cool and store all glassware in a desiccator.

9.1.1.3. Prior to use, weigh empty clean crucible and watch glass, and record value (to the nearest 0.01 g) of the two combined.

9.1.2. Sample handling

9.1.2.1. Obtaining subsamples

9.1.2.1.1. Milk: Pipette a 25- to 50-g aliquot (25 to 50 mL) to a crucible/dish. Replace watch glass and re-weigh; record weight to the nearest 0.01 g.

9.1.2.1.2. Eggs: Collect entire white and yolk, discard shells. Using a magnetic stirrer, Waring blender, or equivalent, stir or blend thoroughly to homogenize. Taking care that the sample remains homogeneous (i.e. that the yolk and white material do not separate), transfer a 25- to 50-g aliquot to a crucible/dish using a pipette, spoon, or other appropriate tool. Do this with the crucible/dish on a balance, to ensure that the amount transferred is in this range. Spread evenly over the crucible. Replace watch glass and re-weigh; record weight to the nearest 0.01 g.

9.1.2.1.3. Feed or bedding: Mix. Transfer a 25- to 50-g aliquot to a crucible/dish using a spatula, spoon, or other appropriate tool. Spread evenly over the crucible. Replace watch glass and re-weigh; record weight to the nearest 0.01 g.

9.1.2.2. Include one blank (SOP M3, Section 11.8) and one Ongoing Precision and Recovery sample (SOP M3, Section 11.3) with each batch of samples (Section 3.12).

9.1.2.3. Put in oven to dry for 12 h at 103°C to 105°C.

9.1.2.4. Remove from oven with tongs and place in the desiccator to cool to room temperature. Do not remove from desiccator until immediately prior to weighing. See Section 5.3 of SOP M3 if working with highly hygroscopic samples.

9.1.2.5. Weigh cooled crucible/watch glass/sample, and record value to the nearest 0.01 g.

9.1.2.6. Heat the sample at 103°C to 105°C for another hour, cool to room temperature in desiccator, and re-weigh. If weight change exceeds 4% or 50 mg (whichever is less), repeat this step until the weight change drops below this threshold.

9.1.2.7. Record final value of the crucible/watch glass/dry sample to the nearest 0.01 g.

9.1.3. Calculations

9.1.3.1. Wet sample weight =

Crucible/watch glass/wet sample (Step 9.1.2.1) – Crucible/watch glass (Step 9.1.1.4)

9.1.3.2. Dry sample weight =

Crucible/watch glass/dry sample (Step 9.1.2.7) – Crucible/watch glass (Step 9.1.1.4)

9.1.3.3. % Total Solids =

((Dry sample weight)/(Wet sample weight)) * 100

9.2. Nitrogen content

9.2.1. Sample preparation

9.2.1.1. Obtain percent total solids of each sample to be analyzed, according to SOP M3.

9.2.1.2. Label digestion tubes as necessary to accommodate all samples in duplicate, plus various QA standards (Precision and Recovery Samples, Calibration Verification Standards, Quality Control Standards, Matrix Spikes, and/or Blanks) as required (Sections 11.2.3 - 11.2.8 state how often each of these must be included).

9.2.1.3. Solid samples (feed, bedding): Bring sample to room temperature if necessary. Thoroughly grind the sample. Weigh 1-2 g of sample into weighing paper, fold and transfer to a 250-mL digestion tube. Add 1 Kjeldahl Digestion Mixture tablet and 20 mL of concentrated H_2SO_4, and place tube on the Tecator Model 2020 heating block.

9.2.1.4. Liquid/slurry samples (milk, eggs): Add 1.1 g of Digestion reagent (Section 8.3.4.3) to a 50-mL digestion tube. Bring sample to room temperature if necessary. For eggs, mix thoroughly (Section 9.1.2.1.2). Pipette sample (0.5-1 g for eggs (Costa et al 1974) or ~ 5 g for milk (Barbano et al 1990)) to the tube. Add 2-3 glass beads, along with 5 ml of concentrated H_2SO_4. Place tube on the Tecator Model 2020 heating block.

9.2.2. Digestion

9.2.2.1. Immediately set up the exhaust system, and place the exhaust manifold so that it covers the mouth of each digestion tube. Turn water to vacuum on low.

9.2.2.2. Digest for 2 h.

9.2.2.2.1. Be sure that the manifold and hood fan are operating properly to remove the fumes released in the digestion process.

9.2.2.3. Remove tubes from digestion block with tongs and transfer to cooling tray to cool, leaving the exhaust manifold in place for a minimum of 30 min after the end of the digestion. After 30 min, turn off water to vacuum, and remove exhaust manifold.

9.2.2.4. Add NH_3-free water to each tube to the level of the top horizontal support on the cooling rack (~50 mL). Place samples in the cooler and cool to <20 ºC.

9.2.3. Distillation

9.2.3.1. Place samples on the Model 2300 and select “Kjeldahl 5”. This selection ensures that the instrument will dispense a sufficient amount of NaOH to the sample.

9.2.3.1.1. Use 0.020 N H_2SO_4 for low-N samples, and 0.25 N for all others. Most samples associated with livestock manure, feed, and bedding are assumed to require 0.25 N H_2SO_4.

9.2.4. Calculations

9.2.4.1. Calculate TKN (in units of mg/g) in the sample as follows, correcting the amount of titrant (0.25N H_2SO_4) added to each sample by subtracting that needed to titrate a blank to endpoint:

$$\mathrm{TKN} = \frac{\mathrm{Titrant_{sample}\,(mL) - Titrant_{blank}\,(mL)}}{\mathrm{Sample\ wt\ (g)}} \times 3{,}500^{*}$$

*If 0.25N H2SO4 is used in the distillation/titration step. If 0.02 N acid is used, replace 3500 with 280.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike errors in writing with a single line. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Total solid and ash (non-volatile solids) contents

11.1.1. Quality Control spiking solutions

11.1.1.1. The composition of a suitable QC spiking solution is given in Section 11.1 of SOP M3. A suitable commercially available product is also listed.

11.1.2. Analyst proficiency demonstration

11.1.2.1. Each new analyst must process a set of Initial Precision and Recovery (IPR) samples as described in Section 11.2 of SOP M3, and meet the performance specifications defined therein.

11.1.3. Ongoing Precision and Recovery (OPR) samples

11.1.3.1. Include one OPR sample (25-50 mL) with each sample batch (Section 3.12), and subject it to all steps of the analytical method.

11.1.3.2. Procedures for preparing OPR solutions, and the required performance ranges, are given in Section 11.3 of SOP M3.

11.1.4. Blanks

11.1.4.1. Include one blank (25-50 mL of deionized water) with each sample batch (Section 3.12), and subject it to all steps of the analytical method.

11.1.4.2. If solid material is detected in the blank at or above the MDL, analysis must be stopped until the source of contamination is identified and eliminated (i.e. a new blank shows no evidence of contamination).

11.2. TKN determinations

11.2.1. Reagent purity

11.2.1.1. Use only NH_3-free water in this method. See Step 6.9 for the methodology used to remove NH_3 from water for use in these procedures.

11.2.1.2. All other reagents will be ACS Reagent Grade or better.

11.2.2. Initial demonstration of analyst & laboratory proficiency

11.2.2.1. Every new analyst performing the TKN procedures in this SOP must demonstrate, as described in detail in SOP M4, an ability to achieve acceptable results with the method. The analyst must determine a Method Detection Limit (MDL), and demonstrate linear results ($R^2 \geq 0.96$) with the five-point range of calibration standards (Section 8.3.5.2). He/she must also analyze an Initial Precision and Recovery (IPR) sample set, Blank(s), and Calibration Verification (CV) standard(s).

11.2.3. Ongoing Precision and Recovery (OPR)
  11.2.3.1. MDLs
    11.2.3.1.1. The procedure for determining MDLs is given in Section 11.3.1.1 of SOP M4.
    11.2.3.1.2. Re-determine/verify MDLs at least once every year.
    11.2.3.1.3. Re-determine/verify MDLs if the method or analytical system is modified.
  11.2.3.2. Precision and Recovery (PR) samples
    11.2.3.2.1. Each batch of 10 samples must contain a minimum of one PR sample.
    11.2.3.2.2. Directions for preparing and analyzing the PR samples, as well as the required performance limits, are included in Section 11.4.2 of SOP M4.
    11.2.3.2.3. All samples must be associated with an acceptable PR standard before their results may be reported.
11.2.4. Calibration curves
  11.2.4.1. Generate a new calibration curve (containing a minimum of five points) whenever a new standard is obtained.
11.2.5. Calibration Verification (CV) standards
  11.2.5.1. Run a Calibration Verification Standard (solid or slurry as appropriate based on the sample type) once per every ten analyses.
    11.2.5.1.1. Acceptance criteria for the CV Standard is 100% ± 5%.
    11.2.5.1.2. If the CV does not meet the acceptance criteria, identify and correct the problem, including possible recalibration of the system.
    11.2.5.1.3. All samples must be associated with an acceptable CV Standard before their results may be reported.
11.2.6. Quality Control standards
  11.2.6.1. Analyze a QC standard with each batch of 20 samples run in one day, or every 12 h, whichever is more frequent.
11.2.7. Matrix Spikes
  11.2.7.1. To assess the performance of the method on a given sample matrix, spike (in duplicate) a minimum of 5% (1 sample in 20) of the samples from a given site.
  11.2.7.2. Procedures for determining the required spiking level, assessing spike recovery, and evaluating the acceptability of results are given in SOP M4 (Section 11.8).
11.2.8. Blanks
  11.2.8.1. Run a minimum of one blank with each batch of 20 samples.
    11.2.8.1.1. Use 10 mL of NH_3-free water as the blank for milk and egg samples, and a 5-g aliquot of blank sand as the blank for feed or bedding samples.
  11.2.8.2. If N is detected in the aqueous or solid blank at a concentration greater than the aqueous or solid MDL, halt analysis of samples until the source of contamination is eliminated and a new blank shows no contamination.
  11.2.8.3. All samples must be associated with an uncontaminated laboratory blank before their results may be reported.

11.3. General

11.3.1. Each time any modification is made to this method, the analyst will verify that the modified method meets or exceeds the Method Detection Limit and Initial Precision and Recovery achieved by the same analyst using the original (i.e. unmodified) method. Procedures for this, and for fully documenting all changes made to the method, are given in SOP M3.

- 11.3.2. Replication
  - 11.3.2.1. Run duplicates for a minimum of 1 in 10 samples (10%), with at least one duplicate per sample batch.
  - 11.3.2.2. Replicate samples for solids determination must agree to within 10% of their average (% total solids); if not, rerun these samples.
  - 11.3.2.3. Replicate samples for TKN determination must agree to within 10% of their average TKN content; if not, rerun these samples.
- 11.3.3. QC Charts
  - 11.3.3.1. Track all IPR, OPR, Calibration Verification, QC Standard, MS, and Blank results to provide graphical representations of continued laboratory performance.
- 11.3.4. Instrument Calibration and Standardization
  - 11.3.4.1. Calibrate analytical balance annually (at a minimum). See SOP M3 for procedures for calibrating balances.

12. References

12.1. USEPA Method 1687. 2001. Total Kjeldahl Nitrogen in Water and Biosolids by Automated Colorimetry with Preliminary Distillation/Digestion (Draft). EPA-821/R-01-004 (CD). USEPA Office of Water, Office of Science and Technology. Washington, DC.
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12.12.EN SOP 65e. 2004. Total Kjeldahl Nitrogen (TKN). Standard Operating Procedure EN65e. Midwest Laboratories, Inc, Omaha, NE.

PRODUCER COLLABORATIONS AT OPEN-SOURCE MONITORING SITES

Standard Operating Procedure (SOP) S7

PRODUCER COLLABORATIONS AT OPEN-SOURCE MONITORING SITES

Standard Operating Procedure (SOP) S7

Prepared by:
Richard H. Grant

Reviewed by:
Bill W. Bogan and Albert J. Heber

Effective Date: November 6, 2006

PURDUE APPLIED METEOROLOGY LABORATORY (PAML)
Agronomy, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The collection of high-quality air emissions data from a livestock facility requires communication and collaboration between the field operations staff (FOS) and the livestock producer and his/her staff.

1.1.1. The livestock producer's staff may or may not have a specific interest in the data collected at the open-source site.

1.2. This SOP describes the following:

1.2.1. Procedures for collaboration between the FOS and livestock producer and his/her staff responsible for open-source sites (lagoons and corrals)

1.2.2. Information related to the open-source sites that must be collected from livestock producers or his/her staff

1.2.3. Expectations placed upon collaborating livestock producers or his/her staff, and on the FOS

1.2.4. Possible modifications to farm operations that may be needed to accommodate the study.

1.3. This SOP applies specifically to the National Air Emissions Monitoring Study.

2. Summary of Method

The research staff must establish and maintain effective communication with any livestock-production that is participating in a research study. The facility design and operational information of the farm must be provided by the producer or his/her staff to the FOS. In addition, the FOS must communicate to the livestock producer and his/her staff those requirements that he/she must meet in order to conduct a successful study. The collaboration and communication will include email messages, phone calls, face-to-face meetings, reports, data forms, presentations, data monitoring, and project documentation such as the Quality Assurance Project Plan (QAPP).

3. Definitions

3.1.	Biosecurity	Measures that are taken to prevent spread of disease to or from livestock or poultry.
3.2.	DM	Data Manager
3.3.	FOS	Field operations staff
3.4.	PM/PI	Project Manager or Pincipal Investigator
3.5.	PPR	Pull plug with recharge
3.6.	QAPP	Quality Assurance Project Plan
3.7.	SOP	Standard Operating Procedure

4. Health and Safety

4.1. Beware of, and do not interrupt, worker traffic. FOS may request a slight delay or interruption in normal farm activities during set up and disassembly of instrumentation, but must always defer to the decisions and activities of the producer and his/her staff.

4.2. Watch out for vehicular traffic such as litter, feed, animal, milk, and egg trucks, loaders, cars, and other vehicles.
4.3. The farm's licensed electrician should conduct or approve all electrical work associated with the study. An example is connecting power to the instrument shelter.
4.4. Be careful around animals and birds to prevent personal injury.
4.5. Post the phone number for medical emergency personnel and directions (map) to the nearest hospital in the instrument trailer close to the entrance.
4.6. Emergency evacuation procedures at each measurement location will be those established by the livestock producer.
4.7. Maintain a first aid kit in the instrument trailer.

5. Cautions

5.1. Take steps to overcome language barriers (e.g. Spanish vs. English). For example, if any worker has Spanish as his/her primary language, distribute a pamphlet in Spanish indicating the objectives of the study and the importance of taking care of the instrumentation. The pamphlet can be complemented with a video and/or PowerPoint presentation in Spanish that can be distributed to all research sites, and can be included in a periodic (quarterly) refresher session (as rotation of workers in the farms can be high).
5.2. Post signs or labels by sensitive test equipment and in measurement paths, indicating that they should not be touched or worked around unless authorized by study personnel. These should also be written in the primary language(s) of the farm workers.
5.3. Fence the region around any light emitters that may cause eye damage.
5.4. FOS must follow all biosecurity protocols and guidelines requested by individual livestock producer or his/her staff. At minimum, these can be expected to include:
  5.4.1. Cleaning research vehicles and equipment entering the farm according to the producer's specific protocol
  5.4.2. Accessing only areas that are directly involved in the study
  5.4.3. Ensuring that FOS have not exceeded producer-specified limits on foreign travel and/or visits to other poultry or livestock farms.
  5.4.4. Notifying the livestock producer prior to visiting the site
5.5. The FOS should, to the greatest extent possible, solicit input and suggestions from the livestock producer and his/her staff as to safe locations for equipment, possible hazards that might occur, and appropriate precautions that might best protect equipment and staff.
5.6. Remember that the producer's involvement and time commitment to the project is less than that of the FOS. The amount of time required for the livestock producer or his/her staff to execute their commitments to the study is a major factor influencing current and future involvement. Take care not to use more of the producer's and/or staff's time than is absolutely required for the study.

6. Interferences

6.1. The participating farms should operate with typical management practices, particularly during active monitoring periods, to minimize the potential for bias in the emission data. If changes to the farm operations occur, they must be documented, and these records retained according to SOP D1.
  6.1.1. Livestock producer or his/her staff should notify FOS if research equipment is

interfering with farm operations and needs to be moved or modified.

- 6.1.2. Livestock producer and his/her staff must agree not to move or modify study equipment themselves.
- 6.2. FOS must not give tours of the study site without livestock producer’s permission. Establish a policy about tours prior to setting up instrumentation on the farm.
- 6.3. Any add-on research projects at the farm must be approved by the livestock producer.

7. Personnel Qualifications and Training

- 7.1. All livestock producer and research staff involved in the study should read this SOP.
- 7.2. A pre-study training and orientation session for the livestock producer and his/her staff will be conducted by the FOS or Project manager, and will include time for the livestock producer or his/her staff to explain the farm operation. The training session will also be conducted in the primary language of the farm workers, with the help of translated video and/or a PowerPoint presentation.

8. Utilities, Equipment and Supplies Provided by Farm Staff

- 8.1. Personal protection equipment
  - 8.1.1. Levels of protective equipment will likely vary at a given facility, depending upon the season, activity, and other factors.
  - 8.1.2. Protective clothing may be provided by the FOS, or by the livestock producer or his/her staff, depending, for example, on the preferences of the livestock producer. Reach an agreement on this point with each producer at the beginning of the study.
    - 8.1.2.1. For example, if livestock producer wishes to supply their own boots as part of their biosecurity program, FOS will abide by this preference.
- 8.2. A suitable area for placement of the open-source instrument trailer, including all-weather (e.g. gravel) access as necessary
- 8.3. Electric power hookup post (SOPs U4 and U5)
- 8.4. Utility located to ensure the FOS does not accidentally damage underground cables, gas lines, tiles, drains, or other underground hazards while sinking anchors.
- 8.5. Phone line (required) and internet service (preferred) (SOP U4)
- 8.6. A garden hose with a nozzle near the site of the open-source instrument trailer
- 8.7. Restroom and shower facilities, if available

9. Procedures

- 9.1. Livestock producer and his/her staff will allow free access to farm by project staff.
- 9.2. Livestock producer or his/her staff will be apprised of all necessary structural modifications (SOPs U4 and U5).
  - 9.2.1. Provide a project schedule and QAPP to the livestock producer at least 90 days prior to initiation of setup.
  - 9.2.2. Set up a monthly phone call with farm management to solve problems, provide updates and facilitate collaboration.

- 9.2.3. Detailed information about the farm will be collected for each participating site as part of the site-selection process. Site-selection criteria and parameters that should be collected before initiating a study are included as appendices.
  - 9.2.3.1. Lagoon and basin site forms are included in Appendix A.
  - 9.2.3.2. Corral site forms are included in Appendix B.
- 9.2.4. At the end of each measurement period, each collaborating livestock producer at a lagoon or basin site is requested to provide the following information (Appendix A: Table A2) for all barn(s) whose waste goes to the lagoon or basin:
  - 9.2.4.1. Animal inventory, average weight and average age
  - 9.2.4.2. Record of animal movements in and out of the barn
  - 9.2.4.3. Animal diet (feed composition, including N and S levels, and feed consumption rates).
  - 9.2.4.4. Production (quantity and weight of marketed animals, eggs, milk, etc.)
  - 9.2.4.5. Record of sludge removals
  - 9.2.4.6. Record of pump outs (contractor or livestock producer)
  - 9.2.4.7. Record of water consumption
  - 9.2.4.8. Advance notice of any change in production schedules and methods
- 9.2.5. At the end of each measurement period, each collaborating livestock producer at a corral site is requested to provide the following information (Appendix B: Table B2):
  - 9.2.5.1. Animal inventory, average weight and average age
  - 9.2.5.2. Animal diet (feed composition, including N and S levels, and feed consumption rates)
  - 9.2.5.3. Production (quantity and weight of marketed animals, milk, etc)
  - 9.2.5.4. Record of cleaning operations
  - 9.2.5.5. Record of animal movements in and out of the corral
  - 9.2.5.6. Record of water consumption
  - 9.2.5.7. Advance notice of any change in production schedules and methods

9.3. Livestock producer and his/her staff should be made aware that placement of equipment or sensors may in some cases require some site modification. FOS and livestock producer staff should work together to ensure that both the equipment and animals are well-protected.

- 9.3.1. Trailers placed in lots accessible to animals will likely need to be enclosed with protective fencing.
- 9.3.2. Equipment placed in areas that may occasionally have vehicular traffic may need additional flagging or warning bumpers.

9.4. Livestock producer or his/her representative should contact the PM/PI whenever there are any questions or concerns relating to measurement operations, or if there is catastrophic damage to farm operations.

10. Data and Records Management

10.1. Site Identification. Each site will be labeled in a standard format to denote site type (in this case, area component), location and number. For example, the finisher swine basin in Iowa is “IA3A”. This format is described in more detail in SOP B5. Producers shall not be identified in each site plan.

10.2. The FOS will maintain a log of farm visits in the lab notebook.

10.3. The livestock producer will maintain a log sheet of non-monitored farm activities that affect emissions (See Appendix C).

10.4. Data collected using Producer Event Forms (Appendix C) will be entered into an Excel spreadsheet and included in the site field notes, as described in SOP D1. Management of this data is also described in SOP D1.

 10.4.1. Scan all producer event forms, and keep them in electronic form and in paper form at the site. Electronic copies will then be ftp transferred to the PM and DM, as described in SOP D1.

10.5. Initial and date any corrections made on hard copies of forms. Use only indelible ink.

11. Quality Control and Quality Assurance

11.1. Each FOS member must maintain a log of animal exposures at other farms.

11.2. Monthly conference calls ensure communication between FOS and livestock producer.

11.3. Livestock producer must check daily to make sure his/her staff are filling out the Producer Event Form, because they do not normally record such data during daily or weekly activities.

11.4. Document all decisions and action items on paper in ink during all planning and status meetings so that it can be confirmed that all parties are in agreement.

11.5. Be sure livestock producer has a copy of the rationale for the study (found in the QAPP) and a copy of the schedule.

 11.5.1. If the livestock producer wishes, provide a copy of any relevant SOPs.

11.6. Training/ information session will include a verification of understanding of the basic aspects of the project, importance of the instrumentation and effects of farm operation on the study. Verification of understanding will be through the use of a question and answer session.

11.7. Livestock producer should designate a responsible staff member (liaison between the farm and the research team) for collecting and transmitting operational information, and also provide the name of his or her substitute when he or she is not available. This person should attend all informational meetings.

12. References

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12.2. SOP U4. 2006. Open-source Instrument Trailer. Standard Operating Procedure U4. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.

12.3. SOP U5. 2006. The Installation of Open-source Measurement Equipment. Standard Operating Procedure U5. Purdue Ag Air Quality Lab/ Purdue Applied Meteorology Lab.

Appendix A Site Information Form for Lagoons and Basins (SOP S7)
Table A1. Lagoon and basin site-selection criteria

Category	Information
Farm name	
Address, phone	Contact Person:
Livestock Producer	Biosecurity: time since farm visit, days:
	Willing to provide production information?
	Cooperative and enthusiastic participant?
	How long has the farm been in operation under current owner?
	Able to provide feed and water consumption data? Sample analysis records?
	Willing to possibly test abatement technologies after the NAEMS?
	Describe management style (tools used, etc.):
Convenience	Distance from university, miles:
	Phone, internet, and electric power available? 240 VAC?
	Lodging nearby for research team?
Facilities	Generally describe rations:
	Animal breed:
	Describe feed delivery system
	Describe waste collection, handling, treatment and storage systems
	Rate lagoon maintenance from 1 to 5 (1 is cleanest):
	Any emission control measures at facility?
Surroundings	Describe surrounding landscape and topography (hills, flat, etc.)
	Describe other pollution sources within one mile:
	Distance to nearest land application sites
	Distance from public road. Type of road (gravel or paved).

Table A2. Characteristics of test site lagoons or basins.

Descriptive parameters	Unit 1	Unit 2	Unit 3
Livestock type			
Year of facility construction			
Separation distance from barn fans, ft			
Type of storage (basin, lagoon or tank)			
Stage of lagoon (1st, 2nd, 3rd)			
Manure contributors to unit			
Animal 1 type (sows, cows, etc.)			
Animal 1 average weight (lb)			
Animal 1 inventory (# head)			
Animal 2 type (sows, cows, etc.)			
Animal 2 average weight (lb)			
Animal 2 inventory (# head)			
Animal 3 type (sows, cows, etc.)			
Animal 3 average weight (lb)			
Animal 3 inventory (# head)			
Manure collection (flush, scrape, PPR)			
Source flush or recharge water (if any)			
Lagoon loading frequency, hours			
Minimum space surrounding unit, ft.			
Volumetric loading rate, lb/d-ft^3			
Surface loading rate, lb/d-ft^2			
Obstructions within 3X height of unit?			
If yes, what kind? (e.g. trees, barns)			
Height of highest obstruction, ft			
Distance from worst obstruction, ft			
Type of cover (crust, straw, none, etc.)			
Are solids separated from influent?			
Odor control: (digester, additives)			
Sludge removal cycle, years			
Last time sludge removed (e.g., 1999)			
Agitation prior to pumpout?			
Manure removal frequency, days			
Pump out (contractor or producer)			
Type of liner (clay, plastic, etc.)			
Volume, cubic ft			
Surface area, square feet			
Berm slope (e.g. 3:1, 3.5:1, 4 :1, etc.)			
Maximum side length, ft			
Minimum side length, ft.			
Actual freeboard, ft.			
Inner berm height, ft.			
Outer berm height, ft.			
Liquid depth, ft.			
Sludge depth, ft.			
Number of inlets (show on drawings)			
Shape (rectangular, oval, etc.)			

Appendix B Dairy Corral Site Information Form (SOP S7)
(Email to Al Heber, Purdue University: heber@purdue.edu)

Table B1. Dairy Corral Site Selection Criteria, SOP S7.

Category	Information
Farm name	
Address, phone	
Livestock Producer	Provide production and herd management information (DC305)?
	Cooperative and enthusiastic about study?
	Willing to make some nonconsequential changes for the test?
	Willing to train herdspersons about importance of test?
	Able to provide feed and water consumption data per cow group?
	Willing to possibly test abatement technologies after the NAEMS?
	Describe management style (tools used, etc.):
Convenience	Distance to site from university, miles:
	Cell phone signal?
	Phone, internet, electric power available?
	Lodging nearby for research team?
Corrals	Generally describe rations (including forages and purchased feeds)
	Describe feed delivery system.
	Describe waste collection, handling, treatment and storage systems
	Rate corral hygiene from 1 to 5 (1 is cleanest).
Surroundings	Describe surrounding landscape and topography.
	Describe other pollution sources within one mile of site;
Farm	Describe all facilities on the site (# hd, size, age);
	Distance to nearest land application sites.
	On-site heifer growing program?

Table B2. Characteristics of test site: corrals, SOP S7.

Descriptive parameters.	Type 1	Type 2	Type 3
Breed			
Inventory (cow capacity)			
Average mass, lb			
Year(s) of construction			
Overall site width (E-W dist), ft			
Overall site length (N-S dist), ft			
Heifer growing program?			
Corrals			
Type (yearlings, lactation, hosp, etc.)			
Number			
Corral orientation			
Corral width, ft			
Corral length, ft			
Corral area, ft^2			
Apron width, ft.			
Apron length, ft.			
Apron cleaning (flush, scrape, vac)			
Maintenance technique (scr, harrow)			
Maintenance frequency (days)			
Shade height, ft.			
Shade length, ft.			
Shade width, deg.			
Side slope, %			
Cross slope, %			
Cow lane width, ft			
Cow lane length, ft			
Windbreak			
Height, ft			
Length, ft			
Lagoon			
Length, ft			
Width, ft			
Depth, ft			
Berm height, ft			
Number of stockpiles			
Weeping pad area, ft^2			
Number of separators			
Number of silage bunkers			
Number of hay barns			
Parlor			
Width, ft			
Length, ft			
Sidewall height, ft			
Roof ridge height, ft.			
Type of ventilation			
Number of air outlets in ridge			
Type of sidewall inlets			
Air circulation fans in ceiling			
Misting?			

Exit lane drenching?			
Holding time, min			
Wash cows?			
Milking frequency, times daily			
Parlor occupancy, # cows			
Holding pen			
Manure removal (flush, hand wash)			
Manure removal frequency			
Width, ft			
Length, ft			
Sidewall height, ft			
Roof ridge height, ft.			
Type of ventilation (NV, MV)			
Number of air outlets in ridge			
Type of sidewall inlets			
How is feed weighed?			
How is manure loads weighed?			
How are animals weighed?			
Number of pumps to monitor			
Access around property for sensors?			

Appendix C Producer Event/Change Form (SOP S7)

In order for the Purdue Air Quality group to do its job, they need to know about events/changes around the lagoon, basin, or corral that affect airflow or air emissions. A few jotted notes here will help them not make mistakes when analyzing the data. Thank you for your cooperation! [Examples of changes include (but are not limited to): major water leaks, power interruptions, sludge removal, pump outs, and diet changes.]

Description of event/change	**Start time/date**	**End time/date**	**Contact person**

Project contact information:
Name(s):____
Office phone: _________________________
Cell phone: _________________________

ON-FARM INSTRUMENT SHELTERS FOR BARN SOURCES

Standard Operating Procedure (SOP) U1

ON-FARM INSTRUMENT SHELTERS FOR BARN SOURCES

Standard Operating Procedure (SOP) U1

Prepared by

Sam M. Hanni and Bill W. Bogan

Reviewed by

Teng-Teeh Lim and Albert J. Heber

Effective Date: November 6, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. A trailer is used to house on-site instrumentation (data acquisition hardware, gas analyzers, computer, etc) for collecting barn emission data at a remote farm site.

- 1.1.1. The On-Farm Instrument Shelter (OFIS) can withstand:
  - 1.1.1.1. Winds of 80 miles per hour
  - 1.1.1.2. Outdoor temperatures from -30 to 110°F
  - 1.1.1.3. Rain falling at rates up to six inches per hour
  - 1.1.1.4. Solar heat gain on the brightest day
- 1.1.2. The OFIS, structurally, is:
  - 1.1.2.1. 8 ft tall, 7 ft wide and 24 ft long
  - 1.1.2.2. Equipped with windows too small for thieves
  - 1.1.2.3. Locked to prevent unauthorized entry
  - 1.1.2.4. Conducive to conducting tours to visitor and site auditors
- 1.1.3. Utilities include:
  - 1.1.3.1. High-speed internet
  - 1.1.3.2. Land line phones
  - 1.1.3.3. Electricity to handle up to 100-A load
- 1.1.4. Barn monitoring can be conducted:
  - 1.1.4.1. With gas sampling locations up to 2,000 ft away
  - 1.1.4.2. With raceway entry to barns up to 150 ft away and 11 ft above the ground
  - 1.1.4.3. From one to five buildings
  - 1.1.4.4. With continuous gas and PM analyzers
- 1.1.5. The OFIS can facilitate integrated samples of TSP, VOC and odor.
- 1.1.6. The OFIS provides three lines of lightning protection (Fig. 1) for sensitive instruments.

2. Summary of Method

This SOP outlines the structural specifications for custom-designed mobile trailers for use at barn air emission monitoring sites. The OFIS (Fig. 2) provides protection and proper operating conditions for the data acquisition system and analytical equipment, such as gas analyzers and PM monitors (Fig. 3) and gas sampling systems. It also provides laboratory space for research personnel, space for safe storage and use of compressed gas cylinders for gas analyzer calibrations, and storage for personal protection equipment and clothing used by research personnel. The OFIS is equipped with heating and cooling air conditioning system to provide comfortable working conditions for research personnel and instruments, and sufficient ventilation to remove any noxious gases released from the gas analyzers, as well as filters to capture dust, gases and odors from entering the OFIS. It has facilities for washing hands, and for storing water, food and/or samples. Certain site preparations must be made, as described in this SOP. Once at the site, the OFIS should be supported securely by blocks to avoid putting weight on the tires. Outdoor steps are put in place to gain access to the OFIS. Hurricane straps are used to secure the OFIS to the ground as a protection against storms and high winds.

3. Definitions

3.1.	DAC	Data acquisition and control
3.2.	DSL	Digital subscriber line
3.3.	GFCI	Ground fault circuit interrupter
3.4.	HVAC	Heating, ventilation and air conditioning
3.5.	O.C.	On-center
3.6.	OFIS	On-farm instrument shelter
3.7.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.8.	QAPP	Quality Assurance Project Plan
3.9.	SOP	Standard operating procedure
3.10.	TEOM	Tapered element oscillating microbalance
3.11.	UPS	Uninterruptible power supply

4. Health and Safety

4.1. Exercise proper care when setting up the OFIS, including setting up the blocks supporting the OFIS and make sure that the trailer is properly leveled.

4.2. Before pulling the OFIS to or from the research site the trailer's brakes, turn signals and trailer lights should be properly connected to the truck pulling the trailer and checked by the driver to ensure proper function.

4.3. Be careful using the outside steps and climbing to the top of the OFIS, particularly in inclement weather. Be mindful of wet or icy steps and ladder.

4.4. Ensure that ventilation systems are working properly, taking into account the following points:

4.4.1. Several of the gas analyzers can release noxious fumes. Make sure that these exhausts are properly ventilated outside the OFIS, away from air inlets.

4.4.2. Avoid positioning the OFIS directly in front of the barn exhaust fans, especially large fans.

4.4.3. Clean, maintain, and replace internal air filters frequently to properly mitigate odors and gases. Check the filters at least weekly.

4.5. Exercise proper care when wiring the OFIS. Connections must be performed by a certified electrician. Follow all applicable local electrical codes.

4.6. During lightning storms, avoid contact with electrical instruments or with the exterior shell of the OFIS.

4.7. Be aware of traffic patterns on the farm. Avoid positioning the OFIS in an area that is frequented by trucks or other service vehicles.

4.8. Use steps with a landing that is at least 4 ft wide.

5. Cautions

5.1. When transporting the trailer to and from the site, make sure that a spare tire for the trailer is available, and that all exterior doors are securely locked. Tow only with vehicles and hitches that are rated for the trailer weight. Follow any applicable state codes, and make sure that the trailer is properly licensed for the state.

- 5.1.1. Do not transport sensitive electronic instruments in the trailer unless they are properly packed and secured.
- 5.1.2. If gas cylinders are to be transported in the trailer, make sure that they are secured as described in SOP G2. Additionally, a strap, fastener, or chain should be used near the bottom of each cylinder to restrain it, and keep it from tipping over. Never transport cylinders with regulators attached (SOP G2).

5.2. Flexing of the undercarriage may occur during transportation (specifically, during turns). This may, over time, cause the lug bolts mounting the wheel rims to the hubs to loosen. Check the lug bolts every 100-200 miles during transportation, and tighten as necessary.

5.3. Locate the hurricane straps before drilling holes for the heated raceway(s) (SOP U3).

5.4. Ensure that the raceway (SOP U3) slopes downward from the OFIS to the barn (3% slope); to keep any raceway moisture out of the OFIS and instruments.

5.5. Plug raceway(s) to prevent air flowing through the raceway and into or out of the OFIS.

5.6. Make sure all instruments are disconnected before supplying power to the OFIS for the first time. To check that power connections are correct before turning on the power switch use a voltmeter to check that the correct voltage is supplied.

5.7. Improper maintenance of the HVAC system can impair performance, leading to uncomfortable conditions.

- 5.7.1. Check and clean filters weekly and replace filters on HVAC unit when needed.
- 5.7.2. Check the outdoor coils once a week (at minimum), and clean as necessary.
- 5.7.3. It is advisable to check the filters and outdoor coils more frequently in summer time, in case the levels of dust and debris are particularly high. If this proves to be true, adjust cleaning schedule as necessary. Clogged air inlets of the HVAC system can impair performance, and may result in damage to the motor, compressor, and/or heating elements.
- 5.7.4. Do not stack or prop anything against the outdoor condenser unit, or block the outdoor coils in any way.
- 5.7.5. Do not allow snow to pile up or drift around the outdoor HVAC unit.
- 5.7.6. Periodically check the permanent drain connection near the inside coil (indoor HVAC unit) to make sure it is unobstructed, and that water is draining properly.

6. Interferences

6.1. Heat-generating motors found on the larger pumps required by some of the equipment could place an undue strain on the air conditioning system. Place all pumps in the under-counter storage compartment (Section 8.1.12.1), which is ventilated/cooled by an individual fan.

6.2. Extreme weather such as lighting strikes, high winds, and extremely high and low temperatures can affect the OFIS conditions. When these extreme weather situations occur, check the OFIS to make sure it is functioning properly. Set up email alarms for OFIS conditions that are out of limits (SOPs B2); the QAPP will specify to whom such e-mails should be sent.

6.3. Flies and dust can enter different equipment and affect the functionality of that equipment. Screen air inlets and exhausts as much as possible.

6.4. Rodents can chew through vacuum tubes, insulation and wiring. Use mouse/rat poison, and inspect all tubing frequently for possible damage.
6.5. Thieves can be thwarted using secure door and latch locks, and small windows.

7. Personnel Qualifications

7.1. Personnel must read and understand this SOP before participating in the setup and/or operation of the OFIS.
7.2. Personnel involved in transporting the OFIS trailer must possess the appropriate driver's license(s), and have experience in towing trailers.
7.3. Individuals and/or companies involved in the transportations of the trailers should be properly insured.

8. Equipment and Supplies

8.1. Trailer: Order or obtain a trailer that meets or exceeds the following minimum specifications, or their equivalents:
  8.1.1. Frame & structural support
    8.1.1.1. 8" JR I-beam outrigger chassis frame
    8.1.1.2. Tandem 6000-lb axles (2 with brakes); springs overslung
    8.1.1.3. 10-ply tires
    8.1.1.4. Standard towing hitch (welded with 2 5/16" cup and jack)
  8.1.2. Floor
    8.1.2.1. 2x4 transverse joists (#3 SPF equal or better), 16" on-center spacing
    8.1.2.2. 5/8" tongue-and-groove (T&G) plywood deck
    8.1.2.3. Standard bottom board (woven plastic insulation support)
    8.1.2.4. R-11 faced fiberglass insulation installed tight to warm side of cavity
    8.1.2.5. 1/8" vinyl composition tile (Class A/1 F.S.)
  8.1.3. Roof
    8.1.3.1. Bow trusses at 16" O.C. (30-lb live load), 12" heel x 14" crown 93" long trusses
    8.1.3.2. 1/2" gypsum ceiling panel (Class A/1 F.S.)
    8.1.3.3. Sheathing: 7/16" OSB 16/0 span index
    8.1.3.4. Tie-downs: 2 over the roof hurricane straps
    8.1.3.5. Gutter: K-60 J-Rail
    8.1.3.6. Roof venting: 1 non-powered screened roof vent
    8.1.3.7. R-19 insulation w/vapor barrier
    8.1.3.8. 30-gage galvanized steel (Class C/3 F.S.)
  8.1.4. Exterior Walls
    8.1.4.1. 2x4 studs, 16" o.c., w/top and bottom plates (all 2x4 #3 SPF)
    8.1.4.2. Wall height = 8'0"
    8.1.4.3. R-11 batt insulation
    8.1.4.4. 1/4" vinyl covered paneling (Class A/1 F.S.)
    8.1.4.5. 1/8" structural thermoply sheathing
    8.1.4.6. 0.019 white aluminum siding and trim
    8.1.4.7. 1-1/4" casing (wood grain) base trim

- 8.1.4.8. 1” batten (vinyl) top & corner trim
- 8.1.4.9. 2-1/2” casing (wood grain) door trim

8.1.5. Interior Walls
- 8.1.5.1. 2x4 stud grade SPF, 16” on-center
- 8.1.5.2. 30” wall height for countertop
- 8.1.5.3. H.P. laminated counter top

8.1.6. Doors
- 8.1.6.1. Interior
  - 8.1.6.1.1. (1) 24x80 hollow core wood grain pocket door
- 8.1.6.2. Exterior
  - 8.1.6.2.1. (1) 36”x80” insulated steel with wood jambs and 10x10 safety glazed window, dead bolt standard lock set, and weather stripping threshold
  - 8.1.6.2.2. 25”x25” aluminum open swing compartment doors w/keyed latch

8.1.7. Electrical system
- 8.1.7.1. 100-A load center
  - 8.1.7.1.1. Two single 50-A lines (with grounds) at 120/240 V (single phase)
  - 8.1.7.1.2. External Pullout Switch (with rainproof enclosure)
  - 8.1.7.1.3. Manual Transfer Switch
  - 8.1.7.1.4. 100-A Maximum
  - 8.1.7.1.5. 60 Hz with ground
  - 8.1.7.1.6. Cat # PE 630-V
  - 8.1.7.1.7. 3-wire single phase
  - 8.1.7.1.8. 12 circuit with main 100-A circuit breaker (GETLM812))(+36” AFF)
- 8.1.7.2. (3) 48” twin-tube fluorescent lights with surface diffusers
- 8.1.7.3. Incandescent light (1) w/cover in bath
- 8.1.7.4. Motion-triggered external light (300 W) above the external door
- 8.1.7.5. (1) 240-V 30-A receptacle dedicated to one circuit breaker
- 8.1.7.6. (8) 110-V duplex 15-A receptacles
- 8.1.7.7. (1) 110-V duplex 20-A receptacle dedicated to 1 circuit
- 8.1.7.8. (2) 110-V 15-A exterior receptacles
- 8.1.7.9. Wall-mounted power strip, with five pairs of outlets, over the “L” of tables in the clean end of the OFIS, such that this power strip can be routed through the uninterruptible power supply (UPS) (SOP U6)
- 8.1.7.10. GFCI receptacle (1) by bath
- 8.1.7.11. Copper Romex 14-gage raceway
- 8.1.7.12. Manual transfer switch from shore power to generator power
- 8.1.7.13. Lightning arrestor
  - 8.1.7.13.1. Minimum of 120k Amps/phase capacity
  - 8.1.7.13.2. Titan 120 BP (Part #T120BP120/240Y-R, EFI Electronics, Salt Lake City, UT, or equivalent).
- 8.1.7.14. Two externally-mounted junction boxes for phone and internet connections

8.1.8. Plumbing system
- 8.1.8.1. (1) 2017 Oval in cabinet lavatory with vanity
- 8.1.8.2. One 20-gal. tank with inline heater for warming water for washing hands
- 8.1.8.3. 110-V on-demand water pump for washing hands.

8.1.8.4. One 40-gallon holding tank under unit.

8.1.9. HVAC system

8.1.9.1. 2.0-ton cooling w/5kW, 240 V electric resistant heat wall hung, return air at unit

8.1.9.2. Blower/filtration system to admit 100 ft³/min of charcoal-filtered and particulate-filtered fresh air. The fresh air exchange rate is 4.5/h.

8.1.9.2.1. This will also create a positive pressure (5-10 Pa) in the shelter with respect to the outside, thus preventing contaminated air from entering the shelter via any cracks which may be present. Pressure differential can be monitored according to SOP A5

8.1.9.3. Exhaust should go out the dirty room to maintain a positive pressure in clean room when pocket door is closed.

8.1.10. General exterior

8.1.10.1. Windows: (7) 8” x 14” horizontal slider with aluminum extruded mill frame single obscured glass, screen and white miniblinds

8.1.10.2. Hurricane straps: (2) over roof at front and rear of OFIS

8.1.10.3. Running lights and tail lights

8.1.11. Furniture

8.1.11.1. (1) 5’ desk w/file cabinet

8.1.12. Storage

8.1.12.1.(2) 30” wide x 30” high x 24” deep storage compartment (under the counter) w/exterior access at front of trailer

8.1.12.1.1. Compartment is cooled and ventilated by its own fan to dissipate heat released by motors (Section 9.3.6.1.2) located in the compartment.

8.1.12.1.2. The cooling fans should be equipped with dust filters to avoid PM from the outside being drawn into the compartment along with the cooling air.

8.1.12.1.3. These compartments can, if necessary, be lined with acoustic tiles to minimize noise reaching the interior of the trailer from the motors.

8.2. Instrument racks (Fig. 3): These should be constructed of steel, and able to accept sliding trays or rails. Open racks help to keep instrument temperature down and allow air to circulate through easily. All racks should have four wheels, with two of those wheels having locks. There is room for four 88” high instrument racks in the space adjacent to the storage compartment.

8.3. UPS (Uninterruptible Power Supply): 120-V In/Out double conversion UPS, with web adapter card and Network Protection Module.

8.4. Install two cylinder racks on the wall partition to hold three gas cylinders each. See SOP G2 for the proper means of securing cylinders to the rack(s).

8.5. The instrument shelter will have a small refrigerator to store lunches, a microwave for heating refreshments, and a lavatory for washing hands.

8.6. Lighting: Light intensity should be 70 foot-candles (750 Lux) in the dirty room and 100 foot-candles (1080 Lux) throughout the clean room.

8.7. Water supply of 3 gal/min or higher is needed to clean the HVAC system, with enough pressure and volume to rinse out the coil. This water will be supplied by the farm.

8.8. Recreational vehicle ladder mounted at the back of the OFIS, for accessing the roof top to maintain weather-related or PM measurement instruments.

8.9. Hitch lock to prevent unauthorized towing.

8.10. Spare tires (minimum of one)
8.11. Blocks: A sufficient number of concrete blocks to construct six supports, each approximately 16″ x 16″ and 2 ft high (this height prevents significant weight on the trailer tires). Wood shims should be placed between the trailer and the blocks to help in the leveling of the trailer.
8.12. The following general supplies and spare consumables should be kept in the trailer:
  8.12.1. Air filters (for A/C inlet, cooling air inlet and trailer circulation air inlet)
  8.12.2. Light bulbs and fluorescent tubes
  8.12.3. Circuit breakers and/or fuses
  8.12.4. Activated charcoal (if charcoal filters are used)
  8.12.5. Cleaning supplies: hand soap, paper towels, cloths, bucket, mop, broom, trash bags and trash can
  8.12.6. Fly traps or strips, mouse/rat poison
  8.12.7. Drinking water and cups
  8.12.8. Tools
    8.12.8.1. Carpenter's level
    8.12.8.2. Hurricane strap anchors

9. Procedures

9.1. Transportation
  9.1.1. While the trailer is being outfitted (i.e. before it is ready to be towed to the site), keep a hitch lock on the hitch at all times for security purposes.
  9.1.2. Before transporting the trailer, verify that all trailer contents have been secured and properly packed.
  9.1.3. After attaching the trailer, ensure that the lights and turn signals are properly wired to the towing vehicle, and that they are operational. The verification of the trailer brakes, lights, and turn signals will be conducted by the individual pulling the trailer, and will follow the standard procedures used by the company for which this individual works.
9.2. Preliminary site preparation and shelter location
  9.2.1. Ensure that there is all-weather access to the OFIS.
  9.2.2. Weight the following two factors when determining a location for the OFIS. A compromise between the two may be necessary:
    9.2.2.1. The OFIS should be as far away as possible from barn fan exhausts.
    9.2.2.2. The OFIS should be as close as possible to the actual sampling points.
    9.2.2.3. Line up trailer so OFIS raceway entry is aligned with barn raceway entry.
  9.2.3. Orient the OFIS so that the front and back are each within 1" of a line which runs parallel to the barns.
  9.2.4. Ensure that the chosen location is accessible to all utilities.
9.3. Instrument shelter installation and set-up
  9.3.1. After the OFIS is positioned properly, prop the hitch and disconnect it from the towing vehicle.
  9.3.2. Level and block up the OFIS.
    9.3.2.1. The orientation of blocks should alternate in each course.

- 9.3.2.2. The distance between the three pairs of supports (front, center and back) should be such that the I-beams of the OFIS will fit directly in the middle of the supports. Refer to the blocking diagram provided in Fig. 4.
- 9.3.2.3. Use a carpenter's level and wood shims to level the floor of the trailer.

- 9.3.3. Install electrical services
  - 9.3.3.1. Drive in ground rod next to service entrance panel.
  - 9.3.3.2. Connect the grounding strap to the rod.
  - 9.3.3.3. Connect a protected 100-A switch box to an appropriate circuit breaker or switch box at the farm and to the electrical panel.
  - 9.3.3.4. Ensure that the shelter is properly grounded.
    - 9.3.3.4.1. Test the neutral to earth resistance to determine whether it meets the requirements of the electric code.
    - 9.3.3.4.2. If the value of the neutral to earth resistance exceeds 2 ohms, correct the installation until the resistance is ≤ 2 ohms.
  - 9.3.3.5. Check polarity of all wiring before connecting instruments.
  - 9.3.3.6. Test all lights, air conditioning, heating systems, and fans during the setup phase.
- 9.3.4. Anchor hurricane straps
  - 9.3.4.1. Use both straps at each end of the OFIS
  - 9.3.4.2. Anchors should consist of concrete-filled holes 1-2 ft deep and 6-8 in. wide, into which the straps are set.
- 9.3.5. Drill holes for raceway(s) (SOP U3).
  - 9.3.5.1. If possible (i.e. if elevations of raceways leaving barns permit), the raceways on either side of the OFIS should enter the barn at the same height.
- 9.3.6. Install two telephone
  - 9.3.6.1. The farm or phone company should provide a phone line to the trailer.
  - 9.3.6.2. Run cables into both rooms of the OFIS.
  - 9.3.6.3. Connect and test two phone sets.
- 9.3.7. Install internet connections.
  - 9.3.7.1. DSL cable will be installed and connected by the internet provider.
  - 9.3.7.2. DSL cable is preferred but satellite connection should be used where there is no DSL service.
- 9.3.8. Environmental controls
  - 9.3.8.1. Temperature control
    - 9.3.8.1.1. Maintain shelter temperature within the range of the dew point of the sample air and the highest minimum temperature of the instruments. The appropriate range is 75-90°F

- 9.4. Initiation of operation
  - 9.4.1. Connect and setup the UPS, in accordance with manufacturer's instructions. Verify that the UPS is operating properly. Assure correct polarity of receptacle.
  - 9.4.2. Connect the following instruments to the UPS. Power up each instrument so that all instrumentation in the OFIS is running simultaneously, and verify that this condition can be maintained without tripping circuit breakers.
    - 9.4.2.1. Computer
    - 9.4.2.2. DAC system
    - 9.4.2.3. Gas analyzers

9.4.2.4. TEOM controllers
9.4.2.5. Do not connect vacuum pumps to the UPS.

9.5. Routine operations

9.5.1. Prepare a table of "routine operations", and post it to the wall of the OFIS. These are duties that must be performed in order to efficiently operate a monitoring site. Each item should have an associated frequency. Included are the following:

9.5.1.1. Check stability of OFIS supports.
9.5.1.2. Check the electrical supply cable and connection box.
9.5.1.3. Check air inlet fan and filter. Verify positive pressure (Step 8.1.9.2.1 & SOP A5).
9.5.1.4. Clean any dust buildup in the pump/motor compartment.

9.6. Periodic maintenance

9.6.1. Clean floors as needed.
9.6.2. Clean desks and counters as needed.
9.6.3. Cleaning, recharging, and replacement of the HVAC system should be completed when the system is not properly functioning. Procedures to note when cleaning the HVAC include the following:

9.6.3.1. Use pressurized air or water for cleaning, but do not flatten the fins on the AC. Soaking with warm, soapy water works well.
9.6.3.2. A bathroom brush and shop-vac are suggested cleaning tools.
9.6.3.3. Pull sidegrills off the unit to reach the coils.
9.6.3.4. If light from a flashlight can be seen through all parts of the coils, they are clean.

9.6.4. Replace supply air filter, including charcoal media, as needed.
9.6.5. Inspect the OFIS roof bimonthly. Repair as needed.
9.6.6. Weed abatement (Note: This is expected to be a responsibility of the producer, but may occasionally need to be performed by research personnel).

9.7. General cleaning

10. Data and Records Management

10.1. Maintain a Site Log with a chronology of events that occur at the monitoring site, and a narrative of problems and their solutions. Items in this log should include the following:

10.1.1. Date, time and initials of person(s) who visit at the site
10.1.2. Brief description of weather
10.1.3. Brief description of any damage to the exterior of the OFIS
10.1.4. Brief description of any changes to the barns and/or production status
10.1.5. Description of work accomplished at the site
10.1.6. Detailed information about the instrument needed for repairs or troubleshooting

10.2. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.3. Manage all data according to SOP B5.

10.4. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

10.5. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. As described in Section 9.3.3.5, conduct a thorough polarity check on all wiring before connecting any equipment.
11.2. An activity sensor will be installed in each OFIS (SOP S3), so that records of site visits by research personnel can be corroborated, and so that unauthorized entry to the OFIS can be documented for future investigation as necessary.
11.3. Keep a visitor log book; visitors should sign and date the book.

12. References

12.1. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.2. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
12.3. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.
12.4. SOP S1. 2006. Producer Collaborations at Barn Monitoring Sites. Standard Operating Procedure S1. Purdue Ag Air Quality Lab.
12.5. SOP S3. 2006. Activity Measurements. Standard Operating Procedure S3. Purdue Ag Air Quality Lab.
12.6. SOP U3. 2006. Heated Raceway. Standard Operating Procedure U3. Purdue Ag Air Quality Lab.

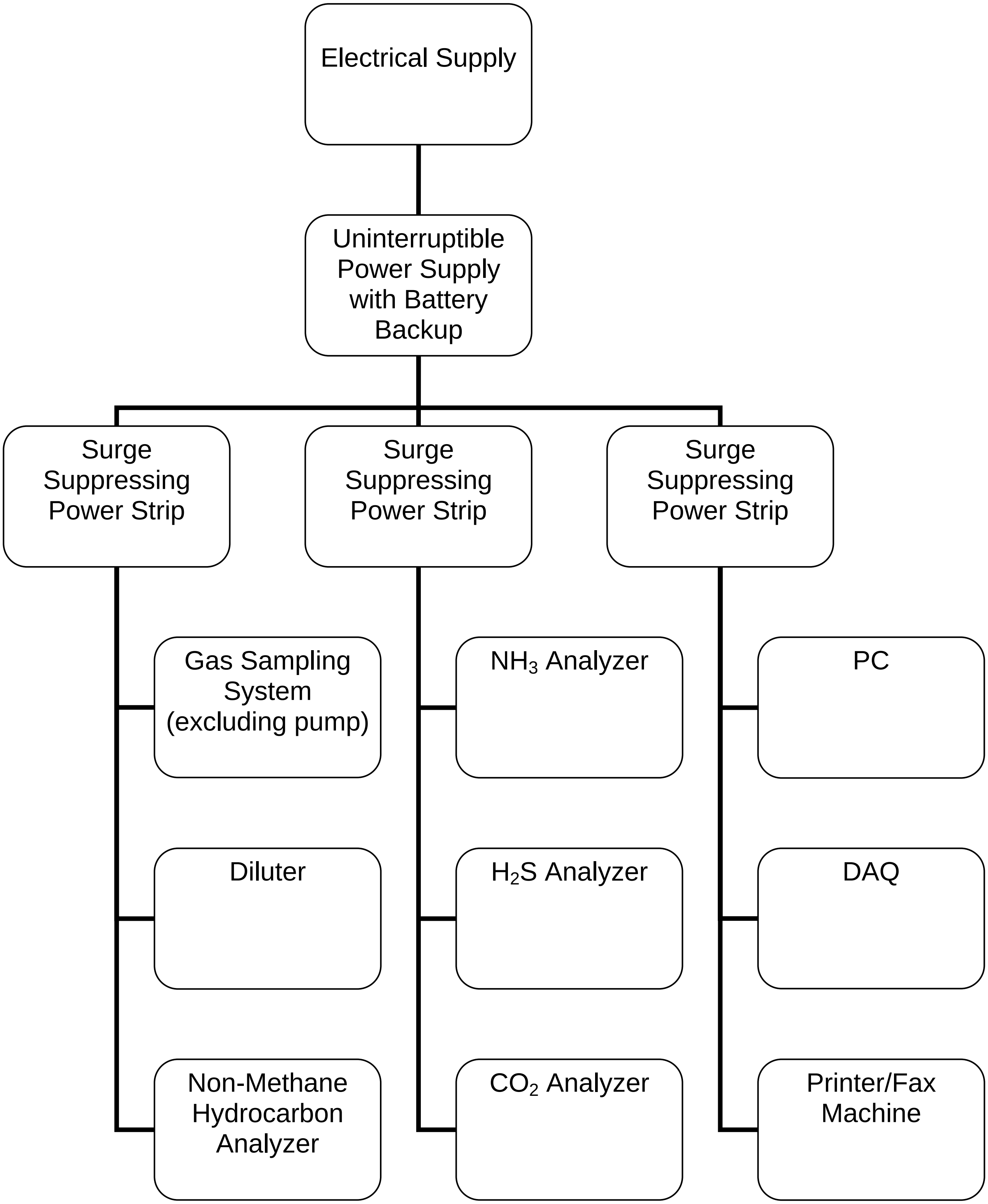


Figure 1. Lightning protection equipment in the OFIS.

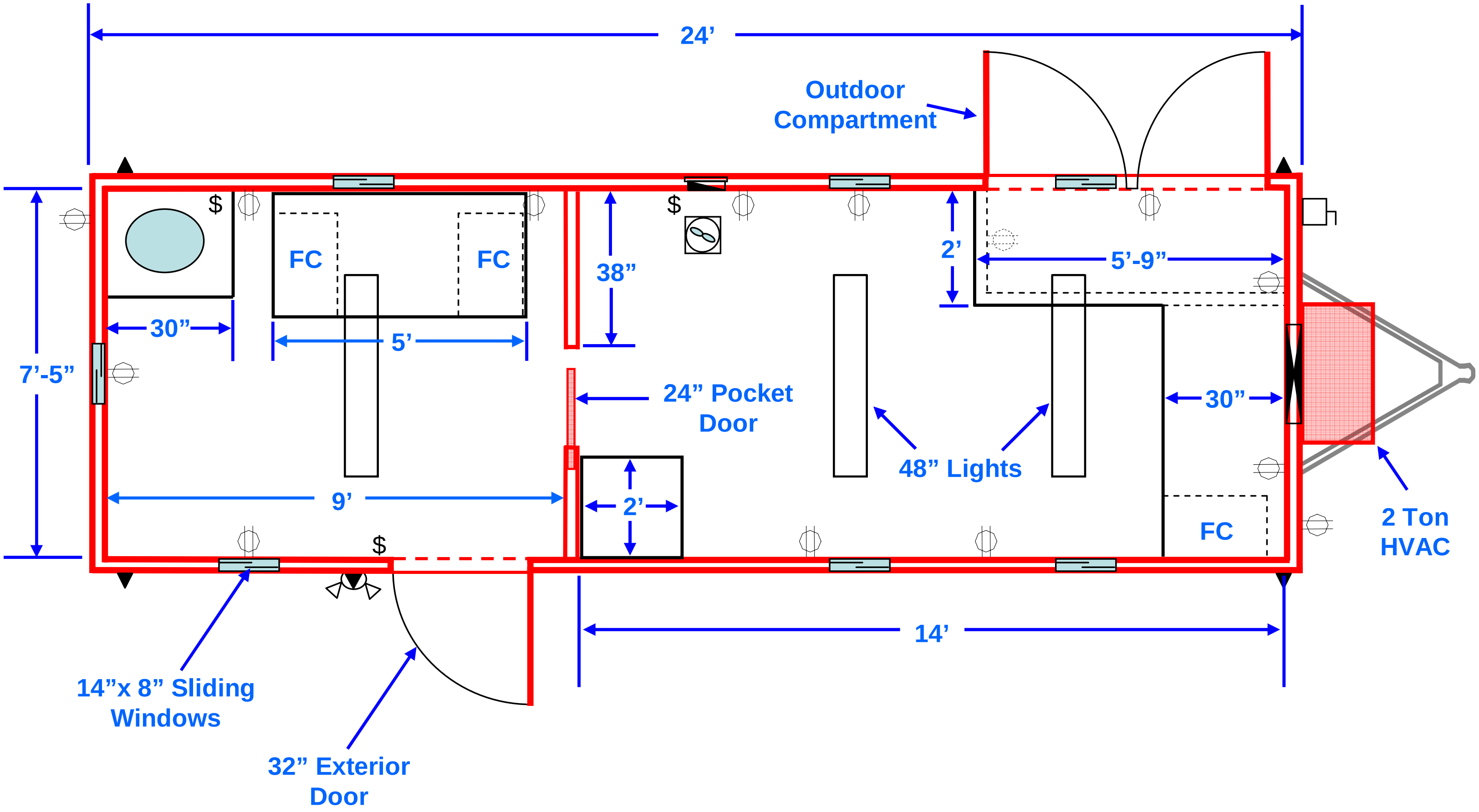


Figure 2. Floor plan of the OFIS. Dirty and clean ends of the lab are left and right of the pocket door.

Figure 3. Instrument racks in the OFIS.

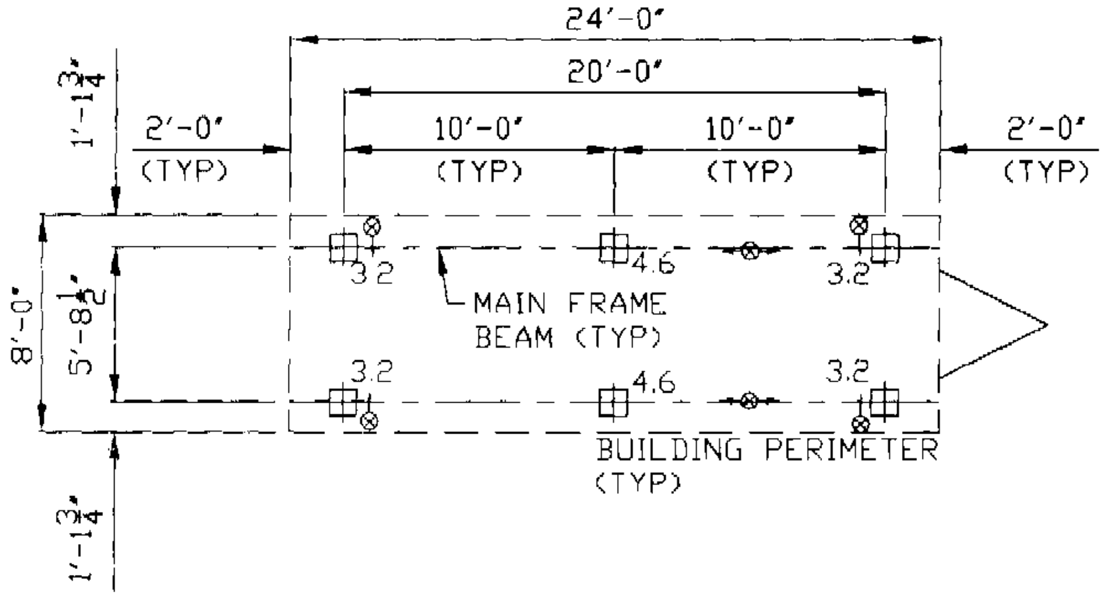


Figure 4. Manufacturer’s blocking diagram, showing placement of six supports.

INSTALLATION OF BARN MEASUREMENT TUBING AND CABLES

Standard Operating Procedure (SOP) U2

INSTALLATION OF BARN MEASUREMENT TUBING AND CABLES

Standard Operating Procedure (SOP) U2

Prepared by

Juan Carlos Ramirez, Sam M. Hanni, and Teng Teeh Lim

Reviewed by

Ji-Qin Ni, Bill W. Bogan, and Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1 Monitoring barn emissions requires a large number of sensors, instruments and sampling points. While most of the analytical instruments are located in a centralized on-farm instrument shelter (OFIS), the measurement sensors and air sampling points themselves can be in remote locations of the barns, or inside of the shelter.

1.2 The objective of this SOP is to outline the efficient installation of the signal cables, power lines, thermocouple wires, and pressure-sensing and gas-sampling tubing that must be installed between the OFIS and the barns for monitoring gas and PM emissions from Animal Feeding Operations (AFO). This includes the initial preparation of the site layouts which will be used to guide the installation process.

1.2.1. The "power cable" in this SOP refers only to the cable to deliver low-voltage power (maximum 24 VDC) for sensors.

1.3 The estimated time to complete the installation ranges from two to six weeks. Progress of the installation should be tracked to ensure that it is proceeding in a timely manner.

2. Summary of Method

This procedure defines the prioritized sequence of activities to efficiently install the instruments, signal and power cables and thermocouple wires, as well as the pressure-, PM- and gas-sampling tubing. The actual sequence will depend on the configuration and limitations of the site. The number of monitored buildings ranges from two to five buildings per site. The procedures outlined in this SOP ensure that the conditions of tubes, signal and power cables meet the requirements stated in the Quality Assurance Project Plan (QAPP) and Site Monitoring Plan(s) (SMP) for the particular project. The method in this SOP provides, through tracking with a Microsoft Project database, appropriate quantitative and qualitative acceptance criteria for determining that the prescribed procedures have been accomplished satisfactorily. The procedures outlined in this SOP also help to verify that the manufacturer-provided specifications for electrical cables and tubing are reviewed for accuracy, noted, and maintained to support the technical requirements of collecting reliable data.

3. Definitions

3.1	GSS	Gas sampling system
3.2	OFIS	On-farm instrument shelter
3.3	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4	PM	Particulate matter
3.5	SOP	Standard operating procedure
3.6	VDC	Volts direct current

4. Health and Safety

4.1 Be careful when working with electrical power connections, especially if the barn or pit floor is wet.

4.2 Discuss the layout of power cables with the farm's certified electrician for safety and avoid any unnecessary interference.
4.3 Wear appropriate personal protective equipment and clothing (SOP S1) while working in the barns.
4.4 Be aware of the animals during the installation.
4.5 Be careful when working near the ventilation fan(s), as the high-speed fan blades can be a hazard, especially if they are not protected by fan shutters or fan guards.
4.6 Be careful when using the outside steps or walkways, and when working on the roof of a barn or OFIS, particularly in inclement weather. Be mindful of wet or icy patches.
4.7 During lightning storms, avoid contact with electrical instruments, or with the exterior shell of the barn or OFIS.
4.8 Inspect and verify that all moving equipment (e.g. manure scrapers, circulating pumps pits, feeders) in the area where tubing and cables are being installed has been locked out or shut off. Contact the barn manager or electrician to reactivate the equipment after installation.
4.9 Use appropriate safety harnesses and/or manlifts when working at dangerous heights such as the open ridge of a naturally ventilated dairy barn.

5. Cautions

5.1 Locate the pressure-, PM- and gas-sampling tubing and signal cables in locations that will not affect the daily activities of the farm personnel.
5.2 Obtain the farm manager's approval in advance to drill holes on any surface.
5.3 Observe the manufacturer's recommended low temperature limits when installing cables. Handling and pulling cables in extreme temperatures can damage the cable sheathing, jacketing, or insulation. To prevent damage of this nature, store the cables in a heated building for at least 24 h prior to installation.
5.4 Seal the tubing ends with electrical tape against moisture and contamination (e.g. dust or sand), especially during and after installation in wet locations. Remove the seal only when the tubing is connected to the corresponding instrument.
5.5 Remove all abrasive or sharp edges that might damage cables and/or tubing. Examples include sharp edges produced during cutting of pipe sections for raceways (SOP U3), or sharp protrusions on barn surfaces along which cable and tubing are strung.
5.6 Minimize the bending of cables and tubing. Follow the manufacturer's recommendations regarding minimum bend radii of cables and tubing.
    5.6.1. Install temporary cable supports in manholes, or in places that otherwise will induce a bend radius smaller than the minimum recommended.
5.7 Minimize stretching stress of signal cables during and after installation. Do not overtighten cable ties

6. Interferences

6.1 One or more barns may be temporarily unavailable for installation because of a scheduled farm activity, such as cleaning or animal removal. Coordinate work with farm personnel for maximum efficiency.

6.2 Incorrect labeling of the pressure and air sampling tubes, and signal and power cables can lead to problems. Avoid labels that may fall off, or become illegible. Attach two adhesive labels on each end, at least 1 ft apart. Wrap label onto tubing or cable with multiple (2-4) passes of transparent tape to keep them securely in place.
6.3 Minimize exposure of air-sampling tubing to external contamination (water, dust or other material). Seal each end of each tube properly with materials such as electrical tape to avoid exposure during the installation process. Remove the seal only when the tube is ready to be connected to the corresponding filter or gas sampling system (GSS).
6.4 Take precautions against farm personnel moving sampling tubing or signal cables, or blocking sensors. Visibly label each sensor's location. Provide contact information for personnel who can answer questions for the farm personnel. Also, inform the farm personnel about the availability of PowerPoint presentation(s) used to educate the producers about the project (SOP S1).

7. Personnel Qualifications

7.1 Personnel must read and understand this SOP before participating in the installation.
7.2 Personnel should receive training on testing power and signal cables with voltmeters.
7.3 Line installers must be able to climb, and maintain their balance while working on ladders or other structures.
7.4 Personnel should be able to lift at least 50 lb.

8. Equipment and Supplies

8.1 Pressure- and air-sampling tubes (3/8″ Teflon tubing) (length to be determined in Section 9.1.3)
8.2 Signal cables (varying low-gage multi-conductor cables, shielded if possible) (length to be determined in Section 9.1.3)
8.3 Type T thermocouple extension wires (SOP E1) (length to be determined in Section 9.1.3)
8.4 Power cables (length to be determined in Section 9.1.3)
8.5 Cable ties
8.6 Plastic ties
8.7 Adhesive paper cable labels and transparent tape
8.8 Drill
8.9 Electrical tape
8.10 Filter holder (Part 6-47-6, Savillex Corporation, Minnetonka, MN) with Teflon membrane filter (47-mm, 1.0-µm pore size)
8.11 Microsoft Project software, and a site-specific schedule file (provided by PAAQL)

9. Procedure

9.1 Preparation of drawings and site layouts for each barn (to be conducted by PAAQL personnel)

9.1.1. Prepare the monitoring diagram to determine the specific routes for the pressure and air sampling tubing, thermocouple wires, and signal and power cables.
9.1.2. Verify the best layout for all tubing and cables.
  9.1.2.1. For air sampling tubing, avoid unnecessary pressure drops and minimize potential interference from farm personnel and machinery.
  9.1.2.2. For signal cables and thermocouple wires, avoid placing near power lines.
  9.1.2.3. Protect the cable or tubing as much as possible from animals and rodents.
  9.1.2.4. Confirm that all of the installed lines and cables will not interfere with the farm's maintenance activities.
    9.1.2.4.1. Obtain the farm manager's approval for the layout. If possible, solicit the participation of the operator and/or maintenance (mechanical or electrical) personnel when developing the layout.
9.1.3. Once these layouts have been finalized, use them to determine the total lengths of sampling tubing, thermocouple wires, and signal and power cables that will be required for each site.
  9.1.3.1. Estimate the specific lengths for each pressure- or air-sampling tube, and for each cable, from the monitoring diagram or site layout.
  9.1.3.2. Sum these lengths to determine the total length required for the site. Obtain enough tubing and cable for the entire layout, including 10% excess to ensure that proper extensions can be made.
  9.1.3.3. Include an extra length (about 3 m long) of tubing or cable sampling and sensor ends, to allow any repositioning of the sampling or monitoring location.
9.1.4. Prepare labels for all pressure- and air-sampling tubing and cables. There should be four labels for each, two on each end.

9.2 Installation of heated raceway(s)
9.2.1. After completing the placement and setup of the OFIS (SOP U1), install the raceway(s) according to SOP U3. Do this before installing tubing and cables, since these will usually need to go through the raceways.
9.2.2. Make sure raceway interiors are clean before installing cables and tubing.

9.3 Tubing handling, protection and installation
9.3.1. Make sure there is no moisture or dust in the tubing before starting sampling.
  9.3.1.1. If contaminated with moisture, flush the interior of the tubing with dry air for a minimum of 5 min, preferably with the tubing extended horizontally.
  9.3.1.2. If contaminated with dust, PM or debris, flush with water for 5 min, and then air for 30 min.
9.3.2. Use a suitable feeder device to protect and guide the tubing or cables from the reel into the raceway.
9.3.3. Uncoil the Teflon tubing correctly when there is no feeder device available. Turn the coil while feeding the tubing. Do not pull the tubing from the coil when the coil lays flat on the ground (Figure 1).
9.3.4. Identify every tube or cable with two labels on each end, separated at least 1 ft apart.
9.3.5. Place a filter holder and membrane filter (Section 8.10) at the inlet end of each air-sampling tube, and before the connection to the GSS. This prevents significant PM from entering the air tubing, GSS, and gas analyzers.

Figure 1. The correct (left) and incorrect (right) way to uncoil Teflon tubing when a feeder device is not used.

9.4 Installation of thermocouple extension wires, and power and signal cables
  9.4.1. Inspect the thermocouple wires and cables for any significant damage.
  9.4.2. Install and connect the thermocouple wire and signal cable according to the corresponding SOPs.
  9.4.3. Only use cable ties to loosely bundle the cable runs for ease of segregation and identification to various work areas.
9.5 Troubleshooting
  9.5.1. Air sampling tubing failure
    9.5.1.1. While passing air through the tubing with a pump, use rotameters or similar device to measure airflow rate at both ends. If the two flow rates do not agree, inspect the tube for damage or leakage.
    9.5.1.2. If tubing was damaged or chewed through by rodents, change out the section and connect using a union. Flush the whole tube with pressurized clean air, and inspect for trapped particles. Measure flow rates again to guard against leakage.
  9.5.2. Power or signal cable failure
    9.5.2.1. Verify the labels on each end of the cable.
    9.5.2.2. Verify that the cable is not broken. Use a multi-meter to test continuity. One easy procedure is to join all the conductors at one end of the cable and test the continuity among the conductors at the other end of the cable. If a discontinuity is found in one or more conductors, follow the cable and check for damage.

10. Data and Records Management

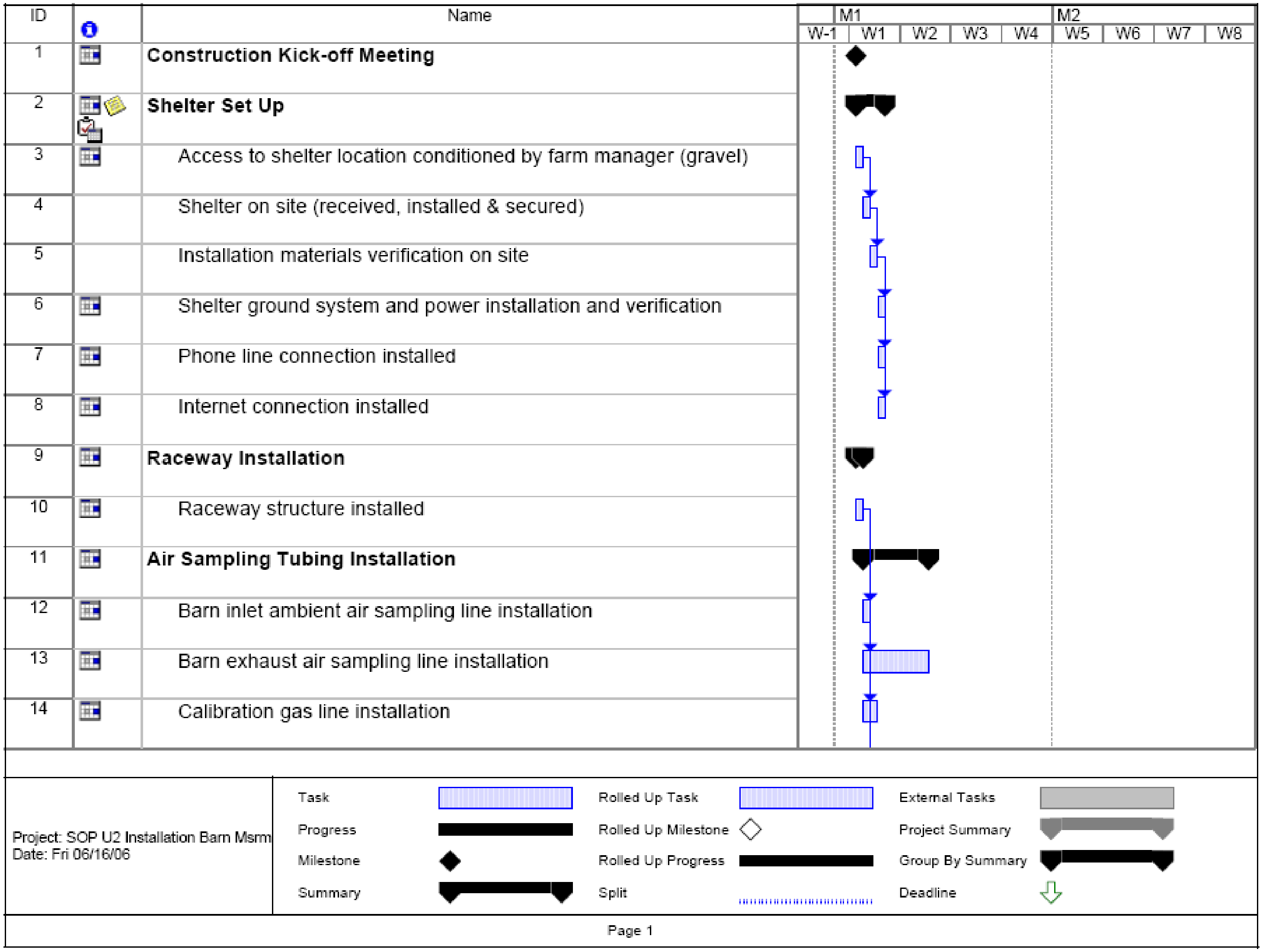
10.1 Fill out a commissioning form (Appendix A) for each line installed, stating all the characteristics of the tubing or cable. Store these forms in a three-ring binder, which is kept in the OFIS.
10.2 Use a Microsoft Project file to track installation progress. A partial example of this file is shown in Fig. 2.

11. Quality Control and Quality Assurance

11.1 Use a single piece of tubing or cable for connection from the sample/measurement location to the OFIS whenever it is possible. Avoid using connector or extensions to the air sampling tubing and cables, to minimize leakage and poor wire connections.
11.2 Test and mark the cables for continuity before installation.
11.3 Flush all tubing with clean pressurized air to ensure that there are no obstructions, blockages or contaminants inside the lines before putting them into use. Keep one end of the tubing open by temporarily removing the filter while the other end of the tubing is to accept pressurized air so that any particles will be flushed out from the opening end.
11.4 Conduct a system configuration check to trace all sampling tubing, and connections to verify the system configuration, and to visually inspect items of equipment to ensure that they are clean, and fit for their purpose prior to undertaking measurement.
11.5 Conduct an instrumentation cabling check to ensure that all instrumentation, alarm settings, microprocessor signals and hardwire connections pertaining to the installation are functional. This will also check that signals from the field instrumentation are correctly relayed to the data acquisition and control hardware (SOP B1) and software (SOP B2) and computer displayed in the computer. Record the testing and characteristics of each pressure-, PM- and gas-sampling tube, signal cable and power cable in a Line Commissioning Form, as shown at the end of this SOP.

12. References

12.1 SOP B1. 2006. Data Acquisition and Control Hardware. Standard Operating Procedure B1. Purdue Ag Air Quality Lab.
12.2 SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.3 SOP E1. 2006. Temperature Measurement Using Thermocouples. Standard Operating Procedure E1. Purdue Ag Air Quality Lab.
12.4 SOP S1. 2006. Producer Collaborations at Barn Monitoring Sites. Standard Operating Procedure S1. Purdue Ag Air Quality Lab.
12.5 SOP U1. 2006. Barn Instrument Shelter. Standard Operating Procedure U1. Purdue Ag Air Quality Lab.
12.6 SOP U3. 2006. Heated Raceway. Standard Operating Procedure U3. Purdue Ag Air Quality Lab.



ID	Name
1	**Construction Kick-off Meeting**
2	**Shelter Set Up**
3	Access to shelter location conditioned by farm manager (gravel)
4	Shelter on site (received, installed & secured)
5	Installation materials verification on site
6	Shelter ground system and power installation and verification
7	Phone line connection installed
8	Internet connection installed
9	**Raceway Installation**
10	Raceway structure installed
11	**Air Sampling Tubing Installation**
12	Barn inlet ambient air sampling line installation
13	Barn exhaust air sampling line installation
14	Calibration gas line installation

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Date: Fri 06/16/06

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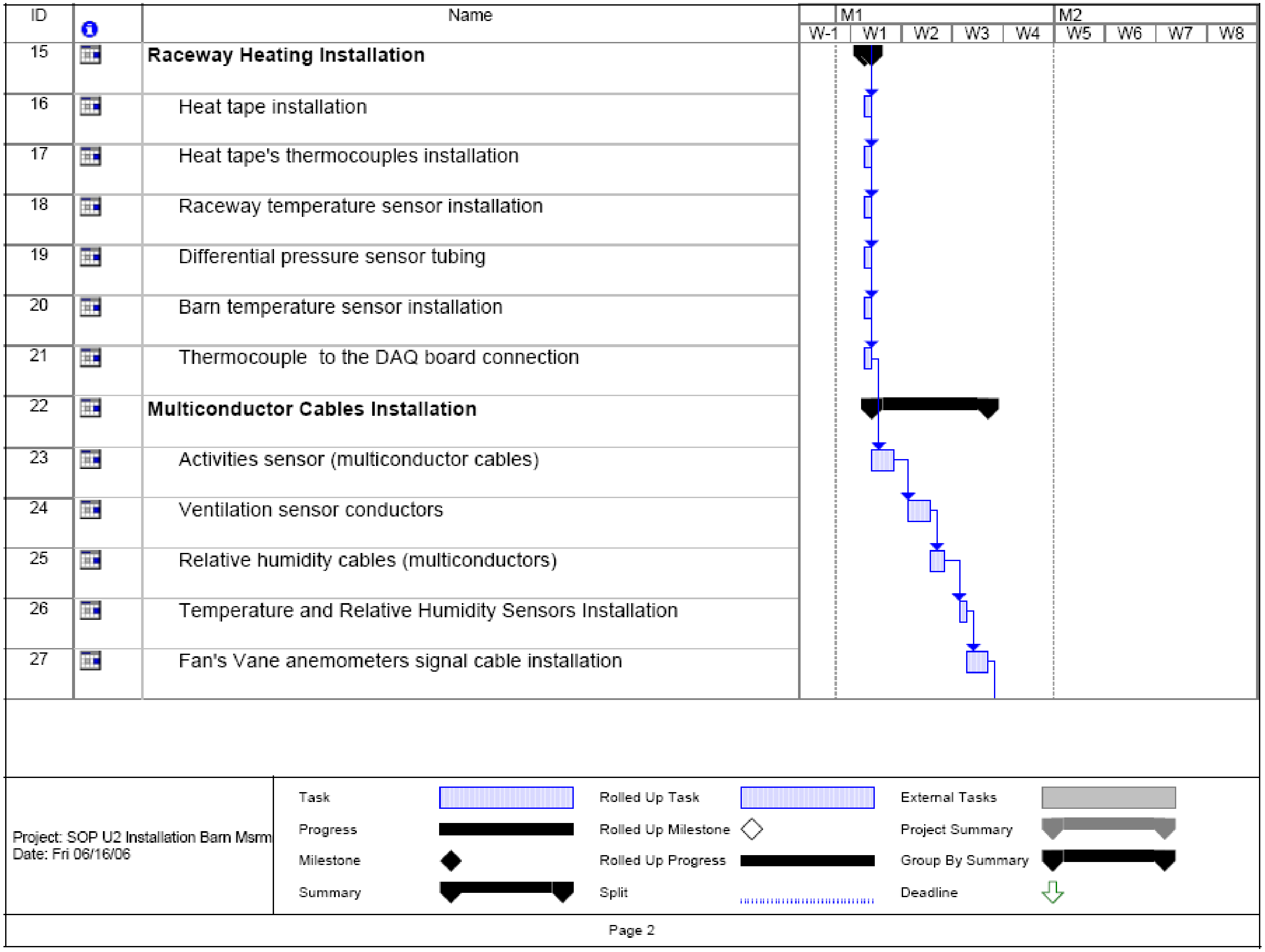
Figure 2. Example of a Microsoft Project schedule for tracking installation of barn measurement lines and cables



ID	Name
15	**Raceway Heating Installation**
16	Heat tape installation
17	Heat tape's thermocouples installation
18	Raceway temperature sensor installation
19	Differential pressure sensor tubing
20	Barn temperature sensor installation
21	Thermocouple to the DAQ board connection
22	**Multiconductor Cables Installation**
23	Activities sensor (multiconductor cables)
24	Ventilation sensor conductors
25	Relative humidity cables (multiconductors)
26	Temperature and Relative Humidity Sensors Installation
27	Fan's Vane anemometers signal cable installation

Project: SOP U2 Installation Barn Msrm
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Figure 2 (Continued)

Appendix A. Line Commissioning Form for Installation of Barn Measurements

Line identification descrition (e.g. farm number/name, barn number, sampling location): ____

Line Type: ☐ Tubing; ☐ Signal cable; ☐ Thermocouple wire; ☐ Power cable
Instrument (if specific to one): ____
Serial Number:____

Verification of Operation

	Yes	No	Comment
Before installation:			
Installation authorized by farm contact person?			
Farm operator informed of installation?			
Tubing:			
Size and type			
Two labels on each end?			
Tubing cleaned?			
Tubing ends protected from contamination?			
Signal cable:			
Size and type			
Two labels on each end?			
Conductivity of each conductor verified using a multimeter?			
Size and type according to specification?			
Cable ends protected from contamination?			
Power cable:			
Size and type			
Two labels on each end?			
Cable conductivity verified using a multimeter?			
Size and type according to specification?			
Cable ends protected from contamination?			
During Installation:			

Name ______________________________________

Date ______________________________________

Signature ___________________________________

HEATED RACEWAY

Standard Operating Procedure (SOP) U3

HEATED RACEWAY

Standard Operating Procedure (SOP) U3

Prepared by

Teng-Teeh Lim, Erin L. Cortus and Juan Carlos Ramirez

Reviewed by

Albert J. Heber, Bill W. Bogan and Kenneth D. Casey (TAES)

Effective Date: December 28, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Gas sampling tubes, particulate matter (PM) sampler vacuum hoses, signal wires and power cables running from a barn or other building at an Animal Feeding Operation (AFO) to the on-farm instrument shelter (OFIS) need to be protected from severe weather, workers and vehicles, rodents and other potential hazards.

1.2. Condensation inside gas sampling tubes, which could occur if air sampling tubes were exposed to lower temperatures, must be prevented. Condensation control and prevention is critical, because many of the target gases are very soluble in water. Condensation in air sampling tubes can cause significant errors in gas-concentration measurements.

1.3. Raceways are heated to prevent condensation in the sample lines.

1.4. Raceways connect the OFIS with the building(s) being monitored, and provide the necessary protection for the sample tubes and cables, which are channeled through the raceway into the OFIS.

1.5. Raceway lengths range from 1 m (3.3 ft) to 40 m (131 ft); most raceways will be at the short end of this range.

2. Summary of Method

Raceways are most often made from 10 cm dia. (4 in) polyvinylchloride (PVC) pipe, although they can be fabricated from square conduits as well. Removable top covers allow maintenance and addition of new tubing or cables. Drainage holes on the bottom of the raceway prevent any potential condensate buildup or rainwater. The raceways are sloped 2% to 5% downwards toward the barn to prevent water accumulation, and to ensure that any drainage that does occur goes into the barn, rather than into the OFIS. Raceways are usually suspended, but can be buried underground (for example, in areas that are heavily traveled by large vehicles). However, access to the raceway is much more limited if buried. Suspended raceways are generally supported by one or more braces, the number of which depends on the raceway length. Heating tapes, installed along the raceway length, prevent condensation. The self-regulated heat tape is controlled by the data acquisition and control software, AirDAC (SOP B2), with a backup thermostat (normally open contact) to ensure heating in case of PC failure. A capillary tube thermostat (normally closed contact) protects the circuit from overheating. An example of a suspended raceway is shown in Fig. 1.

3. Definitions

3.1.	AirDAC	Air quality Data Acquisition and Control software
3.2.	AFO	Animal feeding operation
3.3.	OFIS	On-farm instrument shelter
3.4.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.5.	PM	Particulate matter
3.6.	PVC	Polyvinylchloride
3.7.	QAPP	Quality Assurance Project Plan
3.8.	SMP	Site Monitoring Plan
3.9.	SOP	Standard operating procedure

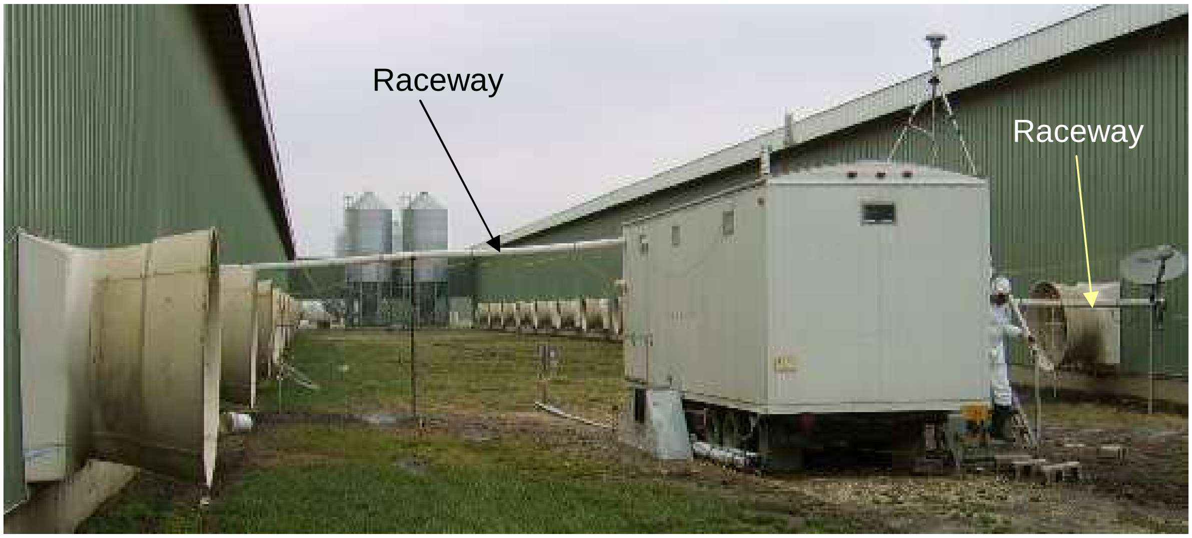


Figure 1. Typical configuration of the OFIS and raceways leading into two barns.

4. Health and Safety

4.1. If a raceway is high enough that it must be accessed using a stepladder, exercise care when using the ladder. Use ladders only on firm, dry, level ground.
4.2. Be careful when working with electrical power connections. Use only non-metallic ladders. The heating tape has power cords carrying 120 V. If possible, disconnect the power to all electric cables in the raceway before working on the interior of the raceway.
4.3. Do not work on the raceway if it is raining, especially when there is lightning.
4.4. Use gloves when handling cables, to avoid cuts from sharp edges.

5. Cautions

5.1. Obtain advance approval to drill holes on any barn surface. The producer should provide the raceway opening (or approve its being made by research personnel) (SOP S1).
5.2. Prevent condensation in sampling tubes due to under-heating in cold weather, or when sample tubing is exposed to the cold air inside the air-conditioned OFIS in summer, through the use of heating tapes.
5.3. A 30 mA ground-fault circuit interrupter may be required in some installations. Use a heat sink with solid-state relays. Always install a cover over the relay, since the exposed 120 V terminals on top of the units constitute a safety hazard. Consult local fire codes for local requirements.
5.4. Provide drainage holes at the bottom of the raceway.
5.5. Prevent overheating by using self-regulated heating tape, with a backup thermostat.
5.6. Clean the raceway before installing cables and tubing. Debris and sharp objects in raceway could damage the exterior cover of the cables and air tubes.
5.7. Remove or cover all abrasions or sharp edges that might damage the tubing or cables.

5.8. Seal both ends of the raceway with spray insulation foam or equivalent before starting sampling. Otherwise, the raceway could funnel air between the barn and the OFIS, due to pressure differences between the barn and the OFIS.

5.9. Install temporary cable supports at the entrance of the raceway, and in places that otherwise would induce a bend radius smaller than the minimum recommended radius of the tubing.

  5.9.1. Recommended minimum bend radius for 1/4" ID (3/8" OD) tubing is 6.5 in.

  5.9.2. Recommended minimum bend radius for 1/8" ID (1/4" OD) tubing is 3.5 in.

5.10. While feeding tubes through the raceway, seal each end of the tubing to keep contaminants (water, dust or other material) that may be inside the raceway from entering the tubing.

5.11. Ensure zero stretching stress of signal cables after installation; make sure there is slack remaining in the cables.

5.12. Do not overstress signal cables by over-tightening cable ties.

5.13. To avoid the risk of electric shock, insulate connection points on heat tape control relays with heat shrink, electrical tape, or equivalent.

5.14. To keep the current draw below the circuit breaker maximum, and to ensure the heat tape provides the rated output, avoid using lengths longer than the recommended maximum length for that cable wattage (Table 1).

Table 1. Maximum heat cable length based on current draw and voltage drop (Nelson Heat Tracing Systems, 2001 and 2004).

W/ft	Maximum Length of Cable (ft) at 50 ºF Start-up Temperature (15-A breaker unless noted)
3 (CLT cable)	221
5 (CLT cable)	178
8 (CLT cable)	142
10 (LT cable)	115 (15A breaker), 150 (20A breaker), or 180 (30A breaker)

6. Interferences

6.1. Traffic around the OFIS could damage the raceway if the raceway is improperly positioned. Consult with the producer to determine a safe position and height.

6.2. Strong winds can affect the stability of a raceway, especially long raceways. Try to avoid positioning long raceways in areas where strong winds will blow perpendicular to the raceway axis. If this cannot be avoided, make sure the raceway is well-supported.

6.3. Rodents can enter the raceway and damage cables or tubing. Seal each end of the raceway with spray insulation foam or equivalent after cables are in place to block access, and check the seals periodically for signs of rodent damage. If traces of rodents are seen, add moth balls to the raceway.

6.4. The hole where the raceway enters the barn can be a source of cold air that can come in contact with tubing, causing condensation. Seal the junction (Section 9.2.5), and extend the heat tape a minimum of 12 inches into the barn to avoid it.

6.5. Cool air entering the trailer (e.g. air conditioner diffusers) can cause condensation if it directly contacts uninsulated, unheated tubes. Tubes inside the trailer can be bundled, insulated and heated to avoid condensation.

7. Personnel Qualifications

7.1. Personnel must read this SOP before installing or maintaining raceways.
7.2. Personnel should be trained to use the thermostats, interpret the thermocouple output signal, and check for condensation in the air sampling tubes
7.3. Personnel must be able to climb and maintain balance while working on ladders, or other structures, and should be comfortable with heights.
7.4.

8. Equipment and Supplies

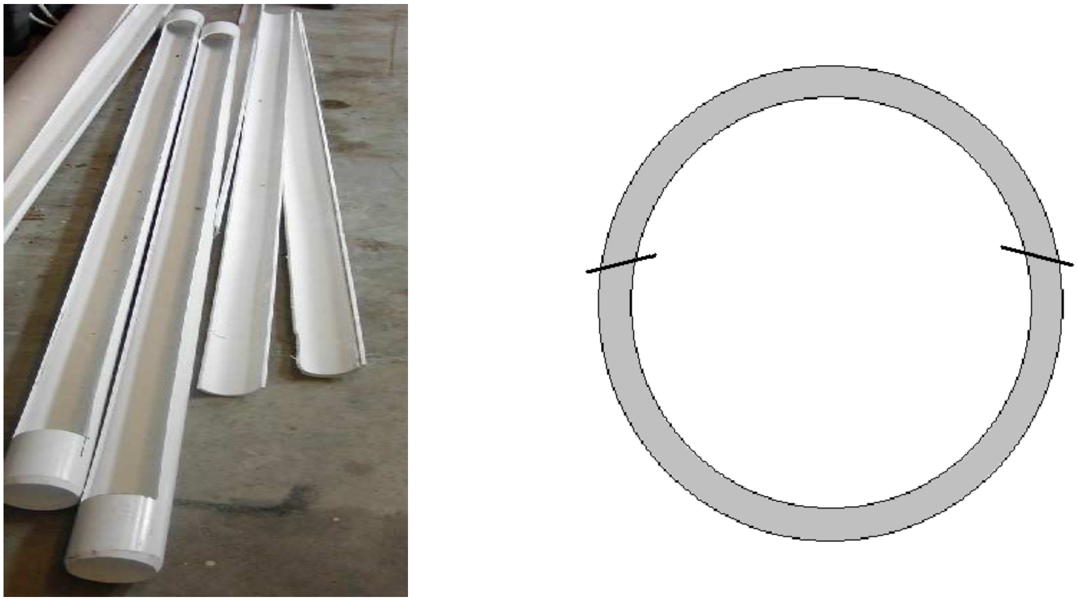
8.1. PVC or metallic tubing (PVC is preferred), typically 10 cm (4 in.) diameter
8.2. Circular saw
8.3. Piano hinges with clasps, pipe clamps, or equivalent hardware to secure raceway cover
8.4. Supporting pole(s) and brace(s), if the raceway is longer than 1.5 m (5 ft)
8.5. Self-regulating heat cable, W/ft rating at 120 V dependent on site conditions, metallic braid, max. length 50 m (170 ft)
8.6. Two thermostats (Sunne 4MY93, or equivalent)
8.7. One solid state relay (Watlow SSR 240-25A-DC1, or equivalent) with heat sink and cover
8.8. Cable straps and cable ties
8.9. Cable and tube supports
8.10. Self-sealing pipe insulation, 3/8-in. thickness, diameter depends on the number of air tubes (usually 1 to 1.5 in for about 10 sampling tubes of 3/8″ outer diameter)
8.11. Cans of spray insulation foam
8.12. Moth balls
8.13. 30-mA ground fault circuit interrupter (may be required in some installations). The circuit interrupter may be in the form of a circuit breaker or a stand-alone unit installed between the power supply and heat tape power connection.

9. Procedure

9.1. Pre-installation fabrication
  9.1.1. Using 10-ft sections of PVC pipe or square conduit, mark a distance of approximately 6 in. away from either end of the pipe.
  9.1.2. If using pipe, cut down 1/3 of the diameter of the pipe (Fig. 2A). If using square conduit, cut down approximately 1/3 of the height of the conduit.
  9.1.3. On each side of the pipe or conduit, cut out the space between the two original cuts, to form a removable “cover” section. If using circular pipe, make this cut at a slight uphill angle (Fig. 2B), to prevent water from flowing into the joint between the lid and main section. If using square conduit, make the cut flat.

9.1.4. Prepare raceway cover using one of the following methods:

9.1.4.1. Attach piano hinges to the lid and base, approximately every 2-3 ft., to allow opening and closing of the cover.



(A) (B)

Figure 2. Cutting of circular PVC pipe to fabricate removable raceway covers (A), and the approximate locations and angles for the cuts (B).

9.1.4.2. Cut a length of thin-wall sewer pipe of the same diameter as the raceway, slightly longer than the raceway opening. Remove a section of the sewer pipe (approximately one-third of the pipe circumference) so that the sewer pipe cover can slide over the raceway opening (Fig. 3). Secure cover with pipe clamps.

Figure 3. Using a cut piece of thin-wall pipe as a raceway cover.

9.2. Raceway Installation

- 9.2.1. After the OFIS has been installed and secured (SOP U1) in a location that lines up the OFIS raceway opening(s) with the desired barn raceway opening location(s), measure the distance(s) from the OFIS wall(s) to the wall(s) of the barns, considering that there should be a downward slope (1% to 2%) from the OFIS to the barn (Fig. 1). The barn opening needs to be lower than the OFIS opening.
- 9.2.2. At the low end(s) of the raceway, drill 2 to 3 small holes (approximately ¼-in. diameter) on the underside of the raceway so that, in the event some water does enter the raceway, it will drain out.
- 9.2.3. Create the opening for raceway entrance(s) into the barn(s) (SOP S1).
- 9.2.4. Determine if the raceway requires one or more intermediate supports.
  - 9.2.4.1. If the raceway requires intermediate support, install a support surface at the end of each supporting pole or brace.
    - 9.2.4.1.1. Use semi-cylindrical support surfaces for cylindrical raceways.
    - 9.2.4.1.2. Use flat support surfaces for rectangular raceways.
  - 9.2.4.2. Drive the supporting pole into the ground (at least 2 ft deep), and attach earth-anchored guy wires on both sides, if needed. An alternative method is to install a concrete foundation for the supporting poles.
- 9.2.5. Thoroughly seal the raceway entrance into the barn (the space between the outer edge of the raceway and the edge of the hole in the wall) with foam insulation.

9.3. Installing Tubing and Cables

- 9.3.1. Separate air-sampling tubes from power/signal cables and thermocouple wires, as the latter do not require heating. Bundle the air tubes (Fig. 4) with cable ties, with the heating tape at the center for efficient and more uniform heating (Fig. 5).

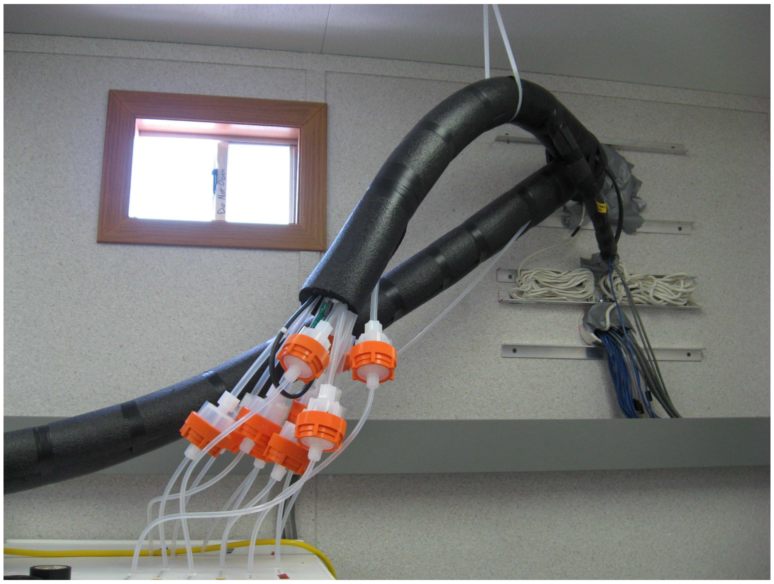


Figure 4. Bundled and insulated tubing and uninsulated cables and wires entering the raceway from the OFIS (Photo courtesy L Cai, Iowa State University).

9.3.2. Place the thermocouple wire and thermostat capillary sensors that will monitor the temperature of the sampling-tube bundle before installing tube insulation. Install one thermocouple between the exterior of the tubing group and the insulating material, at the coolest location inside the insulation, which is most likely at the furthest distance from the surface of the heat tape). This temperature measurement will be used to control the heat tape. An optional second thermocouple may be added at another location in the bundle as a secondary raceway temperature measurement (Fig. 5).

9.3.3.

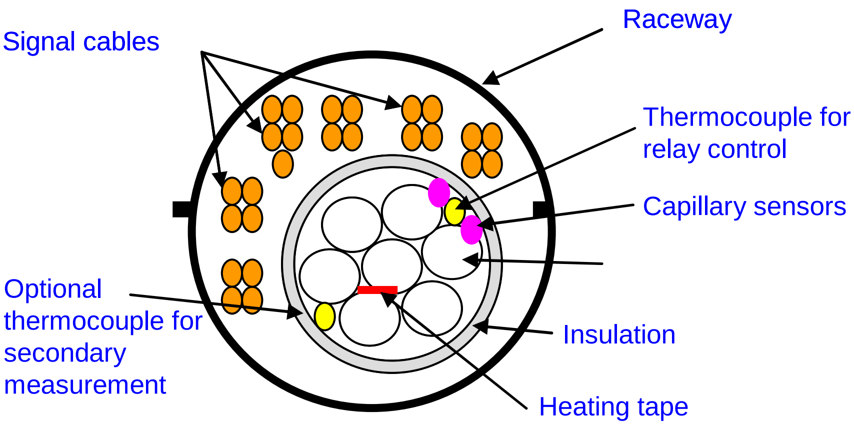


Figure 5. Cross-section of the raceway, showing tubing and signal cables.

9.4. Heating Tape Installation

9.4.1. Install heating tape controls according to Figs. 6 and 7. More information about the heat cable and power connections is provided in Appendix A. The operation of the self-regulating heat tape is activated by the relay contact, which is controlled by the data acquisition and control software, AirDAC (SOP B2). The heat tape operation is also triggered by a backup thermostat (capillary tube) contact (normally open) in the event of data acquisition hardware or software failure (Section 9.3.2). In addition, an overheating protection thermostat (capillary tube) contact (normally closed) is included to prevent any damage to the tubing (Fig. 6). The capillary sensors should be collocated with the thermocouple measurement for relay control.

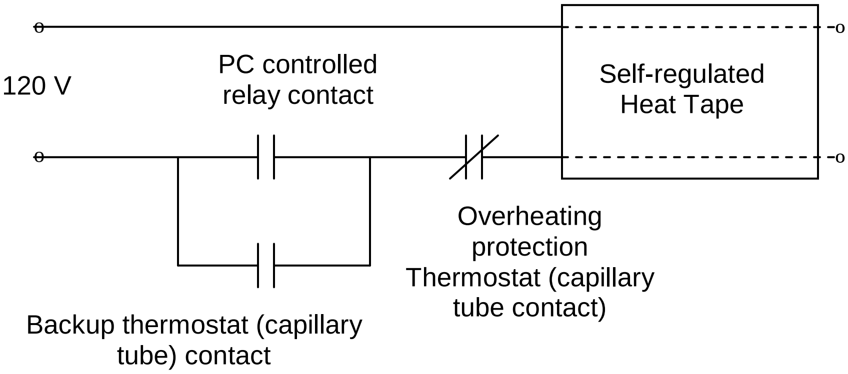
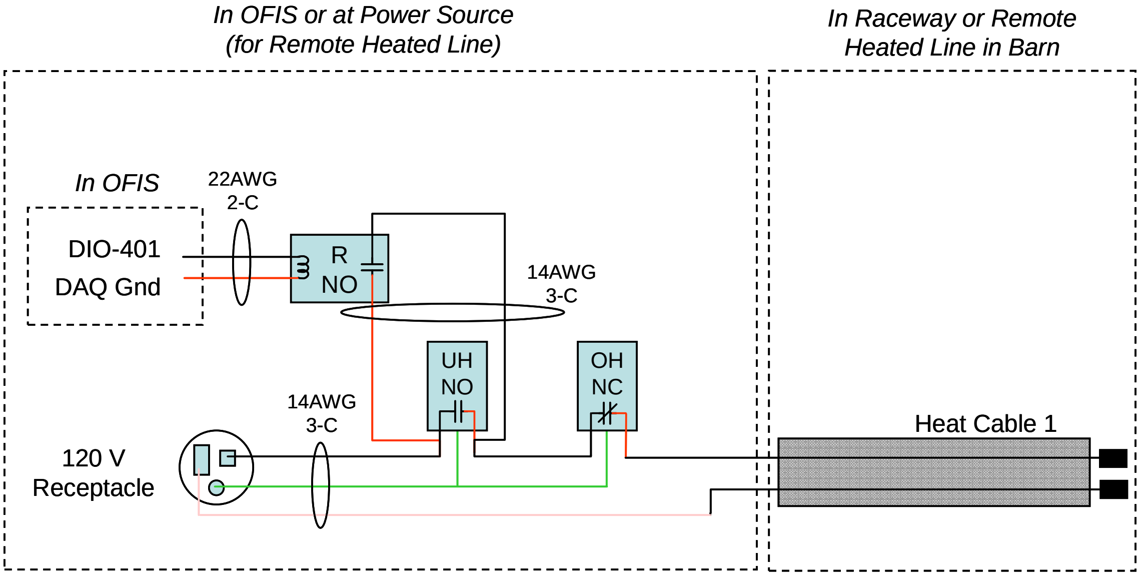


Figure 6. Heating control circuit for maintaining temperatures of air sampling lines above dew point (Heber et al., 2006).



UH: Under-heating thermostat
OH: Over-heating thermostat
R: Relay
NO: Normally open switch
NC: Normally closed switch
Location in italics

Figure 7. Wiring diagram for heat cable control system.

9.4.2. Heating Tape Operation Check

9.4.2.1. Make sure power is supplied to the DAC hardware and heating tape, and that the AirDAC software is operational.

9.4.2.2. The temperature of the air inside each sampling tube needs to be above the dew-point temperature of the sampling point to prevent condensation. To reduce the risk of condensation, a setpoint temperature that is 3 °C above the dry-bulb temperature of the sampling point(s) is recommended (Heber et al., 2006). Actual setpoint temperatures will depend on the sampling point conditions at a site, and are thus site- and season-dependent. Test and review relay and thermostat settings on a seasonal basis. Refer to Table 2 for suggested setpoint temperatures for the relays and thermostats.

Table 2. Heat tape operating setpoints based on sampling point dry-bulb temperature (T_S).

	Setting, °C (°F)	Example Setting, T_S = 30°C
Heat Tape Setpoint (in AIRDAC)	T_S + 3°C (T_S+ 5°F)	33°C
Over-Heating Thermostat Setpoint (Manual Dial Setting)	T_S + 10°C (T_S + 20°F)	40°C
Under-Heating Thermostat Setpoint (Manual Dial Setting)	T_S (T_S)	30°C

9.4.2.3. Set the temperature setpoint and control deadband in the AirDAC program (under the Data DRC tab) or in the site-specific AirDAC Config spreadsheet for the relay controlling the raceway heat tape. Refer to notes and instructions included in AirDAC for more information on the program's operation and syntax. AirDAC provides an on/off relay control signal based on the lower limit for the raceway temperature at the edge of the tubing bundle, referred to as the setpoint. Below this temperature, the relay will activate (close). As the temperature increases to the setpoint plus the control deadband (sometimes referred to as as "Hysteresis"), the relay will de-activate (open).

9.4.2.3.1. Under the column for the thermocouple controlling the relay operation, set the "Limit: Min" of the measurement equal to the desired setpoint of the raceway. Set the "Hysteresis" or control deadband equal to the desired deadband (suggested value is between 0.5°C and 2°C). Set the "Limit: Max" of the measurement equal to the setpoint plus 5°C. The "Limit: Max" value does not impact the heat tape control, but must be set higher than the "Limit: Min" value to avoid an AirDAC error.

9.4.2.3.2. Under the column for the thermocouple controlling the relay operation, set the value in row 14 within the brackets to {<,DO Control #}, where "<" is syntax that tells AirDAC to use the "Limit: Min" as the controlling setpoint, and DO Control # corresponds to the digital output channel number that controls the relay.

9.4.2.4. To test the heat tape control system, use the suggested setpoint temperatures shown for Test 1 in Table 3 to first test the AirDAC control relay. Observe the heating tape operation and temperature for at least 30–60 min to ensure proper relay operation. If the ambient temperature is similar to the air tube temperature, increase the relay control set point for faster response. Repeat using the suggested setpoints shown for Test 2 in Table 3 to test the under-heating thermostat. Monitor the raceway temperature to verify that the under-heating thermostat is controlling the heat tape. Repeat using the suggested setpoints shown for Test 3 in Table 3 to test the over-heating thermostat. Again, monitor the raceway temperature to verify that the over-heating thermostat is controlling the heat tape operation. When using a thermostat as the sole control mechanism, a larger temperature variation may be measured because of a larger internal deadband in the thermostat. Reset the backup thermostat and relay setpoints to their normal operating setpoints after completing the tests.

Table 3. Suggested setpoint temperatures for heat tape control system testing.

Test	Suggested Setpoint Temperatures for Tests, ºC (ºF)		
	Relay	Under-Heating Thermostat	Over-Heating Thermostat
1. for Relay	38 (100)	-18 (0)	49 (120)
2. for Under-Heating Thermostat	0 (32)	38 (100)	49 (120)
3. for Over-Heating Thermostat	0 (32)	-18 (0)	38 (100)

10. Data and Records Management

10.1. Record the results of the heating tape operation check in the field notes.
10.2. Record any temperature set point changes made to the AirDAC software and thermostat.
10.3. Document all data and information on field data sheets, and site logbooks with permanent ink, or in electronic field notes. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Heating System Check
  11.1.1. The temperatures of the heating tape and air tubes require frequent checking. Personnel maintaining the monitoring site and analyzing data should observe the temperatures to ensure proper operation.
  11.1.2. If temperatures are not in the correct range, follow the procedures described in Section 9.4.2 to conduct a check of the heating tape and its control system.
11.2. Thermocouple Check
  11.2.1. Raceway temperature control is used to avoid condensation in gas and PM sampling tubes, and does not require a precision thermocouple calibration. It also does not require that the thermocouples have the same level of accuracy as required in SOP E1. A two-point check (0°C and 30°C) is sufficient (SOP E1). The QAPP will specify how often raceway thermocouples need to be checked/calibrated. If the temperature reading of the raceway thermocouple deviates more than ±3°C from that of a NIST-traceable thermometer, replace the thermocouple.

11.3. Visually check the air tubes for condensation according to the frequency specified in the QAPP. A weekly inspection is recommended in cold weather.
11.4. Perform periodic visual checks of the raceway ends for any traces or rodent damage to the insulation foam. The QAPP for the project will specify the frequency of these checks. Weekly checks are recommended in this SOP.

12. References

12.1. SOP B2. 2006. Data Acquisition and Control Software (AirDAC). Standard Operating Procedure B2. Purdue Ag Air Quality Lab.
12.2. SOP E1. 2006. Temperature Measurement Using Thermocouples. Standard Operating Procedure E1. Purdue Ag Air Quality Lab.
12.3. SOP S1. 2006. Producer Collaborations at Barn Monitoring Sites. Standard Operating Procedure S1. Purdue Ag Air Quality Lab.
12.4. SOP U1. 2006. Specification of On-Farm Instrument Shelters. Standard Operating Procedure S1. Purdue Ag Air Quality Lab.
12.5. SOP U2. 2006. Installation of Barn Measurements. Standard Operating Procedure U2. Purdue Ag Air Quality Lab.
12.6. Heber, A. J., J.-Q. Ni, T.-T. Lim, A.M. Schmidt, J.A. Koziel, P.C. Tao, D.B. Beasley, S.J. Hoff, R.E. Nicolai, L.D. Jacobson, and Y. Zhang. 2006. Quality assured measurements of animal building emissions: Part 1. Gas concentrations. Journal of the Air & Waste Management Association (In Press).
12.7. Nelson Heat Tracing Systems. 2004. Nelson Type CLT Self-Regulating Heater Cable, specification/application information. Tulsa, OK.
12.8. Nelson Heat Tracing Systems. 2001. Nelson Type LT Self-Regulating Heater Cable, specification/application information. Tulsa, OK.

Appendix A: Self-Regulating Heat Tape Connections

The heat tape consists of the following layers (Fig A1):

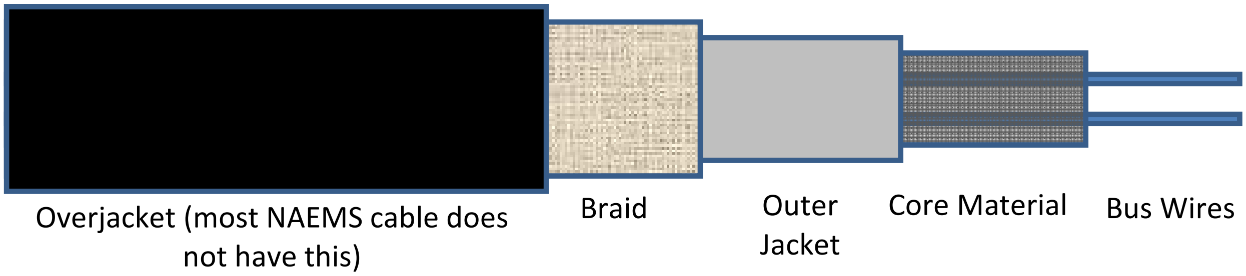


Figure A1. Self-regulating heat tape components.

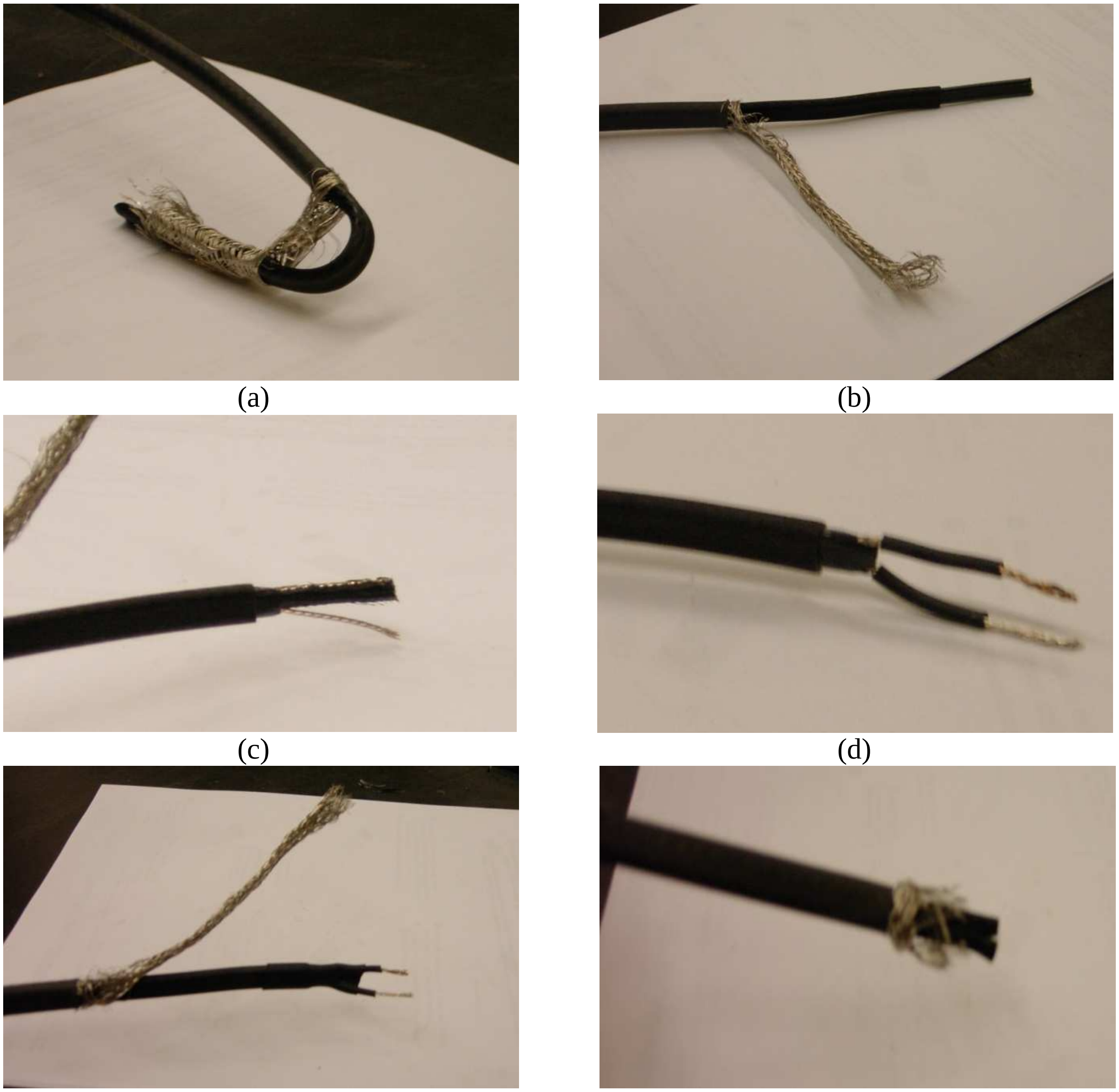
Important notes when working with self-regulating heat tape:

- The core material acts as a bunch of resistors connecting the two bus wires.
- As current passes through the bus wires, it also passes through the resistors, creating heat.
- The braid is the ground protection.
- There should be no exposure of the core material or bus wires at connection points, as they are both part of the circuit.
- The braid should not contact the core material or bus wires at any connection point or end seal.

Instructions for heat cable connections, and the materials necessary to make one power connection and one end seal are available in the power connection kits. The following information and steps are designed to supplement the power connection kit instructions.

To make a power connection:

1. Remove overjacket. Most NAEMS heat tapes do not have this overjacket.
2. Separate the heat cable from the braid. Create a bulge in braid and use a screwdriver to separate the braid and make a hole to pull the heat cable through (Fig. A2.a).
3. Remove the outer jacket from the heat cable, exposing the black core material (Fig. A2.b)
4. Shave the core material from the sides and remove the core material from the middle (Fig. A2.c).
5. Put heat shrink around the bus wires (Fig. A2.d).
6. Put heat shrink around the exposed core material, keeping the bus wires separated. Pinch the heat shrink closed between the two bus wires (Fig. A2.e).
7. The two parallel conductors of the heat tape can then be connected to the hot wire (black) and neutral wire (white) of the power supply and control system.



(a) (b)

(c) (d)

(e) (f)

Figure A2. Heat tape power connection and end seal procedures. The heat cable shown has a black overjacket (most NAEMS cable will not have an overjacket) and a black outer jacket (most NAEMS cable has a grey outer jacket). The core material is exposed by removing the over jacket and pulling the cable through the braid (a), and removing the outer jacket (b); the bus wires are separated from the core material (c) and covered with heat shrink (d); heat shrink covers the exposed core material (e). When making an end seal, heat shrink covers the exposed core material at the cut end of the cable (f).

To make an end seal:

1. Remove overjacket (if necessary).
2. Push back the braid.
3. Remove a small section of outer jacket.
4. Make a small snip in the core material between the heat cable bus wires.
5. Place heat shrink around the outer jacket and exposed core material, sealing the end (Fig. A2.f).
6. Pull braid over the covered end.
7. Place heat shrink around the end of the cable.

THE POWERWARE 9125 UNINTERRUPTIBLE POWER SUPPLY

Standard Operating Procedure (SOP) U6

THE POWERWARE 9125 UNINTERRUPTIBLE POWER SUPPLY

Standard Operating Procedure (SOP) U6

Prepared by

Bill W. Bogan and Sam M. Hanni

Reviewed by

Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. A means is needed to prevent power outages or disruptions to the equipment in the on-farm instrument shelter (OFIS) in order to ensure that data collection is not interrupted.
1.2. A means is also needed to protect the equipment from possible poor power quality. Power surges or spikes, for example, could be damaging to some of the gas analyzers, or to the DAC system.
1.3. This SOP details the use of the Powerware Model 9125 uninterruptible power system (UPS), which provides both of these functions.
1.4. SOP U1 provides a list of which equipment should be connected to the UPS. Sampling pumps and converter ovens are not connected to the UPS.

2. Summary of Method

The Powerware 9125 (Powerware Corporation, Espoo, Finland) UPS filters incoming AC power, and provides consistent, spike-free power with a pure sine wave output. The unit's double-conversion online design constantly conditions and controls AC output, assuring zero delay when transferring to backup power in the event of a power failure. The unit incorporates proprietary "Advanced Battery Management" technology, which allows the unit to operate without draining the battery, extends battery life, reduces battery recharge time, and provides a warning when the batteries are nearing the end of their useful life. The Model 9125 can accept up to four Extended Battery Modules (EBMs), further extending the length of time that the UPS can support equipment in the event of a power disruption or outage. Batteries are hot-swappable, so that power to the equipment does not need to be interrupted.

3. Definitions

3.1.	EBM	Extended battery module
3.2.	OFIS	On-Farm Instrument Shelter
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	QAPP	Quality Assurance Project Plan
3.5.	UPS	Uninterruptible power system

4. Health and Safety

4.1. The Powerware 9125 contains potentially lethal voltages. There are no user-serviceable parts in the unit. Do not attempt any service to the UPS other than changing of batteries. Under no circumstances should repairs to the UPS or its batteries be attempted by anyone other than authorized service personnel.
4.2. Because the Model 9125 contains batteries as a backup power supply, these voltages may be present even when the unit is not plugged in.
4.3. The batteries themselves can cause electrical shocks if they are handled improperly. Do not contact both poles of the battery simultaneously, and do not attempt to service the batteries. Damaged batteries can cause acid burns.
4.4. Remove watches, rings, or any other metal objects when handling the batteries.

4.5. Use only tools with insulated handles around the batteries.
4.6. Do not lay tools or any other metal parts or equipment on top of the batteries, or allow them to contact the battery poles.
4.7. When connecting the UPS and EBM, some arcing may occur. This is normal, and will not harm personnel. Minimize arcing by quickly inserting the EBM cable into the UPS battery connector, and establishing a firm connection.
4.8. Batteries are lead-acid, and must be properly disposed of or recycled. Do not discard in the trash.
4.9. Never unplug the unit while it is turned on, as this will remove the safety ground from the unit, and therefore from all equipment which is connected to the unit.
4.10. The UPS and EBM weigh approximately 100 lb combined. Do not attempt to lift the UPS and EBM without assistance.
4.11. Operate this UPS only in temperature- and humidity-controlled environments (i.e. inside the OFIS). Do not operate if the temperature exceeds 40ºC (104ºF), or if the humidity exceeds 95%. Operation under these conditions can present a fire or shock hazard.
4.12. Total earth leakage current from all equipment plugged into this UPS must be <1.5 mA.

5. Cautions

5.1. If the UPS is positioned vertically, the air vents must be at the top of the unit.
5.2. Although EBM batteries will have charged to 80% of their capacity after approximately 2 h in a plugged-in unit, it is recommended that batteries be allowed to charge for 24 h after they are initially installed, or after long-term storage. Batteries may not perform optimally if the power is interrupted to the UPS during this period.
5.3. Do not turn the UPS off while it is in Configuration mode (Section 9.2), as this will immediately shut off all power to the equipment as the UPS goes into Standby mode.
5.4. Do not plug laser printers into the UPS, as their power requirements are too high.
5.5. Make sure the receptacle into which the UPS is connected has the correct polarity. Setup of the OFIS will include a polarity check (with a GFCI receptacle tester) of all outlets.
5.6. Disconnect power to the UPS when initially connecting power to the OFIS.

6. Interferences

6.1. Batteries in the EBM can wear out. The 🔋 indicator and alarm signal that batteries may need to be replaced. If this indicator is lit, press and hold the Test/Alarm Reset button (Section 9.2) for 3 s. If the indicator remains lit, check the battery connections and, if necessary, replace the batteries.
6.2. For full battery life, operate the UPS at ambient temperatures as close to 25°C (77°F) as possible. Battery life can be reduced if the unit is operated outside this range.
6.3. Dust entering the unit can affect its performance. Keep the surrounding area as dust-free as possible, and vacuum the exterior of the unit periodically if it becomes dusty.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of the UPS before installing or operating it.
7.2. Each individual must read and understand the Model 9125 manual and this SOP.

8. Equipment and Supplies

8.1. Uninterruptible power system (Model, 9125 700-3000 VA, Powerware Corporation, Espoo, Finland)
8.2. EBM: (Powerware Corporation, Espoo, Finland)
8.3. GFCI receptacle tester (to verify outlet polarity)

9. Procedures

9.1. Initial acceptance and installation
  9.1.1. Inspect the unit and its box to ensure that no damage has occurred during shipping. Chapter 3 of the UPS Manual describes procedures to file a claim for receipt of a damaged unit.
  9.1.2. Check the required battery recharge date on the label of the shipping carton. If the date has passed without the batteries being recharged, do not use the UPS until new batteries are obtained. Contact the distributor (Section 13.2).
  9.1.3. Install the Model 9125, and any EBMs, in an instrument rack, following the "Rack-Mount Setup" procedure in the UPS Manual (Pg. 18).
  9.1.4. If installing an EBM, plug the EBM cable into the UPS battery connector (Fig. 1). If installing more than one EBM, plug the EBM cable of the second (and subsequent) module into the EBM Battery Connector of the previous module (Fig. 1). See the note in Section 4.1.6 concerning arcing which may occur at this point.

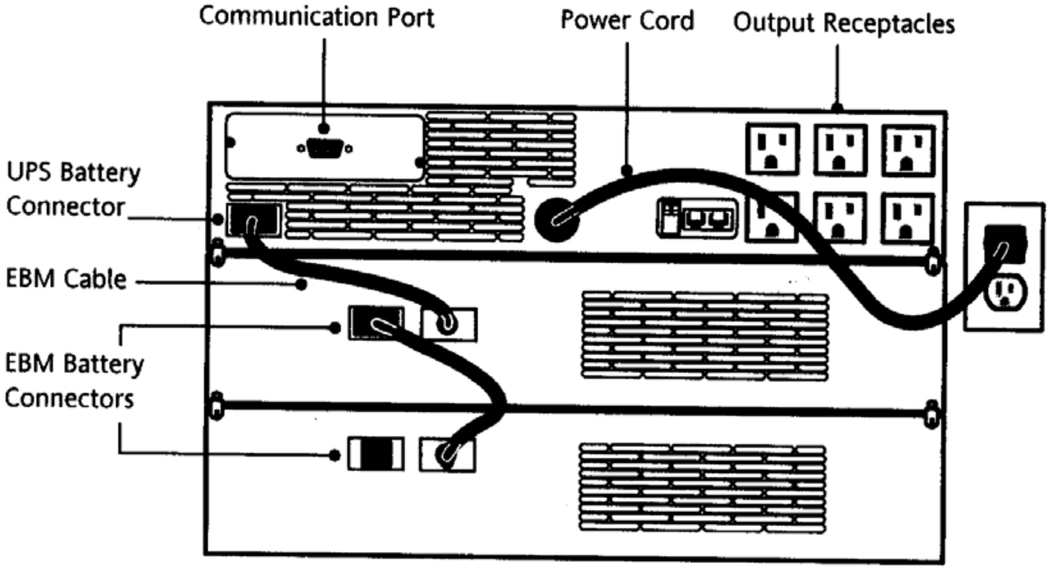


Figure 1. Rear Panel of the Model 9125 and two EBMs, showing connections.

9.2. Operation

9.2.1. Connect UPS to power source. It will conduct a 5-s self-test, and enter Standby mode.

9.2.2. Turn UPS on. The Normal Mode indicator on the front panel (Fig. 2) will come on, and a bar graph indicator will display the connected load (as percentage of capacity).

9.2.3. When the unit is plugged into a working power source (i.e. conditioning power only, not supplying it), it will run in Normal Mode.

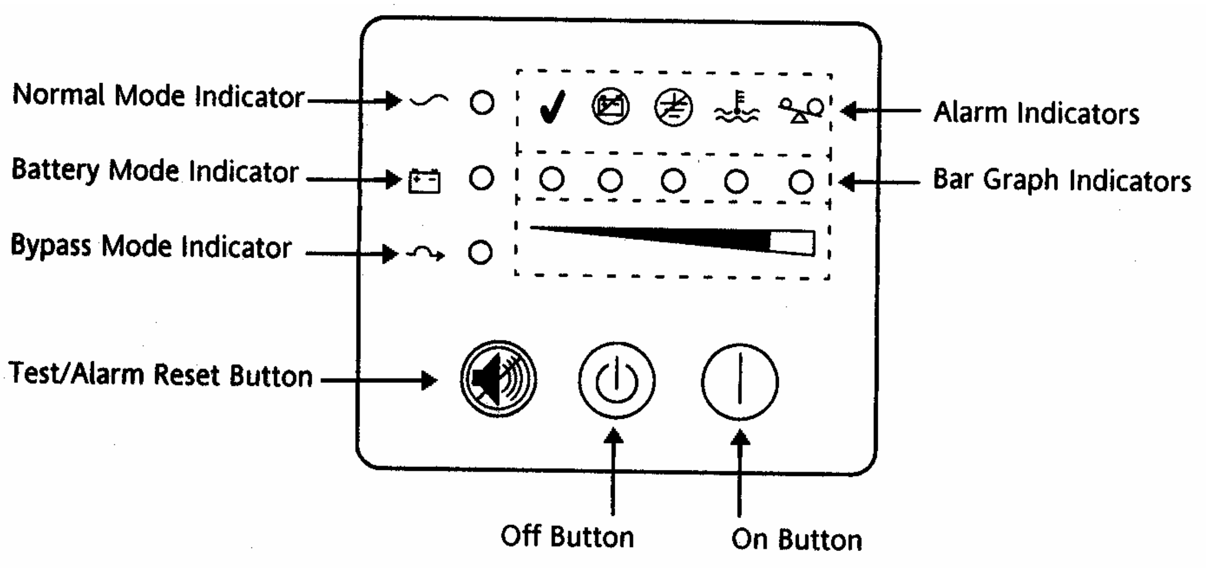


Figure 2. Front panel of the Model 9125, including power buttons and indicator lights.

9.2.4. If power to the Model 9125 is disrupted, it will go into Battery Mode. The Battery Mode indicator will be lit, and an alarm will beep.

9.2.4.1. If power is restored before the batteries become drained, the unit will automatically return to Normal Mode, and begin recharging the batteries.

9.2.4.2. If power is not restored quickly enough, the unit will use up its battery power. The ⊘ indicator will flash, and a continuous alarm will sound, when there is approximately 3 min of battery power remaining. When the check-mark indicator to the left of the low battery indicator begins to flash, a shutdown is imminent. See Section 11.1.1.

9.2.5. The unit will go into Bypass Mode if its temperature is too high, if it detects a fault in its batteries or internal electronics, or if it is overloaded. While in Bypass Mode, the unit continues to condition the utility power source, but the option to switch to Battery Mode in the event of a disruption is not available.

9.3. Configuration

9.3.1. 120 VAC input power is the default setting for the low-voltage version of the Model 9125 (the 700-3000 VA), and should not be changed. If it is changed, reconfigure the unit as follows:

9.3.1.1. Press the On and Test/Alarm Reset buttons simultaneously for one beep. The five Bar Graph indicators will either illuminate (option enabled) or not (option disabled). The proper configuration is as follows:

9.3.1.1.1. First indicator (AC Input Failure Alarm): Illuminated/enabled
9.3.1.1.2. Second indicator (Site Wiring Fault Alarm): Illuminated/enabled
9.3.1.1.3. Third indicator (127 VAC Input): Not illuminated/disabled
9.3.1.1.4. Fourth indicator (110 VAC Input): Not illuminated/disabled
9.3.1.1.5. Fifth indicator (120 VAC Input): Illuminated/enabled

9.3.1.2. If any of these are set incorrectly, use the On button to scroll to the correct indicator. The LEDs immediately above the indicators will light individually to denote which indicator is selected. Once an indicator is selected, if that option is disabled, the indicator will switch from not illuminated to flashing.

9.3.1.2.1. Once the desired indicator is selected, change its status by pressing the Test/Alarm Reset button once.

9.3.2. The unit will automatically exit Configuration Mode if no changes are made for 2 min.

10. Data and Records Management

10.1.1. Record the following in the electronic field notes:
10.1.2. Data pertaining to initial setup (receptacle polarity check, earth leakage current)
10.1.3. Dates and results of all UPS self-tests
10.1.4. Dates and specifics of any changes in configuration
10.1.5. Manage the field notes according to SOP B5.

11. Quality Control and Quality Assurance

11.1. The Model 9125 provides audible alarms for a number of conditions that might affect the unit’s performance. A full list of these alarms is provided in Table 10 (Pgs. 56-57) of the UPS Manual. Included among these are the following:

11.1.1. Warnings indicate when the unit switches to battery power, when the unit has only 3 min of battery power remaining, or when a shutdown is imminent due to low battery power. Under all of these circumstances, switch off all the equipment using the power supplied by UPS. Write down the time and cause of this action in the field notebook, and transfer to the electronic fieldnotes when power is restored.

11.1.1.1. If the total load of all equipment is very close to the maximum of the power circuit, turn off power to most of the equipment, so that there will not be a sudden significant draw when power is restored.

11.1.2. Warnings indicate when the batteries in a plugged-in unit are not charging properly. The last of these can mean that the batteries are not connected properly, or that they need to be replaced. Follow Section 6.1 to run a self-test and address this warning.

11.1.3. Warnings indicate when the unit is overtemperature. Turn off and unplug the unit for at least 5 min to cool, check the airflow around the unit, and verify that there is no dust buildup on the vents. If the alarm persists when the unit is turned back on, contact the distributor.

11.1.4. Warnings indicate when the unit is overloaded. Turn off and unplug the unit for at least 5 min, unplug some of the equipment from the UPS and restart. Determine if a higher-capacity UPS is required. Fig. 3 shows the pattern in which indicator lights will be lit to display the load level of the UPS.

11.2. Even in the absence of alarm messages, perform a self-test (Section 6.1) of the unit on a weekly basis. Record self-tests in the electronic field notes.

11.3. The hot-swapping feature of the batteries allows battery replacement without interrupting power to the equipment that is connected to the UPS, thus preserving the continuity of data.

12. References

12.1. UPS Manual. 2003. Powerware 9125 Two-in-One User's Guide. Powerware Corporation, Espoo, Finland.

12.2. SOP U1. 2006. On-farm Instrument Shelters for Barn Sources. Standard Operating Procedure U1. Purdue Ag Air Quality Lab.

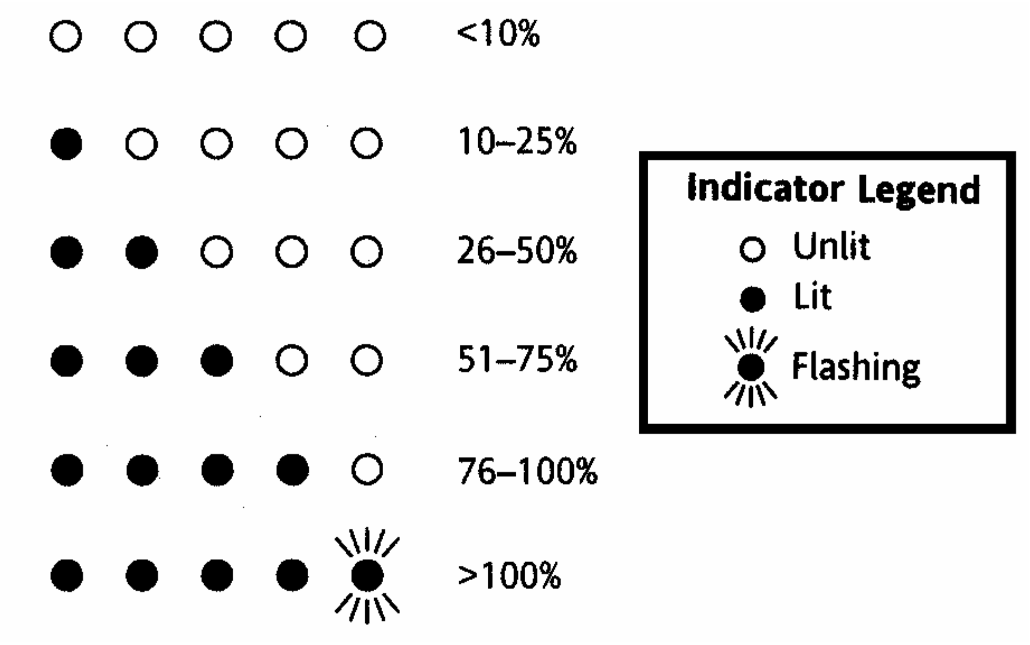


Figure 3. Status of Model 9125 indicator lights in Normal Mode at various loads (% capacity).

13. Contact Information

13.1. Manufacturer:

Powerware Corporation
Koskelontie 13, FIN-02920 Espoo, FINLAND
Phone: +358-9-452 661
Fax: +358-9-452 665 68

13.2. Distributor:

Perfect Power
3405 W. 96th St., Indianapolis, IN 46268
Phone: 317-874-4260
Fax: 219-462-2227

SAMPLING OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR SAMPLES THROUGH USE OF SORBENT TUBES

Standard Operating Procedure (SOP) V1

SAMPLING OF VOLATILE ORGANIC COMPOUNDS (VOCs) IN AIR SAMPLES THROUGH USE OF SORBENT TUBES

Standard Operating Procedure (SOP) V1

Prepared by
Hua Xu and Bill W. Bogan

Reviewed by
Albert J. Heber

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This method samples volatile organic compounds (VOCs) at livestock barns onto sorbent tubes.

1.1.1. Specifically, this method will use sorbent tubes packed with carbopack C/X to sample VOCs. Compounds which are amenable to this method include phenols, volatile fatty acids (VFAs), alcohols, aldehydes, alkanes, aromatics, amines/amides, ketones, esters, and sulfur-containing compounds, such as those listed in Table 1.

Table 1. Compounds suitable for sampling with carbopack C/X sorbent tubes.

ACIDS	ALCOHOLS	AMINES/AMIDES
Formic acid	Ethanol	Trimethylamine
Acetic acid	Isopropanol	Triethylamine
Propanoic acid	1-Propanol	Benzenamine, N-phenyl-
Butanoic acid	1-Butanol	3-methyl Indole
Propanoic acid, 2-methyl -	2-Butanol	Formamide
Pentanoic acid	Phenol	Acetamide
Butanoic acid, 2-methyl-	Phenol, 4-methyl-	Acetamide, N,N-dimethyl-
Butanoic acid, 3-methyl-	Benzyl alcohol	Caprolactam
Hexanoic acid	Phenol, 4-ethyl	Propanamide, N,N-dimethyl-
Hexanoic acid, 2-methyl-	Phenol, 2,4-bis(1,1-dimethylethyl)-	
Benzoic acid	Butylated hydroxytoluene	**Others**
1,4-benzenedicarboxylic acid	,5-di-tert-Butyl-4-hydroxybenzyl alcoh	D-Limonene
ALDEHYDE	**ALKANES**	**AROMATICS**
Acetaldehyde	Hexane	Benzene
Pentanal	Undecane	Toluene
Hexanal	Dodecane	1H-Inden-1-one, 2,3-dihydro-
Heptanal	Tridecane	
Octanal	Tetradecane	
Nonanal	Pentadecane	
Benzaldehyde	Hexadecane	
ESTERS	**S-contain Compounds**	**KETONES**
n-Propyl acetate	Dimethyl disulfide	Acetone
Ethyl citrate	Dimethyl sulfone	Acetophenone
Ethyl Acetate	Thiophene, tetrahydro-, 1,1-dioxide	2-Butanone, 3-hydroxy-

1.2. The stated detection limit for target analytes in the sampled air is 0.5 to 25 parts per billion (ppbv) concentration.

1.3. This method is generally effective for temperatures between 0°C and 40°C. In general, an increase in temperature of 10 ºC will reduce the breakthrough volume (Section 3.1) for sorbent tubes by a factor of 2.

1.4. The methodology described in this SOP is derived from USEPA Method TO-17, “Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes” and ASTM D6196-03 “Standard Practice for Selection of Sorbents, Sampling, and Thermodesorption Analysis Procedures for Volatile Organic Compounds in Air.”

2. Summary of Method

Prior to use, tubes are conditioned by heating to 350°C for at least 150 min, during which time at least 100 mL/min of pure helium carrier gas is passed through them. The monitoring procedure then involves pulling a known volume of air through specially fabricated glass tubes packed with a chemisorbent matrix. Depending on the specific chemical nature and selectivity of the sorbent matrix, this results in collection of one or more particular classes of VOCs. The collected sample is then transported back to the laboratory, where it is analyzed by gas chromatography/mass spectrometry (GC/MS). The analysis of the sorbed VOCs is facilitated by thermally desorbing them from the adsorption tube onto the focusing trap of the GC/MS system. The analytical component of this overall methodology is covered in SOP V4. This SOP includes guidance on selection of packing material for sorbent tubes, as well as procedures for screening the sampling location by taking single-tube samples to allow estimates of the nature and amount of VOCs in the sample. In this process, two tubes are used to collect, nominally, 3 to 6 L (50 to 100 mL/min for 1 h). The results from these are compared to the method’s performance criteria to determine acceptability of the data. This SOP also describes procedures and requirements for suitable laboratory and field blanks.

3. Definitions

3.1.	Breakthrough Volume (BV)	The volume of air (assuming a constant analyte concentration) that may flow through a sorbent tube before a non-negligible percentage (typically 5%) of the analyte passes through the tube without sorbing.
3.2.	GC/MS	Gas chromatography/mass spectrometry
3.3.	PTFE	Polytetrafluoroethylene
3.4.	ppb	Parts per billion
3.5.	QAPP	Quality Assurance Project Plan
3.6.	RH	Relative humidity
3.7.	Safe Sampling Volume (SSV)	A volume of air equal to 2/3 of the breakthrough volume
3.8.	SOP	Standard operating procedure
3.9.	Sorbent Strength	Describes the affinity of sorbents for VOC analytes. Sorbent strength is generally a function of surface area (although matrix hydrophobicity does play a small role). Sorbents are classified according to the

	specific surface area of the matrix. “Weak” sorbents have a matrix surface area < 50 m^2/g. “Medium” sorbents’ matrix surface area is $\approx$ 100-500 m^2/g, and that of “Strong” sorbents is $\approx$ 1000 m^2/g.
3.10. VFA	Volatile fatty acid
3.11. VOC	Volatile organic compound(s)
3.12. NIST	National Institute of Standards and Technology

4. Health and Safety

4.1. When sampling in areas with known or suspected high levels of VOCs, use personal protective clothing.

4.2. Effluent gases from tubes that are undergoing conditioning should be passed through a charcoal filter to prevent desorbed VOCs from polluting the lab atmosphere.

5. Interferences

5.1. Sorbent artifacts

5.1.1. Artifacts are typically less than 1 ng/tube for sorbent tubes with well-conditioned graphitized carbon blank sorbents (e.g. carbopack C and carbopack X).

5.1.2. Stringent tube conditioning (Section 8.1) and careful tube handling procedures after conditioning are essential for minimizing these artifacts.

5.1.3. Some charcoal types contain metals that will catalyze degradation of sorbed VOCs during the thermal desorption step. This phenomenon produces artifacts, and results in low analyte recovery, because the analyte is destroyed and converted to one or more breakdown products. Charcoal traps should not be used with this method unless lack of this interference possibility can be assured.

5.2. Artifacts from long-term storage of tubes

5.2.1. Literature cited in USEPA Method TO-17 states that the levels of artifacts encountered on tubes (Carbotrap^{TM}, Carbosieve^{TM}, Tenax®) which have been conditioned and stored according to the methods described in this SOP are on the order of 0.01 ng after 1-2 mos and 0.1 ng after 6 mos.

5.2.2. Tubes that have been stored for 2 to 6 mos must be re-conditioned for at least 15 min before use.

5.2.3. Tubes stored for more than 6 mos since conditioning must be fully re-conditioned before they are used.

5.2.4. Because contamination of this sort will also occurs as tubes containing sample are stored, all tubes must be analyzed within one month of sample collection.

5.2.5. Contamination of certain other sorbent types – including porous polymers such as Chromosorb 106 can be orders of magnitude higher, even after just after 1 week in storage. Do not use these sorbents under this SOP unless it is feasible to condition them immediately prior to use.

5.3. Additional artifacts generated during sampling and sample storage.
  5.3.1. Literature cited in Method TO-17 states that artifacts such as benzaldehyde, phenol and acetophenone can be formed via oxidative breakdown of Tenax® when sampling air streams with high concentrations (100-500 ppb) of ozone.
  5.3.2. When sampling low levels (<10 ppb) of these analytes with Tenax®-based tubes in any area where appreciable ozone concentrations are either known or suspected, use an ozone scrubber.
5.4. Water interferes with sample collection by condensing on the sorbent matrix and blocking the access of the molecules that are intended to be sorbed/trapped.
  5.4.1. Never use sorbent tubes that are at a lower temperature than the atmosphere being sampled, as this will promote condensation. Tubes must be at least the same temperature as the airstream being sampled.
  5.4.2. Water collection and entrainment within the matrix can be minimized by choosing the most hydrophobic matrix that is appropriate for a particular group of analytes.
    5.4.2.1. SSVs of VOCs on hydrophobic matrices (e.g. Tenax® and other porous polymers, Carbotrap™ and Carbopack™) are relatively unaffected by atmospheric humidity. Carbonized molecular sieve-based sorbents (e.g. Carbosieve™ SIII, Carboxen®) are affected by high humidity, and their SSVs should typically be reduced by a factor of 10 at high humidity (90-95% RH). Hydrophilic zeolite molecular sieves cannot be used at all at high humidity.
  5.4.3. Water can also interfere with the subsequent analytical steps. Approaches for minimizing this interference are discussed in SOP V4.
5.5. Air movement, either outdoors in the form of wind, or indoors as the result of a fan or other ventilation, is not a problem at air speeds less than 10 mph. Above this speed, orient tubes perpendicular to the prevailing wind direction during sampling. Physically shelter tubes from the direct draft if wind speeds exceed 20 mph.
5.6. In areas of extremely high particulate concentrations, it may be necessary to connect a particulate "pre-filter" (e.g., a 2-micron Teflon® filter or short clean tube containing a loose plug of clean glass wool) to the inlet end of the tube.
  5.6.1. Some analytes, however, may be trapped by Teflon® or glass wool.
  5.6.2. Particulates, trapped either on the prefilter or in the sorbent tube, may act as a source or sink for VOCs; if trapped in the tube itself, they may remain there through several cycles of sampling and desorption.
  5.6.3. Replace the particulate filter frequently.
5.7. Compounds that are too labile or reactive for conventional GC analysis are not suitable for this method.
5.8. Inorganic gases such as oxides of C, S, and N (with the exception of CS_2 and N_2O) cannot be sampled by this method.

6. Personnel Qualifications

6.1. Personnel should be trained in the use of all applicable instrumentation, and in appropriate sample-handling procedures, before performing the activities in this SOP.
6.2. Each analyst must read applicable equipment manuals and this SOP before performing these activities.

7. Equipment and Supplies

7.1. Sampling tubes
  7.1.1. Some information on the relative strengths and suitable analytes for a range of common, commercially-available sorbent matrices is given in Table 2.
  7.1.2. Multibed glass tubes packed with 18 mm of Carbopack C 40/60 mesh and 38 mm of Carbopack X 40/60 mesh are appropriate for VOC sampling under this SOP.
  7.1.3. Tubes must be compatible with the thermal desorption unit (GERSTEL TDS-G or equivalent).
    7.1.3.1. Use GERSTEL tubes with an outside diameter of 0.6 ± 0.1 mm, and a length from 117.5 ± 177.8 mm.
    7.1.3.2. The position and length of the sorbent beds must be such that no part of the bed extends outside that tube portion directly heated by the thermal desorption oven.
7.2. Sampling pump
  7.2.1. Must be capable of operating from 10 to 200 mL/min. Should be able to deliver a constant flow rate for a wide range of tube impedances. This allows the pump to compensate for moderate impedance variations between different sorbent tubes.
7.3. Flow meter
  7.3.1. Use a flow meter certified traceable to NIST standards.
7.4. Tube conditioning system (Model TC1, GERSTEL Inc, Baltimore, MD, or equivalent)
  7.4.1. Tube effluent is directed to vent without passing through key parts of the sample flow path (e.g. the focusing trap).
  7.4.2. Conditioning system must be leak-tight to prevent air ingress.
  7.4.3. Conditioning system must allow precise and reproducible temperature selection (±5°C), at a temperature range at least as great as that of the thermal desorber.
  7.4.4. Conditioning system must support inert gas flows in the range of 50 to 100 mL/min.
7.5. Brass, 1/4″ Swagelok® -type fittings and PTFE ferrules
7.6. Uncoated aluminum foil
7.7. 2-µm Teflon® filter cartridge or short clean tubes containing loose plugs of clean glass wool
7.8. FEP tubing (FEP-MET-8×6-TE-1, Norell Inc) and ¼″ Teflon tubing

8. Procedures

8.1. Tube labeling and identification
  8.1.1. All sorbent tubes are pre-labeled by manufacturer with unique numbers.
  8.1.2. Document the following information (some of which will need to be obtained from the manufacturer) for each tube: masses and/or bed lengths of sorbent(s), maximum allowable temperature, packing or repacking date, each date on which the tube was conditioned, date of use, and the date that the tube's SSV was tested (Section 10.4.1).
  8.1.3. Check conditioning by obtaining chromatograms (SOP V4) to verify the absence of contaminating artifacts. Keep and store all such chromatograms together with the other written records for each tube.
    8.1.3.1. For new tubes, analyze a minimum of 10% of the tubes in each batch.

8.2. Conditioning and subsequent handling
  8.2.1. Follow the TC1 Instrument Manual to condition tubes.
    8.2.1.1. Purchased, preconditioned tubes should be conditioned for a minimum of 30 min. To do so, they should be brought to the temperatures given in Table 3, while a pure helium carrier gas is passed through them, at the flow rate given in Table 3.
    8.2.1.2. If the tube history is unknown, it should be conditioned for a minimum of 2 h.
    8.2.1.3. Up to 10 tubes may be conditioned at one time using the TC1.
  8.2.2. Obtain post-conditioning chromatograms (SOP V4) for the required number of tubes (Section 10.7).
  8.2.3. Once conditioned, seal the tubes in the storage container provided by the manufacturer. Never use greased fittings. Wrap the sealed tubes individually in uncoated aluminum foil, and place them in a clean, airtight, opaque container.
  8.2.4. Add a package of clean sorbent material, e.g. activated charcoal or activated charcoal/silica gel mixture, to the container.
  8.2.5. If tubes will not be used within 24 h of conditioning, store them in a refrigerator (organic solvent-free) at 4°C. See Section 5.4.1 concerning the use of tubes that have not yet returned to ambient temperature.
  8.2.6. On second and subsequent uses, tubes will generally not require further conditioning. An exception to this is tubes exposed in their immediate prior use to high levels of VOCs; these should be reconditioned prior to continued usage.

8.3. Preparation for sample collection
  8.3.1. At the monitoring location, keep the tubes in their storage and transportation container until they have reached ambient temperature.
  8.3.2. Using clean gloves, remove the sample tubes from the storage container, remove their caps and attach them to the sampling lines. Use 6 mm ID FEP tubing for these connections. Connect two tubes in series using a Teflon tubing union, formed by bending a piece of ¼″ Teflon tubing into a “U” shape and inserting each end into a short piece of 6-mm ID FEP tubing to allow a connection with the sorbent tube.
  8.3.3. Uncap and immediately reseal the required number of field blank tubes (See Section 10.1.2). Place the field blank tube(s) back in the storage container.

8.4. Set sampling flow rates
  8.4.1. The sampling train (Fig. 1) consists of the following: in-line particulate filter (Optional, Section 5.6), ozone scrubber (Optional, Section 5.3), sampling tubes (two in series), and a flow meter/pump combination (Section 7.2).
    8.4.1.1. All connections coming into contact with the sample stream (all connections before the second tube) must be Teflon, to minimize offgassing. Connections after the sorbent tubes can be standard flexible Tygon tubing.
  8.4.2. Collect samples over 1 h, with a sampling rate of 50 mL/min or 100 mL/min, depending upon whether 3 L or 6 L of air are to be sampled (Section 10.3).
  8.4.3. Establish the approximate sampling flow rate using two “dummy” tubes of identical construction and packing as the sampling tube to be used. Set the flow rates of the pump using the flow meter, which is placed in line after the second tube. Record the flow rate as reached during this period.
  8.4.4. Once the flow rate has been established with the “dummy” tubes in place, and has held stable for one minute, remove the “dummy” tubes and place the sampling tubes

on the sampling train. Make final adjustments to the flow meter as quickly as possible, so as to avoid significant errors in the sample volume. Record the flow rate which is used for the sampling.

8.4.4.1. If multi-bed sorbent tubes are used, they must be oriented so that the air sample passes through a series of sorbents in order of increasing sorbent strength (i.e., weaker sorbent first). This is necessary to prevent contamination of the stronger adsorbent with less-volatile components.

8.5. Sample and recheck flow rates

8.5.1. Sample over the specified sampling period (i.e. 1 h). Recheck all the sampling flow rates at the end of the sampling period, just before switching off the pump. Record the flow rate every 5 to 10 min during the sampling event.

8.5.2. The flow rate measured at the end of sampling must be within 10% of that at the start of the sampling period, or the sample must be invalidated. Use the average value between the beginning and ending flow rates for all calculations.

8.5.3. Make notes of all relevant monitoring parameters: locations, tube identification numbers, pump flow rates, dates, times, sampled volumes, ambient conditions, etc.

8.6. Reseal the tubes

8.6.1. Immediately remove the sampling tubes with clean gloves, put them back in the storage container, rewrap with uncoated aluminum foil, and place in a clean, opaque, airtight container. Do not store “loaded” sampling tubes in the same container as clean tubes.

8.6.2. If tubes will not be analyzed during the same day, place the container in a clean (organic solvent-free), refrigerator (< 4°C) or freezer until they are to be analyzed.

8.6.3. In all cases, conduct analysis within 30 d of sample collection.

8.7. Shipping

8.7.1. Ship all samples by the fastest available means (preferably overnight), and include sufficient amounts of “blue ice” (or equivalent) to keep cold. Avoid shipping that will result in arrival of the samples on days when laboratory personnel will not be available to receive samples.

8.7.2. Include chain-of-custody forms with all sample shipments.

8.8. Receipt of samples

8.8.1. Note condition and temperature of sample containers.

8.8.2. Log in samples such that analyses can be scheduled (Section 8.6.3).

8.8.3. Store samples (Section 8.6.2).

8.8.4. Sign and date chain-of-custody forms.

9. Data and Records Management

9.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

9.2. Manage all data according to SOP B5.

9.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.

9.4. Overstrike all errors in writing with a single line. Initial and date all such corrections.

10. Quality Control and Quality Assurance

- 10.1. Blanks
  - 10.1.1. Lab blanks must be identically prepared tubes, from the same batch, with similar histories and conditioned at the same time as the tubes used for sample collection. At least two blanks are required for each 10 tubes (a "batch") used in a single sampling event (which may stretch over one or more days). If more than 10 samples are taken in a single event, they must be divided into two (or more, as appropriate) batches for the purpose of including blanks. Lab blanks must be stored in the lab in clean controlled conditions (Sections 8.2.4. and 8.2.5). They should be analyzed at the same time as the samples - one at the beginning and one at the end of the samples' analytical sequence.
  - 10.1.2. Field blanks are the same as lab blanks; however, they are transported to and from the monitoring site, and are uncapped and immediately resealed at the monitoring site. They do not actually have air pumped through them. One field blank tube is taken for every ten tubes included in a sampling event (one tube per batch), with the exception that no less than two field blanks may be included, however small the sampling event. Field blanks should be distributed evenly throughout the run when the tubes are analyzed.
    - 10.1.2.1. If the profile/pattern of VOCs on the field blank matches the sampled tubes, and if the areas of peaks in the field blanks are >5% of those in the sampled tubes, pay careful attention to the method of sealing tubes and other storage procedures in future sampling events. If the areas of peaks of field blank are >10% those in the sampled tubes, then invalidate the sampled tube data.
- 10.2. Determination and validation of SSVs
  - 10.2.1. If SSV information is not readily available for the analytes under test on the sorbent tube selected, or if the SSVs need validating, use the following field experiment, taken from Method TO-17.
    - 10.2.1.1. The experiment should be carried out in the atmosphere to be monitored and, if possible, under worst-case conditions (i.e., highest natural humidity and highest typical VOC concentrations). Select a well-ventilated sampling location.
    - 10.2.1.2. Link 2 sorbent tubes together in series. Repeat this five additional times, so that a total of 12 tubes (six pairs) are used.
      - 10.2.1.2.1. Use Teflon tubing unions as described in Section 8.3.2.
    - 10.2.1.3. Connect the sampling end of the backup tube to the exit end of the primary tube.
    - 10.2.1.4. Connect the tube pairs to individual calibrated monitoring pumps, and simultaneously sample at least 3 different air volumes.
      - 10.2.1.4.1. Place the sampling ends of all the tube pairs close together, as much as possible, to ensure that all tubes are sampling the same atmosphere.
      - 10.2.1.4.2. Use pump flow rates between 10 and 200 mL/min.
      - 10.2.1.4.3. Obtain 2 replicates at each air sample volume.
    - 10.2.1.5. Analyze both the primary and backup tubes of each pair by GC/MS (SOP V4).
    - 10.2.1.6. If more than 5% of one or more of the target analytes is observed on any of the backup tubes, breakthrough is shown to have occurred at that sample volume.

10.2.1.7. If the amount of analyte found on the backup tube at a particular sampling volume is in the range of 5-10% (i.e. the sampling volume is at or very close to the actual BV), set the SSV as two thirds (~66%) of that volume.

10.2.1.8. If the amount of analyte found on the backup tube at a particular sampling volume is greater than 10% (i.e. the sampling volume is considerably beyond the actual BV), set the SSV as the next lowest sampled volume (provided that volume does not display breakthrough).

10.3. Initial testing of each sampling site

10.3.1. The first time a sampling location is tested, such as during an initial site characterization, is considered to be an "uncharacterized atmosphere" (using terminology from Method TO-17). Conduct a scaled-down, site-specific (as opposed to compound-specific) version of the experiment detailed in Step 10.2.

10.3.1.1. In these cases, collect distributed volume tube pairs (e.g. 1- and 4-L samples) in parallel (i.e. simultaneously from one sampling location, per Section 10.2.1.4.1).

10.3.1.2. Ideally, the quantity of material collected (after quantitation by GC/MS) should scale linearly with sample volume on a plot forced through the origin.

10.3.1.2.1. If this condition is met (i.e. if the R^2 value for the line is ≥ 0.98), use the larger sample volume (4 L) in future equivalent (i.e. within the same season) sampling events.

10.3.1.2.2. If the R^2 value for the line is <0.98, and the amount recovered in the 4-L sample is less than 4 times that in the 1-L sample, use the smaller (1-L) volume in future sampling events.

10.3.1.2.3. If the R^2 value for the line is <0.9, and/or the amount recovered in the 4-L sample is more than 5 times that in the 1-L sample, repeat the test, as a sampling error has occurred.

10.3.1.3. Backup tubes should be used to investigate situations in which distributed volume pairs do not agree within acceptable tolerance. This will rule out the possibility of experimental error, and validate the decision to use the smaller sampling volume at a given site.

10.4. Instrument calibration and performance criteria

10.4.1. Calibrate pumps according to the manufacturer's instructions.

10.4.2. Calibrate flow meters annually (or as specified in the QAPP) according to SOP A9.

10.4.3. Calibrations conducted at the monitoring location, immediately before sampling begins, are preferred. Alternatively, conduct calibration in a clean environment before the tubes and pumps are transported to the monitoring site.

10.4.4. Calibrate pumps with the type of sorbent tube to which they will be connected during the actual sampling.

10.4.5. Any pump that "fails" Step 8.5.2 (i.e. does not maintain a flow rate for 1 h within 10% of its initial set rate) more than once will be repaired and recalibrated.

10.4.6. Review records of the pump flow rate delivered against the pump flow set rate, stroke rate or pressure at least once per 3 mos. If the performance of any pump has been found to have changed significantly over that time (for example, the flow rate measured at the end of sampling doesn't agree within 10% of the start of sampling, or if completely different pump settings are required to deliver the same pump flow rate), have the pump serviced by the manufacturer or their approved agent.

10.4.7. Certify all flow meters traceable to National Institute of Standards and Technology (NIST) standards.

10.5. Performance criteria for sorbent tubes sampling of air

10.5.1. Precision of duplicate pairs

10.5.1.1. The measure of analytical precision used for this SOP is the absolute value of relative difference between two identical samples.

10.5.1.2. The identical samples must have the same flow rate over the same time period from a common inlet.

10.5.1.3. Calculate the analytical precision as follows:

$$\text{Precision} = \frac{[X_1 - X_2]}{X} \times 100$$

Where:

X_1 = One measurement value (e.g., for a defined sample volume of 1L)

X_2 = Duplicated measurement value

X = Average of X_1 and X_2

10.5.1.4. Agreement within 25% for distributed volume pairs should be met.

10.6. Audit accuracy

10.6.1. Prepare gaseous audit standards using any of the four methods described in Section 9.1 of SOP V6. Concentrations of analytes in the audit standard should be such that the amount trapped on the sorbent tube, given a 4-L sample volume, is approximately in the middle of the concentration range used for the multipoint calibration curve.

10.6.2. Collect the audit standards onto an adsorbent tube with sampling train, following the procedures in this SOP. Collect duplicate samples of the audit standard.

10.6.3. Analyze the audit standard tubes by GC/MS (SOP V4).

10.6.4. The audit accuracy is the relative difference between the measurement result and the nominal concentration of the audit compounds:

$$\text{Audit Accuracy, \%} = \frac{(Spiked \cdot Value - Observed \cdot Values)}{(Spiked \cdot Value)} \times 100$$

10.6.4.1. Audit accuracy must be within 25%.

10.7. “Spot-checks” of sorbent tube conditioning

10.7.1. Initially (i.e. at the start of a project), analyze all tubes individually by GC/MS to verify their proper conditioning.

10.7.2. After the conditioning system has been proven reliable, spot-check a lower percentage of tubes, and certify the entire batch.

10.7.2.1. Check at least 10% of any given batch of tubes, where “batch” refers to the group of tubes conditioned in a given session.

10.7.2.2. Tubes in a batch which are to be spot-checked should have contained similar contaminant levels as a result of their most recent sample collection. If some tubes in a batch are known to have contained higher levels of contaminants than others, give preference to checking some (or all) of these.

11.

11. References

11.1. ASTM D 6196-03. 2003. Standard Practice for Selection of Sorbents, Sampling, and Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air. ASTM International, West Conshohocken, PA.
11.2. EPA Method TO-17. 1999. Determination of Volatile Organic Compounds in Ambient Air Using Active Sampling onto Sorbent Tubes. In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition (EPA/625/R-96/010b). Center for Environmental Research Information, Office of Research and Development, US EPA, Cincinnati, OH.
11.3. TC1 Tube Conditioner Manual. GERSTEL GmbH & Co.KG, Mülheim an der Ruhr, Germany.
11.4. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.
11.5. SOP V4. 2006. Thermodesorption and GC/MS Analysis of VOCs Collected on Sorbent Tubes. Standard Operating Procedure V4. Purdue Ag Air Quality Lab.
11.6. SOP V6. 2006. Standard Operating Procedure For GC/MS Analysis of VOCs Collected in Sampling Canisters. Standard Operating Procedure V6. Purdue Ag Air Quality Lab.

Table 2. Analyte suitability of different common, commercially available sorbent matrices used in air sampling tubes.

Sample Tube Sorbent	Approx. Analyte Volatility Range	Specific Surface Area (m^2/g)	Example Analytes
CarbotrapC® CarbopackC® Amsorb® GCB2	n-C_8 to n-C_{20}	12	Alkyl benzenes and aliphatics
Tenax® TA	bp 100°C to 400°C n-C_7 to n-C_{26}	35	Aromatics (except benzene), Apolar components (bp>100°C) and less-volatile polar components (bp> 150°C)
Tenax GR	bp 100°C to 450°C n-C_7 to n-C_{40}	35	Alkyl benzenes, vapor-phase PAHs and PCBs and as above for Tenax TA.
Carbotrap® CarbopackB® Amsorb® GCB1	(n-C_4) n-C_5 to n-C_{14}	100	Wide range of VOCs, including ketones, alcohols, and aldehydes (bp>75°C) and all apolar compounds within the volatility range specified.
Chromosorb® 102	bp 50°C to 200°C	350	Wide range of VOCs, including oxygenated compounds and haloforms less volatile than methylene chloride.
Chromosorb 106	bp 50°C to 200°C	750	Wide range of VOCs, including hydrocarbons from *n*-C_5 to *n*-C_{12}. Also good for volatile oxygenated compounds.
Porapak Q	bp 50°C - 200°C n-C_5 to n-C_{12}	550	Wide range of VOCs, including oxygenated compounds.
Porapak N	bp 50°C to 150°C n-C_5 to n-C_8	300	Specifically selected for volatile nitriles: acrylonitrile, acetonitrile and propionitrile. Good for pyridine, volatile alcohols from EtOH, and for methylethylketone (MEK).
Spherocarb	-30°C to 150°C C_3 to n-C_8	1200	Good for very volatile compounds such as ethylene oxide, and dichloromethane. Also good for polar VOCs, e.g. MeOH EtOH and acetone.
Carbosieve SIII® Carboxen 1000® Anasorb® CMS	-60°C to 80°C	800	Good for ultra-volatile compounds such as low-molecular-weight hydrocarbons, volatile haloforms and freons.

Table 3. Appropriate conditioning parameters to be used for sampling tubes containing various sorbent matrices.

Sample Tube Sorbent	**Hydrophobic (?)**	**Conditioning parameters**	
		Temperature (°C)	**Gas flow (mL/min)**
CarbotrapC® CarbopackC® Amsorb® GCB2	Yes	350	100
Tenax® TA	Yes	330	100
Tenax GR	Yes	330	100
Carbotrap® CarbopackB® Amsorb® GCB1	Yes	350	100
Chromosorb® 102	Yes	250	100
Chromosorb 106	Yes	250	100
Porapak Q	Yes	250	100
Porapak N	No	180	100
Spherocarb	Yes	400	100
Carbosieve SIII® Varbpxem 1000® Anasorb® CMS	No	350	100
Zeolite Molecular Sieve 13X	No	330	100
Tenaz / CB: comb. Tube Type 1	Yes	330	100
Carb B / CMS: comb. Tube Type 2	No	350	100
Carb 300 type: comb. Tube Type 3	No	350	100

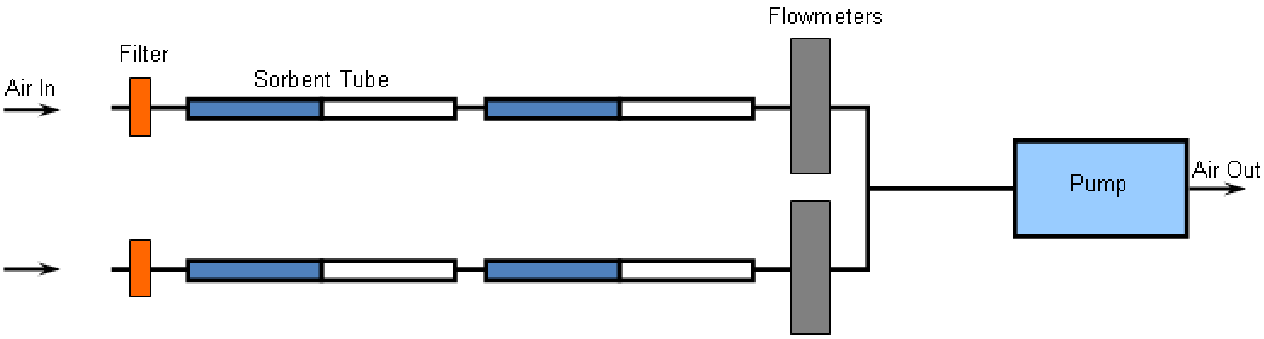


Figure 1. Diagram of the sampling train, as set up for duplicate samples at one location.

VOC SAMPLING USING CANISTERS

Standard Operating Procedure (SOP) V2

VOC SAMPLING USING CANISTERS

Standard Operating Procedure (SOP) V2

Prepared by

Juan Carlos Ramirez, Bill W. Bogan, and Hua Xu

Reviewed by

Albert J. Heber

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. A method is needed to sample volatile organic compound (VOC) emissions from barns and other buildings at livestock facilities.

1.2. This procedure describes the subatmospheric pressure sampling of VOCs using canisters. VOC analysis is described in SOP V6, while the procedures necessary to ensure the cleanliness of the canisters themselves, as well as the other components of the sampling system, are described in SOP V7.

1.3. Time-integrated sampling is conducted in indoor ambient atmospheres at confined animal feeding operations (CAFOs). The typical sampling period, in accordance with USEPA Methods TO-14A and TO-15, and ASTM Method D5466-01, is 24 h.

1.4. The "whole air" sample is collected in stainless steel canisters with specially treated (passivated) interior surfaces (SilcoCan® canisters). Such canisters are rugged, proven and a convenient way of collecting air samples in the field. They can be cleaned and reconditioned (SOP V7) and reused for subsequent samples.

1.5. This procedure is applicable to specific VOCs that have been tested and determined to be stable when stored in subatmospheric pressure canisters. A list of applicable analytes, along with approximate detection limits, are provided in SOP V6. Analyte stability tests are described in detail in SOP V7.

1.6. When sampling under negative pressure (i.e. samples are drawn into the canister by the vacuum inside), the maximal volume which can be sampled is the volume of the canister. Pressurized systems (i.e. those incorporating bellows-type pumps), although not applicable under this SOP, can collect larger volumes.

2. Summary of Method

An ambient air sample is drawn into a conditioned canister through a sampling system (Fig. 1) that includes: a short sampling inlet, a 2-µm particulate filter, a spring washer, an interchangeable critical orifice to restrict the flow range, a Veriflo® SC423XL flow controller to maintain constant sampling flow when a time averaged sample is required, a vacuum gauge and a canister. A canister is a stainless steel vessel in which the internal surfaces have been specially passivated using a unique Siltek® passivation technology, which chemically bonds a fused silica layer to the metal inner surface of the canister. SilcoCan® canisters are suitable for the sampling of most VOC analytes, including polar and sulfur-containing compounds. The canister is evacuated and used to collect an air sample, using the internal vacuum as the driving force. A canister will hold a vacuum >28 in. Hg (>13.8 psi) for up to 30 d. The canisters are subjected to various quality assurance (QA) performance checks, including leak checks and certification of both the canister and the sampling train, both of which are presented in SOP V7. After collection, the canister valve is closed, a tag is attached to the canister, a chain-of-custody (COC) form is completed and the canister is transported to the lab for analysis (SOP V6).

3. Definitions

3.1. atm	atmosphere. 1 atm = 29.92 in Hg (14.96 psi)
3.2. CAFO	Confined Animal Feeding Operation
3.3. Certification	The process of demonstrating, using humid zero air and humid calibration gases, that the sampling system will not change the concentrations of sampled and stored gases (SOP V7).
3.4. COC	Chain of custody
3.5. GSS	Gas sampling system
3.6. NIST	National Institute of Standards and Technology
3.7. PAAQL	Purdue Agricultural Air Quality Laboratory
3.8. PTFE	Polytetrafluoroethylene
3.9. "Practice" Canister	A canister used to calibrate the mass flow controller
3.10. QAPP	Quality Assurance Project Plan
3.11. sccm	standard cubic centimeters per minute
3.12. VOC	Volatile organic compound(s)

4. Health and Safety

4.1. Each person needs personal protection equipment according to the place where the work is being conducted.
4.2. Release or evacuate air from a canister to a fume hood or to outside.
4.3. Wear safety glasses when handling canisters; some suppliers send canisters pressurized.

5. Cautions

5.1. Avoid sources of impurities, such as the following:
  5.1.1. Organic compounds outgassing from the system components ahead of the canister
  5.1.2. Solvent vapors in any location other than the one which is to be sampled
5.2. Canister valves must be closed at the exact end of sampling period. If not, the canister pressure will be lower than the pressure required by the flow controller. The flow in the last portion of the sampling cycle will not be at the same value that the initial flow.
5.3. For reasons specified in Section 6.1, do not exceed 30 d storage of samples prior to analysis.

6. Interferences

6.1. The following loss mechanisms for analytes collected into sampling canisters are generally considered (USEPA Compendium Method TO-15) to be short-term, and could affect the stability of analytes over the periods relevant to this SOP (i.e. the 2 weeks required to assess analyte stability in Section 11.8 of SOP V7). In general, however, most VOCs can be recovered from canisters near their original concentrations after storing them up to 30 d. Do not exceed 30 d storage of samples prior to analysis.
  6.1.1. Reactive sites on the internal surface(s) of the canister and/or sampling train can catalyze loss of analytes. Use only passivated canisters.

6.1.2. Losses due to physical adsorption occur as equilibrium is reached between the condensed and gas phases of an analyte. These are generally considered to occur over minutes to hours, and may be more significant with low-humidity samples.
6.1.3. Conversely, if there is any water condensed in the canister, analyte losses can occur by dissolution, particularly if humid samples are pressurized, leading to condensation.
  6.1.3.1. Loss mechanisms based on aqueous hydrolysis also exist.
6.1.4. Chemical reactions between VOCs and other, more stable substances inside the canister are generally assumed to cause the gradual decrease of concentration over time (i.e., long-term losses over days to weeks).
6.1.5. Biodegradation of analytes can also occur over time.
6.2. Never use non-chromatographic grade stainless steel tubing, non-PTFE thread sealants, or flow controllers with Buna-N rubber components.
6.3. Dust particles can obstruct the orifice, cause valve leaks, and possibly damage the valve. Use a particulate filter (Section 8.2.1, Figure 1).

7. Personnel Qualifications

7.1. Each person sampling VOCs using canisters must read and understand this SOP.

8. Equipment and Supplies

8.1. Equipment (Fig. 1)
8.1.1. Stainless steel canister(s): Leak-free stainless steel pressure vessels of desired volume with valve and specially prepared (passivated) interior surface. For the purposes of this SOP, SilcoCan® canisters (Cat. # 24142, Restek, Bellefonte, PA) or equivalent) will be used.
8.1.2. Passive air sampling kit (Restek Cat. #24160), which includes the following:
  8.1.2.1. Stainless steel sampling tube (¼” ID).
  8.1.2.2. 2-µm frit filter
  8.1.2.3. Spring washer
  8.1.2.4. Critical orifice (0.0012-in. dia.)
  8.1.2.5. Stainless steel vacuum/pressure gauge capable of measuring a vacuum of 0–30 in. Hg (0–14.7 psi) and a pressure of 0–61 in Hg (0–30 psi) in the sampling system. All wetted surfaces are passivated stainless steel.
  8.1.2.6. Mass flow controller (Veriflo™ Model SC423XL, Restek Corp., Bellefonte, PA, or equivalent). Capable of maintaining a constant flow of 2-4 sccm (± 10%) over sampling periods up to 24 h and under conditions of changing temperature (20 – 40°C) and humidity.
    8.1.2.6.1. The specific part number for the MFC is dependent on the desired flow range. Flow ranges outside 2-4 sccm would require a different MFC.
8.1.3. Electronic time meter/timer/stopwatch
8.1.4. Certified mass flow meter (to verify sampling train flow controller) (Allicat Scientific, M-50 sccm, air)
8.1.5. 9/16″ wrench
8.1.6. 3-mm Hex (Allen) wrench (for adjusting the Veriflow Flow controller).

8.2. Supplies
  8.2.1. Particulate matter filter: 2-micron sintered stainless steel in-line filter
  8.2.2. Chain-of-custody forms (original and two copies each-field and lab copies).

9. Procedure

9.1. Sampling train preparation
  9.1.1. Sampling train cleaning, assembly, leak testing and certification as per SOP V7.
  9.1.2. Check the sampler flow controller in the lab, as follows:
    9.1.2.1. Install a “practice” canister (evacuated to the same pressure as the actual sampling canister) to the sampling train to test the flow controller.
    9.1.2.2. Connect 7-µm filter in front of digital flowmeter with ¼″ Teflon tubing; connect the other end of flow meter to the inlet of sampling kit using a ¼″ Teflon union.
    9.1.2.3. Open the canister valve to apply vacuum.
    9.1.2.4. Remove the protective cap from the back of the Veriflo™ Flow Controller SC423XL body. With a 3-mm hex (Allen) wrench, adjust the piston gap screw to achieve the desired flow rate (2.8 – 3.5 ml/min). Allow the flow to equilibrate for several minutes between adjustments.
    9.1.2.5. Replace the protective cap onto the back of the Veriflo™ Flow Controller body.
    9.1.2.6. Turn off the canister valve
  9.1.3. Disconnect the "practice" canister and certified mass flow meter, and pack canister(s) and sampling train(s) for transport to field.
9.2. Sampling procedure
  9.2.1. Open the canister and sampling train boxes and verify that the chain-of-custody (COC) forms (original and field copy) are included.
  9.2.2. Read the pressure of the canister from the vaccum gauge on the sampling kit.
    9.2.2.1. Confirm that the canister valve is closed.
    9.2.2.2. Remove the plug nut that is at the open side of the canister valve.
    9.2.2.3. Attach a pressure gauge to the canister.
    9.2.2.4. Open and close valve quickly (a few seconds).
    9.2.2.5. Read the vacuum on the gauge.
    9.2.2.6. Record the gauge reading on the “Initial Vacuum” column on the canister chain-of-custody form.
      9.2.2.6.1. The vacuum reading should be 0.05 in. Hg (0.025 psi). If it is not, record the pressure, make a note in the COC, and return the canister to the lab. Keep the COC field copy in the field canister file.
    9.2.2.7. Verify that the canister valve is closed and remove the gauge.
    9.2.2.8. Replace the plug nut to the canister valve.
    9.2.2.9. As an alternate procedure, install the sampling train and record the pressure indicated by the sampling train pressure gauge.
  9.2.3. Position the sampling inlet
    9.2.3.1. If the air is dusty (i.e. in highly trafficked areas), the inlet must be positioned at least 2 m above the ground (EPA Methods TO-14A and TO-15) to minimize the entrance of dust particles.
    9.2.3.2. If the ambient air is not dusty, install the inlet at least 12 in. above ground.

        - 9.2.3.3. For barns and livestock buildings, sampling will generally be conducted at the inlet(s) of exhaust fan(s)
    - 9.2.4. Attach a clean, certified (SOP V7) canister to the system.
    - 9.2.5. Open the canister valve, to allow air sample into the canister, and the vacuum pressure gauge.
    - 9.2.6. Record the pressure/vacuum in the canister (as indicated by sampler vacuum/pressure gauge) on the "VOC Canister Field Test Data Sheet", and then close the vacuum pressure gauge. Also record time of day and current ambient and interior temperatures. Reset the max/min thermometer to capture the maximum and minimum temperatures during the 24-h sampling period.
    - 9.2.7. Set the electronic timer, and program it to indicate the end of the sampling period.
    - 9.2.8. At the conclusion of the sampling period, briefly open the vacuum/pressure gauge valve on the sampler, and record the pressure/vacuum on the "VOC Canister Field Test Data Sheet". Close the valve. Record the pressure, the time of day, and elapsed sampling time. Maximum and minimum temperatures during the sampling period can be retrieved from AirDAC.
        - 9.2.8.1. There are four possible scenarios for final canister pressure:
            - 9.2.8.1.1. Ideally, there will be a vacuum of 7"-4" Hg remaining in the canister.
            - 9.2.8.1.2. If >7" Hg vacuum remains, less sample was collected than initially anticipated. The sample will be valid, but the detection limit may be higher than expected. It may be necessary to pressurize the canister (SOP V6) prior to analysis, which will dilute the sample. A dilution factor will then be required to determine final target compound concentrations.
            - 9.2.8.1.3. A vacuum <4" Hg indicates the sample might be skewed toward the initial part of the sampling period. This assumption usually is valid because the flow rate through the flow controller will fall once the vacuum falls below 5" Hg, when the change in pressure across the flow controller diaphragm becomes too small to maintain a constant flow. The sample might still be usable, because sample was collected over the entire interval.
            - 9.2.8.1.4. If the ending vacuum is <1" Hg, the sample is invalid, because it will be impossible to tell when the sample flow stopped.
    - 9.2.9. Disconnect the sampling train from the canister.
    - 9.2.10. Complete the identification tag on the canister, which must include the canister serial number, sample number, location, and date.
- 9.3. Shipment of samples
    - 9.3.1. When a canister has been filled with a sample, include the canister information in the sample log notebook. The information is also included in the COC form.
    - 9.3.2. Include the original COC in the box with the canister, and keep the field copy in the field canister file in the trailer.
    - 9.3.3. Pack canister so that the valve is protected from disturbances that might cause leaks.
    - 9.3.4. Ship the canisters to the laboratory.

9.4. Calculations

9.4.1. Sampling flow calculation

9.4.1.1. To obtain the sampling flow to fill a canister use the following equation:

$$Q = \frac{P \times V}{T \times 60}$$

Where:

Q = flow rate, mL/min

P = final canister pressure (absolute fraction), given a “full canister” pressure of 1 atm and a “fully evacuated canister” pressure of 0 atm

V = volume of canister, mL

T = sample period, h

For example, if a 6-L canister is being used to sample for a 24-h period, and a final pressure of 7 in. Hg (3.44 psi), required by the Veriflo^{TM} flow controller to maintain constant flow, is desired, the flow rate can be calculated by:

Final pressure (vacuum): 7 in Hg = 3.44 psi vacuum = 0.234 atm
Final pressure absolute = 1 atm – 0.234 atm = 0.766 (unitless)

$$Q = \frac{0.766 \times 6000}{24 \times 60} = 3.19 \text{ mL/min}$$

9.4.2. Sampling volume calculation (based on pressure)

9.4.2.1. Sample volume collected can be determined as follows:

$$\text{Sample volume} = \frac{\text{(Initial pressure) - (Final pressure)}}{\text{Atmospheric reference pressure}} \times \text{Canister volume}$$

For example: A sample is collected in a 6-L canister. The initial pressure gauge reading when the canister left the lab was 29" Hg vacuum, and the final pressure gauge reading at the conclusion of sampling was 7" Hg vacuum.

Sample volume = [(29" Hg - 7" Hg) / 29" Hg] x 6 L = 4.55 L collected.

9.5. Troubleshooting

9.5.1. If there is no flow through the sampling train:

9.5.1.1. Check the filter to verify that it is not clogged with particles.

9.5.1.1.1. Clean the filter if necessary.

9.5.1.1.1.1. Disassemble the filter.

9.5.1.1.1.2. Remove the larger particles from the frit by blowing particle-free nitrogen through the frit from the outlet surface toward the inlet surface.

9.5.1.1.1.3. After larger particles are removed, sonicate or rinse filter parts in methanol.
9.5.1.1.1.4. Bake the parts in an oven at 130°C to remove any residual organic vapors.
9.5.1.2. Check the orifice to verify it is not obstructed with particles. This is more critical when using very small orifices.

10. Data and Records Management

10.1. Maintain all lab records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on field (or lab) data sheets, and within site (or lab) logbooks with permanent ink, or in electronic field notes.
10.4. Maintain a permanent log for each individual canister and sampling system, which must include, at minimum, the following information (SOP V7):
 10.4.1. Dates and parameters of all cleanings (i.e. temperature applied, number of cycles required to achieve certification)
 10.4.2. Certification dates
 10.4.3. Data (i.e. chromatograms) on which each certification of cleanliness is based
 10.4.4. Dates and results of all leak tests
 10.4.5. Dates and results of all analyte stability checks
 10.4.6. Dates and locations of all sampling events, as well as analytical results obtained from each sample
 10.4.7. (For sampling systems) Dates and results of all dynamic calibration tests
10.5. Sample tracking
 10.5.1. Record each sample collected by filling out all information required on the "VOC Canister Field Test Data Sheet".
 10.5.2. Canister pressure is recorded on site, and checked upon arrival in the lab to ensure canister is airtight during transport. Samples are invalidated if leaks are detected.
10.6. Overstrike all errors in writing with a single line. Initial and date all corrections on all forms.

11. Quality Control and Quality Assurance

11.1. Calibrate and leak-check all Veriflo^{TM} flow controllers annually (SOP V7).
11.2. Calibrate all mass flow meters at the beginning of the project using a calibrated bubble meter (SOP A9).
11.3. Measure and record canister pressure at the following times:
 11.3.1. In the lab, before it is sent to the field. Pressure should be 0.05 mm Hg (0.025 psi).
 11.3.2. In the field before sampling.
  11.3.2.1. If canister pressure is higher than 0.05 mm Hg, make a note in the COC, along with the temperature, and return the canister to the lab.

11.3.2.2. If canister pressure is lower than 0.05 mm Hg, this indicates that the canister did not remain airtight during transport. If any leaks are determined to have occurred during shipping, do not use the canister.

11.3.3. After sampling, vacuum should be within 10% of 7 in Hg (3.44 psi). If vacuum is higher or lower than this range, the differential pressure through the flow controller was not correct throughout the sampling cycle, and the canister must be invalidated.

11.3.4. At the lab upon receipt, vacuum should be the same value reported in the field. If a leak occurred during transport to the lab, the sample must be invalidated.

11.4. Duplicate samples may occasionally be required to asses the reproducibility of this method. The frequency of replication will be determined by the QAPP for a particular project.

12.

12. References

12.1. ASTM Method D5466-01. 2006. Standard Test Method for Determination of Volatile Organic Chemicals in Atmospheres (Canister Sampling Methodology). ASTM International, West Conshohocken, PA.

12.2. Method TO-14A. 1999. Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition (EPA/625/R-96/010b). USEPA, Center for Environmental Research Information, Office of Research and Development, Cincinnati, OH.

12.3. Method TO-15. 1999. Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition (EPA/625/R-96/010b). USEPA, Center for Environmental Research Information, Office of Research and Development, Cincinnati, OH.

12.4. SOP A9. 2006. Measurement of Airflow Rate or Calibration of Air Sampling Instruments with Gilibrator 2 Calibration Systems. Standard Operating Procedure A9. Purdue Ag Air Quality Lab.

12.5. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.6. SOP G1. 2006. Gas Sampling System. Standard Operating Procedure G1. Purdue Ag Air Quality Lab.

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12.8. SOP V7. 2006. VOC Cleaning, Certification and Pre-Sampling Preparation of Sampling Canisters. Standard Operating Procedure V7. Purdue Ag Air Quality Lab.

12.9. RESTEK Canister Guide. 2002. A Guide to Passive Air Sampling Using Canisters. Catalog 59977B. RESTEK Corporation, Bellefonte, PA. Online at http://www.restek.com/restek/images/external/59977A. pdf. Accessed 3/20/06.

Appendix A.

VOC Canister Field Test Data Sheet

A. GENERAL INFORMATION

SITE LOCATION: ____

SITE ADDRESS: ____

SHIPPING ADDRESS: ____

SAMPLING DATE: ________________________SHIPPING DATE:___________________

CANISTER SERIAL NO.:___________________OPERATOR:________________________

CANISTER LEAK: ______________________

CHECK DATE:_________________________

B. SAMPLING INFORMATION

	TEMPERATURE			PRESSURE	
	INTERIOR	AMBIENT	MAXIMUM	MINIMUM	CANISTER PRESSURE
START					
STOP					

	SAMPLING TIMES		FLOW RATES		
	LOCAL TIME	ELAPSED TIME METER READING	MANIFOLD FLOW RATE	CANISTER FLOW RATE	FLOW CONTROLLER READOUT
START					
STOP					

SAMPLING SYSTEM CERTIFICATION DATE: ___________________________________

QUARTERLY RECERTIFICATION DATE: _______________________________________

____
Signature and Title

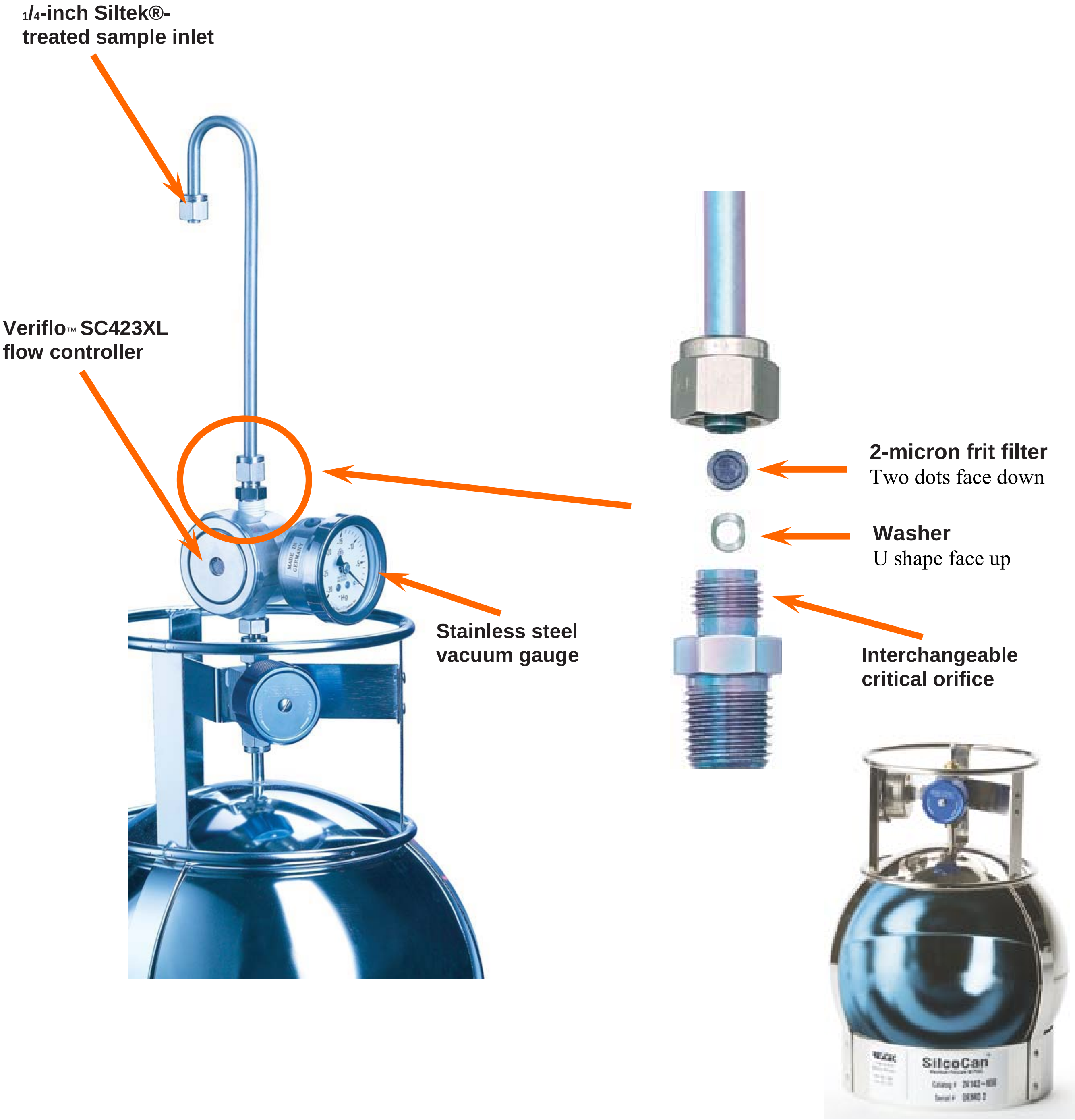

Figure 1. The negative-pressure passive sampling system used to sample air into canisters. Canister itself is shown at lower right.

COLLECTION OF AMINES IN AIR SAMPLES THROUGH USE OF SULFURIC ACID-CONTAINING BUBBLERS

Standard Operating Procedure (SOP) V3

COLLECTION OF AMINES IN AIR SAMPLES THROUGH USE OF SULFURIC ACID-CONTAINING BUBBLERS

Standard Operating Procedure (SOP) V3

Prepared by
Frank M. Mitloehner (Univ. of California-Davis) and Bill W. Bogan

Reviewed by
Congna Li and Albert J. Heber

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

- 1.1. Emissions of non-methane hydrocarbons or total VOC are regulated under the Clean Air Act and regulators are therefore interested in the VOC emissions rates from livestock production.
- 1.2. Amines released from livestock manure contribute to the total mass of NMHC.
- 1.3. Previous research has shown that amines in livestock air are efficiently sampled using sulfuric acid impingers or bubblers, and analyzed using ion chromatography.
- 1.4. Sampling periods are typically 120 min (at 1.0 L/min), but can be longer if the flow rate is lower, and if the pump can maintain this constant rate over the longer period.
  - 1.4.1. The goal is to sample 120 L of air, although this must be reduced if the concentrations of amines and/or ammonia are high enough to exceed the capacity of the trapping solution.
    - 1.4.1.1. This is indicated if the concentrations of amines (determined according to SOP V5) are equal in the first and second bubblers in the sampling train.
  - 1.4.2. Do not exceed a flow rate of 1.0 L/min.
- 1.5. Samples can be stored for up to 14 days prior to analysis.
- 1.6. The amines that can be captured from air with this method include primary amines (methylamine, butylamine) and secondary amines (dimethylamine, dibutylamine). A more complete list of target amines, along with approximate detection limits, is provided in SOP V5.

2. Summary of Method

The method is based on the South Coast Air Quality Management District (SCAQMD) Method 207.1 and the American Public Health Association (APHA) Method 124, “Tentative Method of Analysis for Primary and Secondary Amines in the Atmosphere (Ninhydrin Method)”. A known volume of air is drawn from barn exhaust air through a series of bubblers, which contain 0.1 N sulfuric acid (H_2SO_4) solution. Upon reacting with the H_2SO_4, the amines in the air stream are converted to their sulfate salts. For most amines, these salts are less volatile and more stable (e.g. more resistant to oxidation and chemical decomposition) than the free amine. The collected sample is then diluted for subsequent analysis (SOP V5).

3. Definitions

3.1.	APHA	American Public Health Association
3.2.	Batch	All bubbler trains to be used during a particular sampling event (which may extend over more than one day), but not to exceed ten. If more than ten trains will be used in an event, they must be grouped into more than one batch for the purposes of including blanks (Section 10.1).
3.3.	HDPE	High-density polyethylene
3.4.	NMHC	Non-methane hydrocarbons
3.5.	SCAQMD	South Coast Air Quality Management District

4. Health and Safety

4.1. Each chemical compound should be treated as a potential health hazard. Several aliphatic amines are highly flammable, and can cause severe eye damage; they are also capable of being absorbed through the skin. Some aromatic amines (e.g. certain toluidine isomers) are suspected carcinogens.

4.2. Be careful when working with H_2SO_4 to make the trapping solution.

4.2.1. Wear protective clothing (gloves, lab coats, protective eyewear).

4.2.2. Work in a properly-ventilated chemical fume hood.

4.2.3. Always add H_2SO_4 to isopropanol, rather than isopropanol to H_2SO_4.

5. Interferences

5.1. Ammonia will also be captured by this method. It is possible that, in sampling areas with very high ammonia levels, this could interfere, either by consuming the reactive capacity of the sampler, or by interfering with the subsequent IC analysis.

5.1.1. Ammonia levels will also affect the post-sampling handling procedure for the bubblers. If ammonia concentration is high (above approximately 270 ppm, based on a 120-L sample volume), use 0.1 N H_2SO_4, instead of distilled water, to rinse the bubblers (Step 7.4.3). Analyte losses (i.e. incomplete recovery) could occur otherwise. Consult ammonia monitoring data for the site location (SOP G4 or SOP G10) beforehand to make this determination.

5.2. When analyzing for volatile organics, samples can be contaminated (and/or cross-contaminated by diffusion of volatile organics through the sample container septum during shipment and storage. Although it is unlikely that this will interfere with analysis of amines by this method, trip and method blanks prepared from dilute H_2SO_4 and carried through sampling and subsequent storage and handling, must serve as a check on such contamination. See Section 11.1 for further discussion of method and trip blanks.

6. Personnel Qualifications

6.1. Personnel should be trained in the use of all applicable instrumentation, in appropriate sample-handling procedures, and in appropriate safety procedures, before performing the activities in this SOP.

6.2. Each analyst must read and understand applicable equipment manuals and this SOP before performing these activities.

7. Equipment and Supplies

7.1. Amine trapping solution (0.1 N H_2SO_4): Add 5 mL of concentrated (98%) H_2SO_4 to 1.0 L of MilliQ water.

7.2. 30-mL midget bubbler with sintered glass filter on inlet (Part # 7532-20, Ace Glass, Vineland, NJ) or equivalent.

7.3. Flexible non-outgassing tubing: 7-mm ID flexible FEP tubing (Cat. # FEP-MET-9 × 7-TE, Norell Inc., Landisville, NJ), 6-mm ID FEP tubing (Cat. # FEP-MET-8 × 6-TE, Norell Inc., Landisville, NJ) or equivalent
7.4. Glass fiber filters: Binder-free, 47-mm diameter, 1-µm pore size (VWR Catalog #28150-976, or equivalent)
  7.4.1. Inline filter cartridge capable of holding 47-mm filter discs
7.5. Teflon endcaps (or equivalent) for capping bubblers during transport: These can be made by sealing one end of a short length of 7-mm ID FEP tubing with a heat gun.
7.6. Gerstel Model GS gas sampler
7.7. In-line water/vapor trap (Cat #225-22-01, SKC, or equivalent)
7.8. Flow meter: Must control airflow between 1 and 2 L/min, to within ±2%.
7.9. Glass fiber membrane filters
7.10. Filter-holding assembly: Borosilicate glass or Teflon. Gaskets and/or supports (if present) may be of silicon rubber, Teflon, or Viton.
7.11. Silica gel: Indicator type, mesh size 6-16
7.12. Wash bottles:
  7.12.1. One polyethylene wash bottle containing deionized water
  7.12.2. One polyethylene wash bottle containing reagent-grade acetone to rinse and speed the air drying of the water-rinsed components.
    7.12.2.1. Do not store acetone in plastic bottles; keep it in a glass container and transfer it to the plastic wash bottle when needed.
7.13. Graduated cylinders: Glass or high-density polyethylene (HDPE) graduated cylinders, 20- to 25-mL capacity
7.14. Sample bottles: Pre-cleaned (TraceClean®) amber borosilicate glass with fluoropolymer resin-lined solid-top caps. 40-mL capacity. VWR Catalog #15900-030 (or equivalent).
7.15. Parafilm®, or equivalent
7.16. Aqueous amine calibration (standard) solution (SOP V5) for field spiking – Use the highest concentration standard from the five-point set of standards.
7.17. Transfer pipette capable of delivering 5 mL volume.

8. Procedures

8.1. Bubbler preparation
  8.1.1. Place 15 ml of trapping solution in each bubbler to be used on a particular sampling event (which may consist of one or more days). Note that each sample collected will require two full bubblers and one empty bubbler. Include a minimum of one method blank (Section 10.1.1), one trip blank (Section 10.1.2), and one train for field spiking (Section 10.1.4) with each batch of ten sampling trains.
  8.1.2. Cap the bubblers for transport, and place them in a suitable (cushioned and sealed) container.
8.2. Preparation for sample collection
  8.2.1. At the monitoring location, put on clean gloves, and assemble the sampling train in the following order (Fig. 1): filter assembly with glass-fiber filter, two bubblers with trapping solution, one empty bubbler, in-line vapor trap, GS sampler, flow meter.

8.2.2. Remove the bubblers from the container and assemble the sampling train. Keep the inlet of the first bubbler in the train capped until ready to connect to the sampling line (Step 8.3.2). Use FEP tubing to connect the train components that come into contact with the sample stream. Bend ¼″ Teflon tubing to a proper shape and length to connect the first two bubblers (containing trapping solution). At each end of this ¼" Teflon tube, insert the ¼″ tube into a short piece of 6 mm ID FEP tube, then insert that into a short piece of 7 mm ID FEP tubing. This is necessary to form good connections with the bubbler inlets and outlets. Use this same connection to connect to the inlet of the first bubbler. Components after the second trapping solution-containing bubbler can be connected with standard flexible Tygon tubing.

8.2.3. Uncap and then reseal the required number of field blank bubblers (Section 10.1.1.1). Keep the field blank bubblers uncapped for a length of time comparable to length of time that the bubblers used to assemble the sampling train were uncapped. Process the field blanks according to Section 8.4.

8.3. Sample collection

8.3.1. Sampling periods are typically 120 min (at 1.0 L/min), but can be longer if the flow rate is lower, and if the pump/sampler can maintain this constant rate over the longer period.

8.3.1.1. The goal is to sample 120 L of air, although this must be reduced if the concentrations of amines and/or ammonia are high enough to exceed the capacity of the trapping solution.

8.3.2. Establish the approximate sampling flow rate (1.0 L/min) using a "dummy" bubbler train identical to that which will be used for sampling. Set the flow rate of the GS sampler using a mass flow meter, which is placed in line after the filter assembly (Section 8.2.1). Record the flow rate as reached during this period.

8.3.3. Once the flow rate has been established with the "dummy" bubbler train in place, and has held stable for one minute, remove the "dummy" bubbler train and connect to the sampling bubbler train.

8.3.4. Leak-test the sampling train using the leak test program of the GS sampler. The leak rate must not exceed 0.02 L/min through the flow meter. If it does, locate and fix leaks, or switch to another bubbler train.

8.3.5. Restart the sampler, and make final adjustments to the flow controller as quickly as possible, so as to avoid significant errors in the sample volume. Record the flow rate which is used for the sampling.

8.3.6. Sample for approximately 120 min. Record exact starting and stopping times for sampling.

8.3.7. Recheck the sampling flow rate at the end of the sampling period, just before switching off the sampler. Record the flow rate at the end of the sampling period.

8.3.8. The flow rate measured at the end of sampling must agree within 10% with that measured at the start of the sampling period, or the sample cannot be considered valid. The average value between the beginning and ending flow rates should be used for all calculations.

8.3.9. Make notes of all relevant monitoring parameters including locations, sampler flow rates, dates, times, sampled volumes, ambient conditions etc.

8.4. Post-collection sample handling

8.4.1. Depending on air stream humidity, the volume of liquid in the bubblers may have changed during sampling. Determine the volume of liquid in each of trapping solution-containing bubblers by pouring their contents into individual clean graduated cylinders. Record the volume from each bubbler on the data sheet.

8.4.2. Pour the contents of each graduated cylinder into a separate 40-mL amber borosilicate glass bottle.

8.4.3. Use the deionized water wash bottle to rinse out all interior surfaces of the two trapping solution-containing bubblers, as well as their corresponding graduated cylinders. Add this rinse water to the respective bottles for the two bubblers.

8.4.3.1. Limit the volume of rinse water so that the total volume of each bubbler plus its rinses is no more than 30 mL. This will allow 20 mL of rinse water to be used in the lab to transfer the sample to a 50-mL volumetric flask.

8.4.3.2. In general, it is preferred not to rinse glassware with acetone to dry it. If, however, acetone must be used to dry the glassware, do not combine the acetone rinse with any sample. Discard the acetone rinses in a proper manner.

8.4.4. Tighten the cap on each bottle securely, place each bottle in a plastic bag, and record a sample number and identifying information on the bag with an indelible marker. Alternatively, use prepared labels, if these can be firmly affixed to the bags and will not come off or deteriorate during storage and/or shipping on ice.

8.4.5. Field spikes

8.4.5.1. Open the first sample bubbler of the train designated as the field spike. Pipette 5 mL of the aqueous amine calibration standard into the bubbler.

8.4.5.2. Process this bubbler only (not the second) through the steps in Sections 8.4.1 – 8.4.4.

8.4.6. Place the samples on ice in a suitable cooler, and transport to the lab for analysis.

8.4.6.1. Do not freeze samples at any point.

8.4.6.2. If samples must be shipped to the lab, do so by overnight shipping, in an ice-filled cooler. If shipping is not possible on the same day as sample collection, store the samples in a refrigerator (4°C) until shipping. Do not ship such that the samples will be held in transit longer than overnight (i.e. over a weekend or holiday), nor such that they arrive at the lab on a weekend or holiday.

8.4.7. Store the samples in a refrigerator (4°C) until analysis.

8.4.8. Analyze the samples (by ion chromatography as described in SOP V5) no more than 2 weeks after collection.

9. Data and Records Management

9.1. Maintain all lab records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

9.2. Manage all data according to SOP B5.

9.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes. Overstrike all errors in writing with a single line, and initial and date all such corrections.

10. Quality Control and Quality Assurance

10.1. Blanks and field spikes
  10.1.1. Collect a minimum of one method blank with each batch of samples. This will be processed and analyzed (See SOP V5) with that sample batch.
    10.1.1.1. Prepare method blanks (field blanks) as follows. Prepare bubblers containing trapping solution, and ship them to the sampling location. As sampling is being conducted, open them and transfer the trapping solution to a clean graduated cylinder (for volume determination – Step 8.4.1), and then to a pre-cleaned borosilicate glass bottle (both bubblers of trapping solution may be combined into one bottle). Keep method blanks uncapped and open for a period of time comparable to the period which the actual sampling bubblers are uncapped. Rinse the two bubblers from the method blank with deionized water (Section 8.4.3), and add these rinsates to the bottle. Label this bottle, pack it together with the rest of the samples from that batch, and return it to the lab.
  10.1.2. Include a minimum of one trip blank each time a set of samples is processed and analyzed.
    10.1.2.1. Trip blanks will consist of clean bubblers which are filled at the lab with trapping solution, sealed, transported to the sampling location (but not opened), and then returned to the lab with the sample batch.
  10.1.3. Blanks (either method or trip blanks) must not contain any analyte at greater than the detection limit. Corrective action if this occurs is discussed in SOP V5.
  10.1.4. Field spikes
    10.1.4.1. Collect a minimum of one method blank with each batch of samples. This will be processed and analyzed (SOP V5) with that sample batch.
    10.1.4.2. Procedures for conducting field spiking are given in Section 8.4.6.
10.2. Instrument calibration
  10.2.1. GS sampler
    10.2.1.1. Calibrate according to the manufacturer’s instructions.
    10.2.1.2. Calibration should preferably be conducted at the monitoring location immediately before sampling begins. Alternatively, calibrate in a clean room before the bubblers and sampler are transported to the monitoring site.
    10.2.1.3. Calibrate samplers with the type of bubbler to which they will be connected during the actual sampling.
    10.2.1.4. Repair and recalibrate any sampler that “fails” Step 8.3.5 (i.e. does not maintain a flow rate for 120 min within 10% of its initial set rate) more than once.
    10.2.1.5. Review records of the sampler flow rate delivered against the pump flow set rate, stroke rate or pressure at least every three months. If the performance of any sampler is found to have changed significantly over that time (for example, if completely different settings are required to deliver the same flow rate), the sampler should be serviced by the manufacturer or their approved agent.

10.2.2. Flow meter
  10.2.2.1. All flow meters will be certified traceable to NIST standards.
  10.2.2.2. Calibrate all mass flow meters at the beginning of the project using a calibrated bubble meter (SOP A9).

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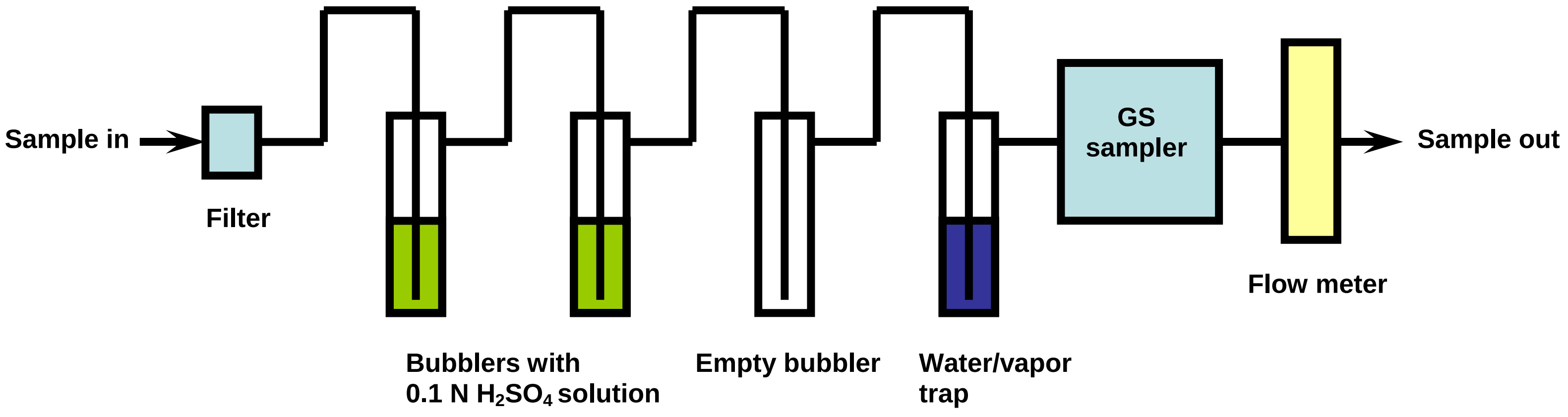

Figure 1. Proper configuration of the bubbler-based sampling train.

THERMODESORPTION AND GC/MS ANALYSIS OF VOLATILE ORGANIC

COMPOUNDS (VOCs) COLLECTED ON SORBENT TUBES

Standard Operating Procedure (SOP) V4

THERMODESORPTION AND GC/MS ANALYSIS OF VOLATILE ORGANIC COMPOUNDS (VOCs) COLLECTED ON SORBENT TUBES

Standard Operating Procedure (SOP) V4

Prepared by
Bill W. Bogan and Hua Xu

Reviewed by
Albert J. Heber

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. This SOP describes a gas chromatography/mass spectrometry (GC/MS)-based method for detecting and quantitating volatile organic compounds (VOCs) in ambient air at livestock facilities.

1.1.1. Specific VOC target compounds that are covered under this SOP are listed in Table 1 of SOP V1.

1.2. The VOCs in question will have been collected using sorbent tubes, as described in SOP V1; a necessary prerequisite for this analysis is therefore the desorption of the VOCs from the sampling tubes, which is accomplished using a thermal desorption unit.

1.3. The stated detection limit for this method is in the range of 0.5 to 25 parts per billion (ppbV) concentration in the air stream in question.

1.4. The methodology described in this SOP is derived from USEPA and ASTM methods (References 12.2, 12.6, 12.7, and 12.9)

2. Summary of Method

Sorbent tubes containing VOC analytes are collected according to SOP V1; the sampling matrix which is used (Carbotrap C/X) is particularly well-suited to the collection and retention of airborne VOCs. Tubes containing the samples are thermally desorbed, in what is referred to as the primary desorption step. Analytes driven off the tube in the primary desorption step are refocused on a secondary trap, which concentrates them into a very small volume. Rapid desorption of the trap (the secondary desorption step) follows, and then injection/transfer of target analytes into the GC. The above steps are accomplished using a GERSTEL TDS (ThermoDesorption System) 2 unit, and/or a GERSTEL TDS A 20-tube autosampler unit. The GC (Agilent Model 6890) accomplishes the separation of individual target analytes through the use of a Restek Rtx®-1 GC column. Identification of target compounds is accomplished by comparing their GC retention times and mass spectra (determined using an Agilent Model 5975 MSD) with those of authentic standards. Quantitation of each compound is then accomplished by comparing the response (preferably peak area of its primary characteristic ion, but peak height may also be used) relative to that of an internal standard. Suitable internal standards for this SOP include 1,4-dichlorobenzene-d_4, naphthalene-d_8, and acenaphthene-d_{10}.

3.

3. Definitions

3.1. **Thermal Desorption**: The use of heat and a flow of inert (carrier) gas to extract volatiles from a solid matrix directly into the carrier gas and transfer them to a downstream system element (in this case, the analytical column of a GC). No solvent is required.

3.2. **Two-stage Thermal Desorption**: The process of thermally desorbing analytes from a solid matrix, reconcentrating them on a focusing tube and then rapidly heating the focusing tube to “inject” the concentrated compounds into the GC system. This concentrates the analytes into a narrow band of vapor (equivalent to a small injection volume), which is compatible with high resolution capillary gas chromatography.

3.3. **Focusing Tube (Focusing Trap):** Narrow (typically <3-mm I.D.) tube containing a small bed of sorbent, which is maintained near or below ambient temperature and used to refocus and concentrate analytes which have been thermally desorbed from the sorbent tube. Once all the VOCs have been transferred from the sorbent tube to the focusing tube, the focusing tube is heated very rapidly to transfer the analytes into the capillary GC analytical column in a narrow band of vapor.

3.4. **Cryofocusing:** Use of coolant (for example, liquid nitrogen, liquid argon, or liquid CO_2) to lower the temperature of the focusing trap, promoting more rapid and complete sorption of analytes on the trap.

3.5. **Relative Retention Time (RRT):** The ratio of the retention time of an individual analyte over the retention time of the internal standard with which the analyte is being compared for purposes of identification. RRT is a unitless quantity, as the numerator and denominator time units cancel out. For identification of the analyte peak to be valid, RRT must be within 0.94 and 1.06 (i.e. agreement within 0.06 units).

3.6. **Response Factor (RF):** Instrument sensitivity towards a particular compound. The relationship between instrument output (e.g. peak height or integrated area) and analyte concentration.

3.7. **Relative Response Factor (RRF)**: The comparison of the Response Factor of an analyte (i.e. a calibration standard, target compound, or surrogate) to that of an internal standard.

3.8. **MS-SCAN**: Mode of operation of a GC/MS in which all mass ions over a given mass range are swept over a given period of time.

3.9. **MS-SIM**: Mode of operation of a GC/MS in which only a single mass ion (or a selected number of discrete mass ions) are monitored.

3.10. **Total Ion Chromatogram (TIC):** Chromatogram produced from a mass spectrometer detector operating in full scan (MS-SCAN) mode.

3.11. **Extracted Ion Current Profile (EICP):** A plot showing the abundance of an ion of a particular mass, plotted as a function of retention time or scan number.

3.12. **Primary Characteristic Ion:** The particular ion, as defined by USEPA or other methods, which provides the best results in terms of quantitating a particular compound.

3.13. **Target Compound:** A compound designated by the QAPP or Statement of Work for analysis (qualitative or quantitative).

3.14. **Internal Standard (IS)** – A pure analyte which is added to a sample (or standard) solution in a known amount, and is used to measure the relative responses of target compounds and/or surrogates in the solution. The internal standard(s) must not already be present in the sample.

3.15. **Tuning Standard** – A standard which is used to (a) verify that the MS system is operating properly and (b) guard against reactive sites in the system (especially the injection ports, lines, and the first segments of the column) which might cause chemical breakdown or degradation of the sample.

3.16. **Surrogate Standard** – A compound that is chemically similar to the analyte group but is not expected to occur in an environmental sample. Surrogate(s) should be added to each sample, blank or standard just prior to processing. The recovery of the surrogate standard is then used to monitor for unusual matrix effects, gross sample processing errors, etc. Surrogate recovery is evaluated for acceptance by determining whether the measured concentration falls within the acceptance limits.

3.17. **Laboratory Control Standard (LCS)** – A blank sample tube (identical to the tubes to be analyzed), to which known quantities of all method analytes (target compounds, internal standards and surrogates) are added in the laboratory. The LCS is analyzed exactly like a sample, and is used to assure that the system and analyst are capable of making accurate and precise measurements, and that there are no matrix effects (i.e. that analytes sorbed to the resin in sampling tubes are quantitated the same as those in solution.

3.18. **Method Blank** – A blank sample tube that is treated exactly as a sample, and is processed simultaneously with other samples in the analysis batch through all steps of the analytical procedure. This is done to determine if method analytes or other potential interferences are present in the lab environment, reagents, or apparatus.

3.19. **Calibration Check Compounds (CCC)** – A group of compounds used as a standard to evaluate the calibration from the standpoint of system integrity. Highly variable results with the CCCs may indicate system leaks or reactive sites on the column.

3.20. **System Performance Check Compounds (SPCC)** – SPCCs are compounds which are known to have very low RFs (0.1-0.2), and which tend to decrease rapidly in response as the chromatographic system (or the standard material) begins to deteriorate. They are usually the first to show poor performance, and are therefore used to ensure that the system is performing adequately.

4. Health and Safety

4.1. The red-anodized system parts in the TDS G and TDS A may become very hot, and may cause burns if touched. Particular care should also be exercised when opening the transfer chamber, as the inside of this chamber may reach 400°C. Always wait for the system to cool down before working on the transfer line.

4.2. Never operate the thermodesorption system in the presence of explosive fumes or gases.

4.3. Treat each chemical compound as a potential health hazard, and reduce exposure to chemicals as much as possible.

  4.3.1. Always wear protective clothing (gloves, lab coats, protective eyewear) when working with chemicals.

  4.3.2. Conduct all operations with solvents in properly-ventilated chemical fume hoods.

  4.3.3. Keep analytical balances and other work areas clean; deal with spills promptly.

4.4. Maintain a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method.

4.5. Also maintain a reference file of Material Safety Data Sheets (MSDSs), which will be made available to all personnel involved in these analyses.

5. Cautions

5.1. Contact between the capillary column and the wall of the GC oven can affect both chromatographic performance and column life. Do not allow the column to touch the oven walls.

5.2. Carrier gas should be scrubbed to remove traces of oxygen and scrubbers should be changed regularly. If the Agilent “big universal trap” (See Section 8.7.1) is used to purify helium, it should be changed after every 13th cylinder of ultra-high-purity helium is consumed.

5.3. The use of a guard column between the injection port and the analytical column may help prolong analytical column performance. Use guard columns (either as part of a pre-fabricated column (Section 8.3), or separate) when conducting analyses under this SOP.

5.4. When the online TDS G or TDS A is not in use, an empty tube must be inserted to avoid contamination of the CIS by airborne contaminants in the laboratory.

5.5. Do not operate the TDS G or TDS A in damp areas.

6. Interferences

6.1. Sample tubes awaiting analysis on an automated desorption system must be completely sealed before thermal desorption in order to prevent entry of VOC contaminants from the laboratory air, and/or losses of weakly retained analytes from the tube.

6.1.1. Keep all tubes that are awaiting analysis individually wrapped in uncoated aluminum foil in an airtight container in a refrigerator $\leq$ 4°C.

6.1.2. In no cases should the period between sampling and analysis exceed 30 d.

6.2. Use of other than inert materials (deactivated fused silica, glass lined tubing, glass, quartz and PTFE) in the sample flow path can result in degradation of some analytes.

6.3. Very volatile compounds can display peak broadening and co-elution with other species if the compounds are not delivered to the GC column in a small volume of carrier gas.

6.3.1. Refocusing of the sample after collection on the primary trap (Section 9.3.7) mitigates this problem.

6.4. Contamination by carryover can occur whenever high-concentration and low-concentration samples are sequentially analyzed. Whenever an unusually concentrated sample is encountered, it should be followed by the analysis of a humid zero air blank to check for cross-contamination.

6.5. When sample components are not resolved chromatographically, the result will be a mass spectrum containing ions contributed by more than one analyte. When gas chromatographic peaks obviously represent more than one sample component (i.e., a broadened peak with shoulder(s), or a valley between two or more maxima), appropriate selection of analyte spectra and background spectra is important.

6.6. When analytes coelute (i.e., only one chromatographic peak is apparent), the criteria for identification may be met, but each analyte spectrum will contain extraneous ions contributed by the coeluting compound. In these cases, examination of extracted ion current profiles of appropriate ions can aid in the selection of spectra and in qualitative identification of compounds.

6.7. Sorbent Artifacts

6.7.1. Artifacts are typically < 1 ng per tube for well conditioned graphitized carbon sorbents.

6.7.2. Stringent tube conditioning (See Section 8.1 of SOP V1) and careful tube handling procedures after conditioning are essential for minimizing these artifacts.

6.8. Water collected in the sorbent tubes during sampling can interfere with the subsequent analyses. Follow the approaches for minimizing the amount of water collected in sampling tubes that are given in SOP V1.

6.9. Compounds which are too labile or reactive for conventional GC analysis are not suitable for this method.

6.10. Several phenolic compounds outside the scope of this SOP (e.g. 4-nitrophenol, 2,4-dinitrophenol, 4,6-dinitro-2-methylphenol, and 4-chloro-3-methylphenol) can be subject to erratic chromatographic behavior when analyzed by this method; this is especially true if the GC system is contaminated with high-boiling-point material (high-molecular-weight, nonvolatile compounds).

  6.10.1. It is therefore possible that phenols relevant to this SOP may also display this behavior; care should thus be taken to keep the system free of contamination of this nature. The phenol-specific System Performance Check Compounds (SPCCs, Section 9.2.3.1) are run as standards to guard against this.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of all applicable instrumentation, and in appropriate sample-handling procedures, before performing the activities in this SOP.

7.2. Each analyst must read applicable equipment manuals and this SOP before performing these activities.

7.3. Each individual analyst must demonstrate the ability to generate acceptable results with this method (Section 11.13).

8. Equipment and Supplies

8.1. Thermodesorption unit (GERSTEL Model TDS G Online Thermodesorption System) or thermodesorption autosampler (GERSTEL Model TDS A) with CIS 4 Cooled Injection System (CIS) as the interface between the TDS and gas chromatograph (GC).

8.2. Gas chromatograph: Agilent GC 6890 System (Agilent Technologies, Palo Alto, CA)

  8.2.1. This GC meets the required capabilities detailed in Methods 8270C and TO-15.

8.3. Column: Columns that are suitable for use under this SOP are the following:

  8.3.1. Rtx®-1 column capillary column 60m × 0.32 mm × 1.0 µm (Restek Corp., Part #10157).

  8.3.2. An equivalent column (or column/guard column combination) may be used if equal performance can be achieved.

8.4. Mass spectrometer: Agilent MSD 5975 System (Agilent Technologies, Palo Alto, CA)

  8.4.1. This MSD meets the required capabilities detailed in Methods 8270C and TO-15.

8.5. GC/MS Interface: Capillary-direct into the MS source

  8.5.1. This interface meets the required capabilities detailed in Methods 8270C and TO-15.

8.6. Data Analysis System: A computer system that allows continuous acquisition and storage of all mass spectra. Vendor (Agilent)'s software allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number (Extracted Ion Current Profile (EICP)). Vendor's software also integrates the abundances in any EICP between specified time or scan-number limits.

8.6.1. The most recent version of the EPA/NIST Mass Spectral Library will be utilized.

8.7. GERSTEL Adsorbent Tube Injector System (ATIS^{TM})

8.8. Helium cylinders - 99.999% or higher purity He as the GC carrier gas

8.8.1. Scrubber: The Agilent "big universal trap" (Part # RMSH-2), or equivalent should be used to purify the helium carrier gas.

8.9. Liquid N_2 for cooling the thermodesorption unit's Cooled Inlet System

8.10. Standards

8.10.1. Stock standard solutions

8.10.1.1. The identity of chemicals to be used as standards will be dependent on the specific target analyte class in a particular analytical run. This information will be included in the QAPP and/or Statement of Work. General procedural steps common to all standards are given in the following sections.

8.10.1.2. Prepare stock standard solutions by weighing (on an analytical balance capable of weighing 0.0001 g) about 0.0100 g of pure material. Dissolve the compound in pesticide-quality solvent and dilute to volume in a 10-mL volumetric flask.

8.10.1.2.1. Use methanol whenever possible, as it is considerably more volatile than most target analytes, and can be purged from the tube (See Step 8.10.2.4) after spiking with minimal (or no) loss of analyte.

8.10.1.2.2. In cases where methanol use and purging is not feasible (i.e. very volatile target analytes, compounds which are insoluble in methanol) use ethyl acetate instead, as it is very readily resolved chromatographically from most target analytes.

8.10.1.2.3. When compound purity is assayed to be 96% or greater, use weights without correction to calculate the concentration of the stock standard. Otherwise, use appropriate correction factors to calculate analyte stock concentrations.

8.10.1.2.4. Commercially-prepared stock standards may be used at any concentration if they are certified by the manufacturer or by an independent source.

8.10.1.3. Store stock standard solutions in bottles with PTFE-lined screw-caps. They should be protected from light, and maintained at -10°C (or less if so recommended by the standard manufacturer).

8.10.1.4. Check stock standard solutions frequently for signs of degradation or evaporation, especially just prior to using them to prepare calibration standards.

8.10.1.5. Replace stock standard solutions after one year.

8.10.2. Calibration standards

8.10.2.1. Prepare calibration standards at a minimum of five different concentrations (e.g. a minimum of a five-point calibration curve). Each standard should contain each target compound which is intended to be detected/quantified by this method.

8.10.2.1.1. The calibration standards should correspond to the range of concentrations found in actual samples but should not exceed the range of the GC/MS system.

8.10.2.2. Load the calibration standards onto clean tubes using the GERSTEL ATIS system. Turn on nitrogen cylinder connected to the ATIS.

8.10.2.3. Turn the flow controller valve to "ON".

8.10.2.4. Flip the power switch to "High"(50 °C ~ 120 °C).

8.10.2.5. Check the thermometer to verify that the temperature reaches >10°C above the boiling point of the solvent used to prepare the standards. It may take a couple of hours to reach the desired temperature.

8.10.2.6. Loosen the white wheel on the left side of the unit, insert a sorbent tube (paying attention to the flow direction indicated on the tube), and tighten the white wheel.

8.10.2.7. Connect the Alltech digital flowmeter at the end of the tube to check the flow rate (~ 50 mL/min). Use flexible Tygon tubing, with a short piece of 6-mm ID PFE tubing as the connection between the Tygon tubing and sorbent tube.

8.10.2.8. Adjust the flow controller valve to ~ 50 mL/min

8.10.2.9. Use the microsyringe to inject standards into the ATIS.

8.10.2.9.1. Change the green septum every 25 injections to maintain a good seal

8.10.2.10. Do not inject more than 25 uL of the standard solution.

8.10.2.11. If the liquid standard has been prepared in a solvent which will pass through the sorbent while analytes are quantitatively retained, do not disconnect the tube from the injector until the solvent has been eliminated from the sorbent bed (approximately 5 min under the conditions specified).

8.10.2.11.1. In cases where the solvent can be purged from the tube while quantitatively retaining the analytes, make a 5-10 µL injection (Step 8.10.2.2), as greater accuracy is possible with larger volumes.

8.10.2.11.2. If the solvent cannot be purged from the tube, keep the injection volume in Step 8.10.2.2 as small as possible (0.5 - 1.0 µL), to minimize solvent interference in the GC analysis.

8.10.2.12. Loosen the white wheel and take the sorbent tube out. Iimmediately cap it and place it in an appropriate storage container.

8.10.2.13. Do not store tubes containing calibration standards more than 30 d prior to use.

8.10.3. Internal standards

8.10.3.1. Choose internal standards such that most of the analytes of interest in a chromatogram will have retention times of 0.80-1.20 relative to one (or more) of the internal standards.

8.10.3.2. Because 1,4-dichlorobenzene-d_4, naphthalene-d_8, and acenaphthene-d_{10} are each appropriate as internal standards with some phenols (but not others) according to Method 8270C, all three should be used as internal standards when running samples that are expected to contain multiple phenolic compounds and VFAs.

8.10.3.2.1. Other compounds that are used as surrogates in Method 8270C, and therefore may be of some use as internal standards under the present method, include phenol-d_6, 2-fluorophenol, 2,4,6-tribromophenol, nitrobenzene-d_5, 2-fluorobiphenyl, and/or *p*-terphenyl-d_{14}.

8.10.3.3. Dissolve 0.200 g of each compound with a small volume of methanol. Transfer to a 50-mL volumetric flask and dilute to volume with methanol.

8.10.3.3.1. As described in Section 8.10.1.2.2, ethyl acetate may be substituted for methanol if the particular compound(s) are insufficiently soluble in methanol.

8.10.3.3.2. The resulting solution contains each standard at a concentration of 4,000 ng/µL.

8.10.3.4. Following the procedures in Section 8.10.2, spike each sample tube which is to be analyzed with 10 µL of the internal standard solution, such that approximately 100 ng of each internal standard compound is introduced to the tube.

8.10.3.5. Area counts of the internal standard peaks should be between 50-200% of the areas present in the midpoints of the calibration curves for each target compound.

8.10.3.6. Store internal standard mixtures at -10ºC (or below) when not in use.

8.10.3.7. Prepare fresh internal standard mixtures once a year.

8.10.3.8. When using premixed certified solutions, store according to the manufacturer's documented holding time and storage temperature recommendations.

9. Procedures

9.1. Set up the GC/MS, and establish the operating conditions. Method development at PAAQL has yielded the following recommendations for setting the various parameters:

Mass range	34-265 amu
Scan time	5.84 s/scan
Initial temperature	35ºC, hold for 1 min
Temperature program	35-100ºC at 10ºC/min, 100-250°C at 25°C/min
Final temperature	250ºC, hold for 10 min
Injector	Cooled Injection System (CIS)*
Transfer line temperature	270ºC
Thermodeportion final temperature	250ºC
CIS final temperature	280ºC
MS interface temperature	280ºC
Carrier gas	Helium (22 cm/s)
Ion trap only	Set axial modulation, manifold temperature, and emission current to manufacturer's recommendations

*Cooled injection system is used as the inlet for the GC associated with TDS.

9.2. Initial tuning, initial calibration, and system performance check

9.2.1. Initial tuning and calibration

9.2.1.1. Use Perfluorotributylamine (PFTBA) as the tuning compound along with the 5975's built-in calibrant delivery system to perform Autotune (standard spectra tune) as initial tuning or after any maintenance.

9.2.1.2. Perform quick tune daily, at the beginning of each batch of samples (i.e. once per 24-h time period of operation).

9.2.1.3. Use the following as tuning acceptance criteria for the PFTBA standard:

9.2.1.3.1. The ratio of the ion at m/z 69 to that at m/z 70 must be 1±0.50%.

9.2.1.3.2. The ratio of the ion at m/z 219 to that at m/z 220 must be 5±1.25%.

9.2.1.3.3. The ratio of the ion at m/z 502 to that at m/z 503 must be 10±1.0%.

9.2.1.3.4. The peak width at half-height for the ions at m/z 69, 219, and 502 must be 0.5±0.2 amu.

- 9.2.1.3.5. The mass assignments for the ions at m/z 69, 219, and 502 must be correct to within 0.1 amu (e.g., 69.0±0.1 amu).
- 9.2.1.4. Alternatively, use other documented tuning criteria (e.g. manufacturer's instructions), provided that performance is not adversely affected.
- 9.2.1.5. Special Autotune can be performed to meet the tuning criteria of decafluorotriphenylphosphine (DFTPP) and 4-bromofluorobenzene (BFB) required by EPA for semivolatiles and volatiles.
- 9.2.1.6. Do not begin analyses until the tuning criteria are met.
- 9.2.2. System performance check
  - 9.2.2.1. Perform a system performance check daily to ensure that minimum average RFs are met before the calibration curve is used. For this SOP, the System Performance Check Compounds (SPCCs) are: chloromethane, 1, 1-dichloroethane, bromoform, chlorobezene, and 1,1,2,2-tetrachloroethane (volatitiles);N-nitroso-di-n-propylamine; hexachlorocyclopentadiene; 2,4-dinitrophenol; and 4-nitrophenol (semivolatiles).
  - 9.2.2.2. These SPCCs typically have very low RFs (0.1-0.2) and tend to decrease in response as the chromatographic system (or the standard material) begins to deteriorate. They are usually the first to show poor performance. Calculate RF for each of the four SPCCs; the minimum acceptable average RF is 0.050. This check must be met before sample analysis begins.
  - 9.2.2.3. If the minimum response factors are not met, evaluate the system and take corrective action before sample analysis begins. Possible problems include:
    - 9.2.2.3.1. Standard mixture degradation
    - 9.2.2.3.2. Injection port inlet contamination
    - 9.2.2.3.3. Contamination at the front end of the analytical column
    - 9.2.2.3.4. Reactive (i.e. non-inert) sites in the column and/or system
- 9.2.3. Perform the daily calibration check (Section 11.6) after the GC/MS system has met the tuning criteria for PFTBA, but before any actual samples are run.

9.3. Sample analysis

- 9.3.1. Remove the sampling tubes (including any backup tubes that were used in the sampling event), as well as all necessary blanks, from their storage container and allow the tubes to come to room temperature. Always wear clean gloves when handling tubes.
- 9.3.2. Spike each tube with internal standard. See Section 8.9.3.
- 9.3.3. Load the tubes into the thermal desorption unit.
  - 9.3.3.1. If using the TDS G desorption unit, the procedures are as follows:
    - 9.3.3.1.1. Free the receiving member by pushing the locking member to the left.
    - 9.3.3.1.2. Pull the receiving member out of the TDS oven.
    - 9.3.3.1.3. Pull the TDS tube last used out of the receiving member.
    - 9.3.3.1.4. Push a new TDS tube containing the sample onto the receiving member.
    - 9.3.3.1.5. Push the receiving member and the inserted TDS tube into the TDS oven as far as it will go.
    - 9.3.3.1.6. Lock the online TDS G by pushing the locking member to the right again.
  - 9.3.3.2. If using the TDS A autosampler, the procedures are as follows.
    - 9.3.3.2.1. Insert the TDS tube into the sample magazine, as in Fig. 1.

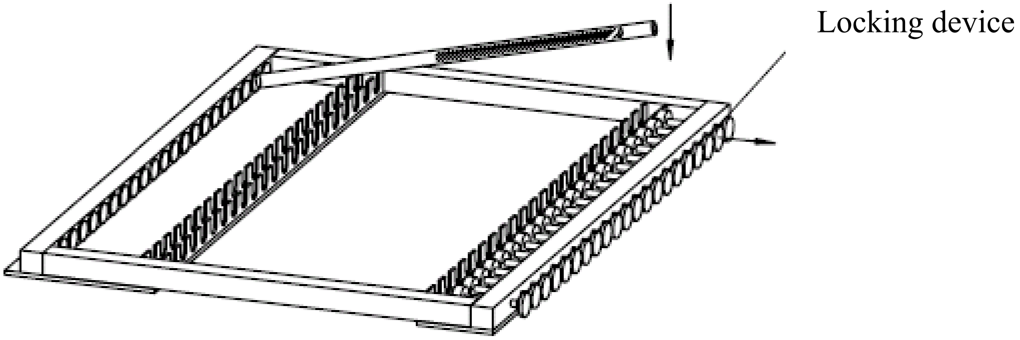

Figure 1. Inserting a sample tube into the tray of the TDS A autosampler.

- 9.3.3.2.2. Insert the left-hand side of the tube with the left hand into the left-side of the sample magazine.
- 9.3.3.2.3. Pull the appropriate locking device against spring pressure to the right with the right hand.
- 9.3.3.2.4. Introduce the tube completely with the left hand and release the locking device.

9.3.4. Check for TDS leaks
- 9.3.4.1. Perform leak checks after the system has been serviced, and after each new installation of the system.
- 9.3.4.2. The following symptoms indicate leaks in the system:
  - 9.3.4.2.1. After the TDS has been opened and closed, it takes longer than usual to build up the head pressure.
  - 9.3.4.2.2. The head pressure is not maintained during splitless transfer or at the end of the oven program.
  - 9.3.4.2.3. Sensitivity and reproducibility are reduced.
- 9.3.4.3. First, conduct a rapid check of system flows.
  - 9.3.4.3.1. Set the GC to Splitless mode.
  - 9.3.4.3.2. Total flow is the sum of column flow, septum purge flow and TDS purge flow.
  - 9.3.4.3.3. If total flow is significantly higher than the expected sum of the individual flows, there is either a leak or the flows are not set properly.
  - 9.3.4.3.4. If these flows are properly set and actual flow is higher than the set flow, there is probably a leak.
- 9.3.4.4. An electronic leak detector may subsequently be used to check all connections for leaks.
- 9.3.4.5. Halt the run if any leaks are detected in the TDS.

9.3.5. Primary desorption
- 9.3.5.1. Set the flow rate of UHP He gas to at least 20 mL/min, in the reverse direction to that of the air flow during sampling. Analytes are thus desorbed from the tube in “backflush” mode.

9.3.5.2. Heat the tube up to 325°C (use 250 °C)with a heating rate from 1°C/min to 60°C/min.
9.3.5.3. Set a transfer line temperature at least 20°C above the highest desorption temperature. Typically, the transfer line is held between 250°C ~ 350°C. (use 270 °C)
9.3.5.4. VOCs are transferred onto the GERSTEL Cooled Injection System (CIS), which functions as both a focusing trap and a GC inlet. Thermal desorption continues until all target species are transferred to the focusing trap (the liner of the inlet).

9.3.6. Secondary desorption
9.3.6.1. After the primary desorption step is complete, rapidly (e.g. a ramp of 40°C) heat the focusing trap to 325°C (use 280 °C), and apply a flow of at least 3 mL/min of dry UHP helium carrier gas.
9.3.6.2. Desorb analytes from the focusing trap in "backflush" mode, with the gas flow through the trap in the opposite direction from that used during the focusing step.
9.3.6.3. Choose the proper CIS inlet mode (solvent vent is strongly recommended) and set the right split ratio and split flow in the GC Chemstation.
9.3.6.4. The GC oven program starts when CIS program begins.

9.3.7. GC/MS analysis
9.3.7.1. Appropriate operating conditions for capillary GC columns used under this SOP are as follows:

Initial temperature	35ºC, hold for 1 min
Temperature program	35-100ºC at 10ºC/min
	100-250°C at 25°C/min
Final temperature:	220ºC, hold for 3 min
Carrier gas	Helium (22 cm/s)

9.3.7.2. Operate the GC/MS system to scan the atomic mass range from 34 to 265 amu.
9.3.7.3. Acquire at least ten scans per chromatographic peak.
9.3.7.4. Selected ion monitoring (SIM) is acceptable for applications requiring detection limits below the normal range of electron impact mass spectrometry. However, SIM may provide a less definitive compound identification, unless multiple ions are monitored for each analyte.
9.3.7.5. Acceptance criteria for samples are as follows:
9.3.7.5.1. If the retention time for any internal standard component changes by more than 20 s relative to the latest daily calibration check standard, inspect the GC/MS system for malfunctions and make corrections as required.
9.3.7.5.2. If the area response (Y) for the primary ion in any internal standard component changes by more than ±40% relative to the latest daily calibration check standard, inspect the GC/MS system for malfunctions and make corrections as required.
9.3.7.5.3. Mark any samples that fail these criteria as invalid data, as re-running of the same samples under this SOP is not possible.

9.3.8. Qualitative analysis (peak identification)

9.3.8.1. In keeping with EPA Method 8270C, base qualitative identification of compounds upon (a) retention time and (b) comparison of the sample mass spectrum (after any necessary background correction) with a reference mass spectrum. Conditions which must be met to identify compounds are as follows:

9.3.8.1.1. The relative retention time (RRT) of the sample component must be within ±0.06 RRT units of the RRT of the standard component.

9.3.8.1.2. The intensities of the characteristic ions of a compound must maximize in the same scan or within one scan of each other. For the purposes of this SOP, peak selection is done by a data system target compound search routine based on the presence of a target peak, containing ions specific for the target compound, at a compound-specific retention time.

9.3.8.1.3. The characteristic ions from the reference mass spectrum are defined as the three ions of greatest relative intensity, or any ions over 30% relative intensity, if less than three such ions occur in the reference spectrum.

9.3.8.2. The relative intensities of the characteristic ions in the spectrum of the sample component must agree to within 30% of the relative intensities of the same ions in the reference spectrum.

9.3.8.2.1. For example: If an ion has an abundance of 50% in the reference spectrum, the abundance of the same ion in a sample spectrum must be 20% -80%.

9.3.8.3. Structural isomers that produce very similar mass spectra should be identified as individual isomers only if they have sufficiently different GC retention times.

9.3.8.3.1. Sufficient GC resolution is achieved if the height of the valley between two isomer peaks is less than 25% of the sum of the two peak heights.

9.3.8.3.2. If this criterion is not met, structural isomers should be identified as isomeric pairs.

9.3.8.4. For samples containing components not associated with the calibration standards (e.g. unknown or unidentified components), a library search may be made for the purpose of tentative identification. Guidelines for tentative identification are as follows:

9.3.8.4.1. The molecular ion(s) and all major ions in the reference spectrum (ions > 10% of the most abundant ion) should also be present in the sample spectrum.

9.3.8.4.2. The relative intensities of the major ions should agree within ±20%. As an example, an ion with an abundance of 50% in the spectrum of the standard must have an abundance in the sample of between 30 and 70%.

9.3.8.4.3. Ions present in the sample spectrum but not in the reference spectrum should be reviewed to determine if they may be due to background contamination or the presence of coeluting compounds.

9.3.8.4.4. Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting peaks. Data system library reduction programs can sometimes create these discrepancies.

9.3.9. Quantitative analysis

9.3.9.1. Once a compound has been identified, base its quantitation upon the integrated abundance of the primary characteristic ion from the EICP.

9.3.9.2. Where applicable, estimate the concentration(s) of any non-target analyte(s) identified in the sample by using the formula given in Section 11.5.6.
9.3.9.2.1. Take the areas A_x and A_{is} from the total ion chromatograms, and assume the RF for the compound to be 1.
9.3.9.2.2. Use the nearest internal standard which is free of interference.
9.3.9.2.3. Report all concentrations derived in this way as estimates, and note which internal standard was used in the calculation for each analyte.
9.3.9.3. Structural isomers that produce very similar mass spectra should be quantitated as individual isomers if they have sufficiently different GC retention times.
9.3.9.3.1. Sufficient GC resolution is defined as the height of the valley between two isomer peaks being less than 25% of the sum of the two peak heights.
9.3.9.4. Quantitate structural isomers that do not meet this criterion for separation together as isomeric pairs.
9.3.9.5. Quantitative results (mass of analyte per tube) must be divided by sample volume (See SOP V1) to determine concentration in the original air sample.
9.4. Restoring the sorbent tubes
9.4.1. A proper thermodesorption step will leave the tubes ready for re-use.
9.4.2. Remove the tubes from the thermal desorber.
9.4.3. Using clean gloves, rewrap the tubes with aluminum foil, replace in the clean, airtight container, and re-store the tubes in a cool environment (≤ 4°C) until their next use.
9.4.4. See SOP V1 for information as to how long tubes may be stored without needing partial or full re-conditioning. Conditioning of tubes is done with the GERSTEL Model TC1 Tube Conditioner.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on laboratory data sheets, and within logbooks with permanent ink, or in electronic notes files.
10.4. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

11.1. Carrier gas
11.1.1. Inert, 99.999% or higher purity helium will be used as carrier gas.
11.1.2. All carrier gas lines will be either stainless steel or copper.
11.1.3. Install “big universal trap” scrubber (See Section 8.8.1) on the carrier gas lines supplying the analytical system. Replace these filters regularly, according to the manufacturer’s instructions (i.e. after every 13th He cylinder).
11.2. Reagent purity
11.2.1. Use only reagent-grade inorganic chemicals.

11.2.2. Unless otherwise indicated, ensure that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

11.2.3. If any other grade of reagent is to be used, it must be first ascertained that it is sufficiently pure to maintain the accuracy of the determination.

11.2.4. Use only pesticide-quality (or equivalent) solvents.

11.3. Tube labeling and identification must follow Section 10.1 of SOP V1.

11.4. Compatibility between sorbent tubes and desorption unit

11.4.1. The position and length of the sorbent bed must be such that no part of the sorbent bed extends outside that portion of the tube which is directly heated by the thermal desorption oven. Only use tubes that meet this criterion.

11.5. Five-point (full) calibration

11.5.1. Do a full calibration during initial instrument setup, whenever the analytical method parameters are substantially changed, or whenever significant maintenance is performed on the system. Significant maintenance includes:

11.5.1.1. Ion source cleaning or repair

11.5.1.2. Injection port cleaning (e.g. change septa, O-ring, liner, and/or gold-plated seal)

11.5.1.3. Column replacement

11.5.2. Do a full calibration whenever the system fails the daily single-point calibration check (Section 11.6) twice in the same day.

11.5.3. Calibrate the system at a minimum of five concentrations that span the monitoring range of interest. The lowest point on the calibration curve must be below the lowest concentration which meets the data quality objectives of the project, and should be close to the lower detection limit for the analyte in question. One point of the full calibration curve must correspond to the concentration in the daily single-point calibration check standard (Section 11.6).

11.5.4. Add internal standard with each point of the calibration curve. The volume and mass of internal standard added must be the same for all calibration samples, and must be the same mass and volume added for all samples.

11.5.5. Use the primary ions for each compound to quantitate all analytes in the calibration curve, unless interferences are present, in which case use a secondary ion.

11.5.6. Calculate relative response factors (RRFs) for each target compound in each of the calibration standards, relative to the internal standard component with the closest retention time, according to the following equation:

$$\mathrm{RRF} = \frac{A_s \times M_{is}}{A_{is} \times M_s}$$

Where:
A_s = Peak area (or height) of the analyte or surrogate
A_{is} = Peak area (or height) of the internal standard
M_s = Mass of the analyte or surrogate (ppbV)
M_{is} = Mass of the internal standard (ppbV

11.5.6.1. Calculate mean RRF (using each of the five concentrations in the standard curve), as well as the standard deviation and %RSD.

11.5.7. Calculate relative retention times (RRTs) for each target compound in each of the calibration standards, relative to the internal standard component with the closest retention time, according to the following equation:

$$RRT = \frac{RT_c}{RT_{is}}$$

Where:
RT_c = Retention time of the target compound
RT_{is} = Retention time of the internal standard

11.5.8. Calculate mean RRT (using each of the five concentrations in the standard curve), as well as the standard deviation and %RSD.

11.5.9. Calculate mean retention time (RT), using each of the five concentrations in the standard curve.

11.5.10. Tabulate the area response (Y) of the primary ion for each compound and the corresponding mass for each compound and internal standard.

11.5.11. Calculate the mean area response for each internal standard compound over the entire calibration range.

11.5.12. Technical Acceptance criteria for the initial calibration are as follows:

11.5.12.1. The calculated %RSD for the RRF for each compound in the calibration table must be less than 30%. There may be at most two exceptions with %RSDs up to 40%. No compounds may have an RRF %RSD greater than 40%.

11.5.12.2. The RRT for each target compound at each individual calibration level must be within 6% of the mean RRT for the compound.

11.5.12.3. For each internal standard component, the area response Y of each target compound's primary ion at each calibration level must be within 40% of the mean area response for that ion over the entire calibration range.

11.5.12.4. For each internal standard component, the retention time at each calibration level must be within 20 s of the mean retention time over the initial calibration range.

11.5.13. Initial calibration acceptance criteria must be met before analysis of actual field samples is initiated.

11.5.13.1. If the initial calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions.

11.5.14. Do not report quantitative results for target compound(s) not included in the calibration standard(s), unless they are estimated (and denoted as such) according to Section 9.3.10.2.

11.5.15. Keep a control chart (SOP Q1) of calibration curve results, so that they may be compared over time to assess possible detector drift or other biases/inaccuracies that may develop over time. If the average peak area per unit concentration of any given analyte drifts from its baseline value established at the beginning of the study by more than ±10%, troubleshoot the system to identify and rectify the problem.

11.6. Daily (single-point) calibration checks

11.6.1. Perform a check of the calibration curve once every 24 h – after the GC/MS system has met the tuning criteria for PFTBA, but before any actual samples are run.

11.6.2. Analyze the mid-level calibration standard (with internal standards added) for the calibration check.

11.6.3. Perform the following calculations:

11.6.3.1. Calculate a relative response factor (RRF) for each target compound using the equation in Section 10.5.6.

11.6.3.2. Calculate the percent difference (%D) in the RRF of the daily RRF compared to the mean RRF in the most recent full calibration. Calculate the %D for each target compound using the following equation:

$$\%D = \frac{\left(RRF_c - \overline{RRF_i}\right)}{\overline{RRF_i}} \times 100$$

Where:
RRF_c = RRF of the target compound in the daily calibration check run
$\overline{RRF_i}$ = Mean RRF of the target compound in the most recent full calibration

11.6.4. Acceptance criteria for daily calibration checks are as follows:

11.6.4.1. The %D for each target compound in a daily calibration sequence must be within ±30% in order to pass the calibration check and proceed with the analysis of samples and blanks.

11.6.4.2. A control chart showing %D values for each daily calibration check will be maintained. Values for %D which are steadily increasing over time (but still within the acceptable range) may be an indication that maintenance will be needed in the future.

11.6.5. If the daily calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective action(s).

11.6.5.1. Rerun the daily calibration check standard. If the %D criterion still cannot be met, more thorough corrective action may be needed.

11.6.5.1.1. In this case, rerun the full calibration (Section 11.5).

11.7. Conduct a calibration check standard approximately every tenth sample during an extended analytical sequence, as a check on system performance. (EPA Method TO-15)

11.7.1. For runs containing more than 15 samples, a calibration check standard may be inserted near the middle of the run, and evaluated as per Section 11.6.3. For runs longer than approximately 30 samples, conduct two calibration checks.

11.8. Check each analytical run for saturation. The level at which an individual compound will saturate the detection system is a function of the overall system sensitivity and the mass spectral characteristics of that compound. Denote any analyte(s) in a particular sample that are found to be saturated as “above the quantitation limit” (with the limit identified) in that sample.

11.9. Use secondary ion quantitation only when there are sample matrix interferences with the primary ion.

- 11.9.1. If secondary ion quantitation is performed, document the reasons for doing so.
- 11.10. Blanks
  - 11.10.1. Lab blanks must be identically prepared tubes, from the same batch, with similar histories and conditioned at the same time as tubes used for sample collection.
    - 11.10.1.1. Include at least two lab blanks per sampling event.
    - 11.10.1.2. Store lab blanks in the lab in clean controlled conditions prior to use.
    - 11.10.1.3. Analyze lab blanks at the same time as the samples (after the calibration check) - one at the beginning and one at the end of the sequence of runs.
    - 11.10.1.4. Add internal standard to labblanks in the same mass and volume added to samples.
    - 11.10.1.5. Acceptance criteria for laboratory blanks are as follows:
      - 11.10.1.5.1. The area response (Y) for the primary ion of each internal standard component in the blank must be within ±40% of the mean area response (Section 10.5.11) of the IS in the most recent valid full calibration.
      - 11.10.1.5.2. The retention time for each of the internal standard components must be within ±20 s of the MRT in the most recent valid full calibration.
      - 11.10.1.5.3. The blank should not contain any target analyte at a concentration greater than its quantitation level (three times the MDL, as defined in Section 10.11).
      - 11.10.1.5.4. The blank should also not contain any additional (non-target) compounds with retention times and mass-spectral features that would interfere with identification and measurement of a target analyte.
    - 11.10.1.6. If the blanks do not meet the technical acceptance criteria, investigate the source of the contamination and take (and document) appropriate corrective measures before proceeding with further sample analysis.
    - 11.10.1.7. Whenever a particularly concentrated sample is encountered (i.e., one outside the calibration range), run a blank tube immediately after the sample is completed, as a check against carryover effects.
  - 11.10.2. Field blanks are the same as lab blanks. However, field blanks are transported to and from the monitoring site, and are uncapped and immediately resealed at the monitoring site. They do not actually have air pumped through them.
    - 11.10.2.1. Take one field blank for every ten tubes included in a sampling event. No less than two field blanks may be included, however small the study.
    - 11.10.2.2. Distribute field blanks evenly throughout the run when the tubes are analyzed.
- 11.11. Method detection limits
  - 11.11.1. Determine the method detection limit for each compound on a particular GC/MS system by making seven replicate measurements of the compound of interest at a concentration near (within a factor of five) the expected detection limit. Calculate the standard deviation for the seven replicate concentrations, and multiply it by 3.14 (the Student's *t* value for 99% confidence for seven values).
- 11.12. System precision checks
  - 11.12.1. Test the precision of the analytical system using six calibration check standard tubes.
  - 11.12.2. Conduct system precision checks once every tenth batch of samples or once every three months, whichever happens first.

11.12.3. Conduct system precision checks whenever the analytical method is changed or modified.

11.12.4. Include the report produced from the most recent precision test with the report generated for each batch of samples.

11.13. Initial demonstration of analyst proficiency

11.13.1. Whenever new analysts are trained to conduct the analyses described in this SOP, they will be required to successfully complete all of the calibrations, performance checks, and verifications outlined in this SOP prior to generating actual data.

11.14. Modifications or changes to the system

11.14.1. If any changes are made to the system (e.g., the column is changed, a septum is changed), the following guidance (from Section 8.2 of USEPA Method 8000B) dictates whether or not recalibration of the system is necessary.

11.14.1.1. The following procedures will automatically require recalibration of the system:

- Changing, replacing, or reversing the column
- Cleaning the MS source
- Changing the electron multiplier, ion source chamber, or injector port

11.14.1.2. The following procedures will probably not require recalibration of the system, but must still be followed by a calibration check:

- Changing compressed gas cylinders and/or PTFE transfer lines
- Changing septa or split seals
- Changing syringes
- Changing moisture, hydrocarbon, or oxygen traps
- Changing column fittings, inlets, or filaments
- Cleaning the inlet port
- Breaking off or changing a guard column

12. References

12.1. Agilent MSD ChemStation Help. 2005. Overview of MSD Productivity ChemStation. Agilent Technologies, Inc. Palo Alto, CA.

12.2. ASTM D 6196-03. 2003. Standard Practice for Selection of Sorbents, Sampling, and Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air. ASTM International, West Conshohocken, PA US.

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ANALYZING AND QUANTITATING AMINES BY ION CHROMATOGRAPHY

Standard Operating Procedure (SOP) V5

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Standard Operating Procedure (SOP) V5

Prepared by

Bill W. Bogan, Frank M. Mitloehner (Univ. of California-Davis), and Hua Xu

Reviewed by

Albert J. Heber

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PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Amines are one class of volatile organic compound (VOC) known to be emitted from some livestock operations. For example, some highly odorous manure-related compounds (e.g. trimethylamine, putrescine) are amines.

1.1.1. A list of analytes which may be quantified with this method follows Section 9.4.1.

1.2. Ion chromatography provides a convenient method for identifying and quantitating amines collected from environmental samples (in this case, barn air). Amines are separated based on affinity towards a cation-exchange resin (which provides separation from ammonia and alkali cations), and quantitated based on conductivity (which avoids potential chromatographic interference from other, non-ionic organic compounds).

1.3. The method described in this SOP uses a column and mobile phase which are suited for analysis of linear and cyclic aliphatic amines.

1.3.1. The method is adapted from USEPA Conditional Test Method CTM-027, and from Dionex Corporation's Product Manuals for the IonPac® CS16 and CS17 cation exchange columns.

1.4. Suppressed conductivity detection is used, which allows detection of most compounds down to the level of approximately 10-100 μg/L in the solution.

1.4.1. This concentration is equivalent to amine concentration of 0.08-0.8 ng/L for 120-L sample. Thus, this method applies to samples containing greater than 0.1-1 ppb of any amine analyte.

1.5. This SOP applies to the Dionex Ion Chromatography System, consisting of the following:

1.5.1. Model AS40 autosampler
1.5.2. Model GP50 gradient pump
1.5.3. Model CD25 conductivity detector
1.5.4. Model LC20 column enclosure
1.5.5. IonPac® CS17 cation exchange column
1.5.6. IonPac® CG17 guard column
1.5.7. Cation Self-Regenerating Suppressor (CSRS® ULTRA)
1.5.8. Cation Trap Column (4-mm CTC-1)

2. Summary of Method

The chromatographic separation of individual amine components of the sample is achieved using a column packed with cation-exchange resin. The amines, which are protonated in the acidic trapping solution, display varying affinity for the resin, and are therefore separated as the mobile phase moves through the column. The column (IonPac CS17, Dionex, Sunnyvale, CA) is a hydrophilic, carboxylate-functionalized cation exchanger specifically designed for analysis of amines, and provides excellent efficiency (e.g., run time and sample throughput) and peak shape. The mobile phase consists of a mildly acidic (dilute methanesulfonic acid) solvent/water mix. Temperature control of the column is included to improve retention time reproducibility. Detection is based on conductivity increases monitored in the mobile phase as individual amines elute from the column.

3. Definitions of Terms and Acronyms

3.1.	CSRS	Cation self-regenerating suppressor
3.2.	CTC	Cation trap column
3.3.	HDPE	High-density polyethylene
3.4.	HPLC	High-performance liquid chromatography
3.5.	MΩ-cm	Megaohm-centimeter
3.6.	MSA	Methanesulfonic acid
3.7.	OSHA	Occupational Safety and Health Administration
3.8.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.9.	QAPP	Quality Assurance Project Plan
3.10.	Sample batch	All samples corresponding to a single sampling event at a site (which may take place over more than one day), provided the total does not exceed ten (10) samples. More than ten samples must be divided into multiple batches for the purpose of including blanks.
3.11.	SOP	Standard operating procedure
3.12.	VOC	Volatile organic compound(s)

4. Health and Safety

4.1. Treat each chemical compound as a potential health hazard. Several aliphatic amines are highly flammable, and can cause severe eye damage; they are also capable of being absorbed through the skin. Some aromatic amines (e.g. certain toluidine isomers) are suspected carcinogens.
  4.1.1. Reduce exposure to chemicals as much as possible.
    4.1.1.1. Wear protective clothing (gloves, lab coats, protective eyewear) when working with chemicals.
    4.1.1.2. Conduct all operations involving solvents in properly-ventilated fume hoods.
    4.1.1.3. Keep analytical balances and other work areas clean; deal with spills promptly.
4.2. Methanesulfonic acid (MSA) is corrosive, and is a strong irritant. Avoid breathing the vapors while working with MSA. Always wear gloves and goggles. Prepare and handle (e.g. degas) MSA-containing mobile phases in a fume hood.
4.3. The laboratory will maintain a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method.
4.4. A reference file of material safety data sheets (MSDS) will also be maintained at PAAQL, and will be made available to all personnel involved in these analyses.

5. Cautions

5.1. Filter and degas all eluents (mobile phases), and filter all samples (using the filters built in to the caps of the 5-mL autosampler vials).
  5.1.1. Do not use bottled HPLC-grade water, since most bottled water contains an unacceptable level of ionic impurities. Use only distilled, deionized water with a resistance of 18 megohms (MΩ)/cm^2.
  5.1.2. When purging or degassing mobile phases containing solvents, do not purge or degas excessively, since this can possibly cause a volatile solvent to be “boiled” off from

the solution, causing unintended shifts in the composition of the mobile phase. Bubble gently with helium for 5 min. Degas aqueous eluents every 24 h.

- 5.1.3. Degas and store all eluents in plastic eluent bottles which are pressurized with helium. Failure to do so can allow more-soluble atmospheric gases to enter the reservoir, and then dissolve into the mobile phase. Do not use nitrogen for this purpose, as nitrogen is soluble in solvent-containing eluents.

5.2. When handling clean autosampler vials and caps, always wear disposable, powder-free PVC gloves that have been rinsed with deionized water and air-dried. Powder from gloves can be a source of contamination if it gets into samples.

5.3. Failure to control the temperature of the column can result in variations in retention times, causing peaks to be misidentified.

5.4. The typical operating pressure for the CS17 column or CG17 guard column is 2,000 psi, and the maximum pressure for either component is 4,000 psi. Pressures in excess of this can irreparably damage the column. Out-of range pressure will cause the IC system to beep a warning. If a different column is used in place of the CS17, consult the applicable manual for pressure limits.

5.5. Always observe the following rules when switching from an eluent containing one solvent to one containing a different solvent, or when changing from a solvent-containing mobile phase to one free of solvents:

- 5.5.1. When changing from one solvent to another, equilibrate the column for approximately 10 min with an eluent containing only 5% of the first solvent. Exchange this eluent for an eluent with 5% of the new solvent type, and equilibrate again under these conditions (approximately 10 min). Next, run a 15-min gradient, starting at 5% of the new solvent and running to the highest percentage that will be used during the new analysis protocol.
- 5.5.2. When changing from a solvent-containing mobile phase to a solvent-free one, first equilibrate the column with between 1% and 5% of the solvent for approximately 5 min. Next, run a 10-min gradient from this solvent level to the new (0% solvent) aqueous eluent.
- 5.5.3. The column is shipped with eluent (most often 10 mM MSA) as the storage solution; this will be specified in a test chromatogram which is included with the column. Before using a new column, equilibrate it with the desired eluent for 30 to 60 min, or until the baseline become stable.
- 5.5.4. The column is considered to be properly equilibrated when two consecutive injections of a standard produce the same retention times.

5.6. If a particular column will not be used for one week or more, prepare it for long term storage by flushing for a few minutes with the eluent. Disconnect the column, and cap both ends securely, using the plugs supplied with the column.

5.7. Do not run suppressors (including the CSRS® ULTRA) at temperatures over 40°C. If the CSRS is being used, and the application requires a higher temperature, place the suppressor outside of the chromatographic jacket or oven.

5.8. When using solvent containing eluents (as in this procedure), the CSRS should be used in its AutoSuppression™ External Water Mode.

5.8.1. Do not use the AutoRegen™ Cation Regenerant Cartridge in conjunction with the CSRS when performing these analyses, as it cannot be used with eluents containing acetonitrile. See Section 3.10 of the CS17 Product Manual.

6. Interferences

6.1. Ammonia will be trapped (as ammonium ions) along with the amines in these samples. If the ammonium concentration in a particular sample is high, adjust chromatographic conditions (i.e. flow rate, gradient composition) to allow for resolution of the amine peaks from that of ammonia. The risk for overlap will be highest between ammonium and short-chain aliphatic amines (e.g. methylamine, ethylamine).

6.2. Group I and Group II cations (e.g. lithium, sodium, potassium, magnesium, and calcium), if present in the sample, will elute at retention times similar to some common amines. Use of an in-line filter in the amine sampling procedure (SOP V3) is intended to remove any dust-entrained cations that could otherwise enter the sample. Thus, they are not expected to occur in the sample, allowing them to be used as internal standards. As a check that the in-line filter actually accomplished this, analyze samples without the cation internal standard, and compare with the internal standard alone. This will guarantee that the cations which are being used as internal standards have not been trapped with the samples.

6.3. Baseline shift can occur due to increasing cationic contaminant levels in the eluent as the ionic concentration of the eluent is increased over the course of the gradient analysis. Install an IonPac® Cation Trap Column (CTC-1) between the gradient pump and the injection valve. Install the CTC-1 by following the procedures in Section 3.2 of the CS17 Product Manual ("Installing the Cation Trap Column for Eluent Step change or Gradient Operation").

6.4. Over time, columns can become contaminated with material that does not elute during routine analyses. Section 6 of the CS17 Product Manual (Pages 31-38) gives cleanup procedures for removing polyvalent cations (e.g transition metals), hydrophobic cations, and organic compounds from the column.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of all applicable instrumentation, in appropriate sample-handling procedures, and in methods of data processing and analysis, before performing these analyses. It is suggested that analysts run standards of the various analytes covered in this SOP, as well as the Group I and II cations used as internal standards, to familiarize themselves with the elution order and retention times of the various analytes and standard components.

7.2. Each analyst must read the entire instrument manual and this SOP before working with any of the instrumentation described herein.

7.3. Each individual analyst must demonstrate the ability to generate acceptable results with this method.

8. Equipment and Supplies

8.1. Ion Chromatography (IC) system (Dionex Corporation, Sunnyvale, CA), consisting of the following components:
  8.1.1. Model AS40 autosampler (Fig. 1)
  8.1.2. Model GP50 gradient pump
  8.1.3. Model CD25 conductivity detector
  8.1.4. Model LC20 column enclosure
  8.1.5. IonPac® CS17 cation exchange column and CG17 guard column (or equivalent)
  8.1.6. Cation Self-Regenerating Suppressor (CSRS® ULTRA)
  8.1.7. Cation Trap Column (4-mm CTC-1)
  8.1.8. Software: Chromeleon Chromatography Management Systems (v. 6.7 or equivalent)
8.2. Methanesulfonic Acid (MSA) (>99% pure)
8.3. Distilled deionized (DI) water (specific resistance ≥ 18.2 MΩ-cm, which has been filtered through a 0.2-micron filter. Do not use bottled, HPLC-grade water.
8.4. Solvents: Ultrahigh purity HPLC/spectrophotometric solvents (acetonitrile, methanol)
8.5. H_2SO_4 solution for preparing standards: Add 5 mL of concentrated (98%) H_2SO_4 to 1.0 L of distilled deionized water (MilliQ water from ABE Room 101).
  8.5.1. Dilute 30 mL of this solution to 100 mL with distilled DI water, and use this 0.03N solution as the solvent for the aqueous calibration standards (Section 8.10.2).
8.6. Analytical balance: Minimum of 160-g capacity, capable of measuring to 0.0001 g
8.7. Volumetric flasks, Class A: Appropriate sizes with ground-glass stoppers
8.8. Autosampler vials: 5 mL polyvials and filter caps (Dionex Corporation P/N 038141)
8.9. Standards
  8.9.1. Stock standard and secondary dilution solutions
    8.9.1.1. Use the highest-purity reagents that are commercially available to make standards. Prepare stock standard solutions by accurately weighing (on an analytical balance capable of weighing 0.0001 g) about 0.0100 g of pure material. Dissolve this in ultrahigh-purity (HPLC/spectrophotometric grade) methanol and dilute to volume in a 10-mL volumetric flask.
      8.9.1.1.1. When compound purity is assayed to be 99% or greater, use the weight without correction to calculate the concentration of the stock standard. Otherwise, use appropriate correction factors in calculating analyte stock concentrations.
      8.9.1.1.2. Commercially-prepared stock standards may be used at any concentration if they are certified by the manufacturer or by an independent source.
    8.9.1.2. Store stock standard solutions in amber glass bottles with PTFE-lined screw-caps. Protect from light, and maintain at -10°C (or as recommended by manufacturer).
    8.9.1.3. Check stock standard solutions frequently for signs of degradation or evaporation, especially just prior to using them to prepare calibration standards.
    8.9.1.4. Replace stock standard solutions after 6 mos.
    8.9.1.5. Using stock standard solutions, prepare secondary dilution standards, as needed, that contain the compounds of interest, either singly or mixed together. Prepare the secondary dilution standards at concentrations such that the aqueous calibration standards (below) will bracket the analytical system's working range.

8.9.1.5.1. Store secondary dilution standards with minimal headspace.

8.9.1.5.2. Check secondary dilution standards frequently for signs of degradation or evaporation, especially just prior to preparing aqueous calibration standards.

8.9.2. Aqueous calibration standards

8.9.2.1. Prepare a minimum of five calibration standards at five different concentrations (e.g. a minimum of a five-point calibration curve). Prepare standards in 0.03N H_2SO_4 solution(Section 8.5.1). Each standard should contain each target compound that is intended to be detected/quantified by this method.

8.9.2.1.1. The exact list of target compounds will likely be project-specific, and should be compiled before initiating a project. If new analytes of interest are identified during a project, add them to the calibration standards mixture.

8.9.2.1.2. Do not report quantitative results for any compound(s) not included in the calibration standard(s).

8.9.2.1.3. At least one of the calibration standards should correspond to a concentration at or below that necessary to meet the data quality objectives of the project.

8.9.2.1.4. The remaining standards should correspond to the range of concentrations found in actual samples but should not exceed the working range of the IC.

8.9.2.1.5. Note the following precautions when preparing aqueous calibration standards from secondary dilution standards:

8.9.2.1.5.1. Do not inject methanolic standards into water at levels higher than 20 µL standard into 100 mL of water.

8.9.2.1.5.2. Use a 25-µL Hamilton 702N microsyringe or equivalent. Variations in needle geometry in other syringes will adversely affect the ability to deliver reproducible volumes of standard. Never use pipettes to dilute or transfer samples or aqueous standards when diluting VOC standards.

8.9.2.1.5.3. Fill the sample syringe from the standard solution contained in the expanded area of the flask (do not use solution from the neck of the flask).

8.9.2.1.5.4. Rapidly inject the secondary dilution standard into the filled volumetric flask, and remove the needle as quickly as possible after injection.

8.9.2.1.5.5. Mix diluted standards by inverting the flask three times only.

8.9.2.1.6. Spike each 1-mL aliquot of calibration standard with 10 µL of the internal standard solution (Section 8.8.3) prior to analysis.

8.9.2.2. Prepare the calibration standard weekly and store at 4°C.

8.9.3. Internal standards

8.9.3.1. Choose internal standard(s) such that most of the analytes of interest in a chromatogram will have retention times between 80% and 120% of the retention time of one (or more) of the internal standards. Suitable internal standards for this method include Group I and II cations, specifically Li, Ca, K, and Mg. Verify that none of these are already present in the samples (Section 6.2.1).

8.9.3.2. Dissolve LiCl (0.6108 g), KCl (0.1907 g), $MgCl_2 \bullet 6H_2O$ (0.8365 g), and $CaCl_2 \bullet 2H_2O$ (0.3668 g) in a small volume of deionized, distilled water. Transfer to a 50-mL volumetric flask and dilute to volume.

8.9.3.3. Spike each 1-mL sample extract with 10 µL of the internal standard solution, resulting in a concentration of 20 ng/µL of each internal standard cation.

8.9.3.4. Area counts of the internal standard peaks should be between 50-200% of the areas of the target compounds which are present in the midpoints of the calibration curves for those compounds.
8.9.3.5. Store internal standard mixtures at 4ºC (refrigerated, not frozen) when not in use.
8.9.3.6. Prepare fresh internal standard mixtures once a year.
8.9.3.7. When using premixed certified solutions, store according to the manufacturer's documented holding time and storage temperature recommendations.

9. Procedures

9.1. Pre-analysis sample handling
9.1.1. Keep samples refrigerated (not frozen) at 4°C (39°F) prior to analysis.
9.1.2. Allow samples to slowly warm to lab temperature just before initiating analysis.
9.1.3. Always analyze samples within 14 days after their collection in the field.
9.2. Sample preparation
9.2.1. Bubbler solutions:
9.2.1.1. Pour the solutions from bubblers 1 and 2 from their HDPE sampling bottles into separate 50-mL volumetric flasks.
9.2.1.2. Rinse out the interior walls of the bottles several times with approximately 5-mL portions of deionized water; add each rinse to the applicable 50-mL volumetric flask until the total volume reaches the mark.
9.2.1.3. This process takes the 0.1N H_2SO_4 impinger solution to an approximately 0.03N H_2SO_4 solution, an acidity level which is compatible with the CS17 column.
9.2.1.3.1. If 0.1 N H_2SO_4 was used to rinse the impingers (Step 7.4.3 of SOP V3), then it will be necessary to dilute the sample by a factor of three (3) to five (5) to reach the 0.02–0.03 N level that is compatible with the column. Use a suitable dilution factor in subsequent calculations.
9.2.1.4. Add 500 µL of internal standard solution to the diluted samples in 50-mL volumetric flasks.
9.2.1.5. Fill autosampler vials and use insertion tool to push the cap into the vial (Fig. 2); then use the other end of insertion tool to level off the caps. Fill vials to the shoulder or below. Do not fill to the top. Cap all vials tightly.
9.2.1.6. Load the vials into the AS40 Autosampler tray. Load the tray into the autosampler, and close the compartment door.
9.2.1.7. Turn the autosampler power on press “run”.
9.3. . Sample analysis
9.3.1. Ion chromatography conditions
9.3.1.1. Proper system configuration (flow rates, sample injection volumes, configuration of pumps, etc.) is given in Section 2 (Pages 7-8) and Section 4.1 of the CS17 Manual. Several parameters will vary, depending on whether a 2-mm diameter column (cation capacity = 325 µeq) or a 4-mm column (1300 µeq) is used.
9.3.1.2. Suitable gradient profiles for analysis of amines are given in Section 5 of the CS17 Product Manual. In general, this SOP uses a mobile phase consisting of 3-6 mM MSA, at a flow rate of 1.0-1.5 mL/min.

- 9.3.1.3. Operating conditions may need to be adjusted to allow for resolution of the amine peaks from those of the various cations in the internal standard.
  - 9.3.1.3.1. The final gradient program must achieve separation of all analytes and internal standard components in the highest-concentration calibration standard such that the inetrsection between any two adjacent peaks (the "valley" on the chromatographic profile is no more than 25% of the mean height of the two peaks themselves. Resolution all the way to baseline is not required.
- 9.3.1.4. Program the GP50 Gradient Pump to deliver the above gradient profile. See Section 3 of the GP50 Operator's Manual for further detail.
- 9.3.1.5. Make sure that the CD25 Conductivity Detector is operating properly, and is programmed for the correct method. See Section 3 of the CD25 Operator's Manual for further detail.

9.3.2. Inclusion of standards in analytical runs

- 9.3.2.1. Bracket each sample batch with a set of the five standards for the standard curve, run in duplicate. Arrange the standards in each set from low to high concentration (Section 11.3.3), and include a solvent blank after each highest-concentration standard (Section 11.3.4).
- 9.3.2.2. Use a quadratic regression to generate the standard curve.
  - 9.3.2.2.1. In certain cases (those where all concentrations are in the range of 10-100 ppb), linear regression can also be used for some amines.
  - 9.3.2.2.2. Do not include the origin for the purposes of generating the standard curve.

9.3.3. Flush the CTC-1 at the end of each day of operation to remove any impurities that may have accumulated on it.

- 9.3.3.1. At the end of the day, disconnect the CTC outlet, and connect a waste line to it.
- 9.3.3.2. Using a 10x concentration of the strongest eluent required in the sample analysis, run 30 mL through the CTC at a flow rate of 2 mL/min.
- 9.3.3.3. At the beginning of the next analysis day, flush the CTC with 30 mL of a 1x solution of the strongest eluent used in the gradient program.
- 9.3.3.4. Reconnect the CTC to the eluent line.

9.3.4. Calculations

- 9.3.4.1. Export or cut and paste the data from the IC quantitation to a Microsoft Excel spreadsheet reserved for amine concentration calculations.
- 9.3.4.2. Determine total volume of air sampled by multiplying average flow rate of the sampling pump (Section 8.3.8 of SOP V3), which is recorded in the electronic field notes, by the total sampling time. Average flow rate of the pump is the average value between the beginning and ending flow rates, provided that the two did not differ by more than 10%.
  - 9.3.4.2.1. If the difference between the initial and final flow rates is greater than 10%, invalidate the sample.
- 9.3.4.3. Correct this sample volume to standard conditions (20 °C, 760 mm Hg) using the following equation. Express Vm(std) in L (One m^3 = 1000 L).

$$V_{m(std)} = V_m\, Y \left(\frac{T_{std}}{T_m}\right) \left[\frac{P_{bar} + \frac{\Delta H}{13.6}}{P_{std}}\right]$$

Where:

$V_{m(std)}$ = Volume of gas sample, corrected to standard conditions
V_m = Volume of gas sample
T_{std} = Standard absolute temperature, 293 K
T_m = Absolute average temperature during sampling, K
P_{bar} = Barometric pressure at the sampling site, mm Hg
P_{std} = Standard absolute pressure, 760 mm Hg
ΔH = Average pressure differential across the orifice meter, mm H_2O
13.6 = Specific gravity of mercury

9.3.4.4. Determine the concentration of each amine in the diluted impinger solution by application of the ion chromatography (IC) calibration equation. Express this in milligrams of each amine compound per liter of solution.

9.3.4.5. Calculate the volume of each individual amine analyte present in the sample:

$$V_a = \frac{(N)(0.1)(24.04)(0.001)}{(FW_a)}$$

Where:

V_a = Volume of individual amine gas in the sample of gas from the source
N = Mean amine concentration (mg/L) between the two impinger solutions ((Impinger 1 Conc. + Impinger 2 Conc.)/2)
0.1 = Conversion factor, assuming sample in each of the two impingers was diluted to 50 mL (0.05 L)
24.04 = Liters of ideal gas per mole of substance
0.001 = Factor to convert mg/L to g/L
FW_a = Formula weight of amine analyte (g/mole). Formula weights of various possible target analytes for this SOP include those listed in Table 1.

9.3.4.4. 9.3.4.6. Calculate the ppmV (C_a) of each amine analyte present in the gas sample:

$$C_a = \frac{V_a, L}{V_{m(std)}, L} \text{ x } 10^6$$

9.4. Troubleshooting

9.4.1. Section 6 of the CS17 Product Manual provides a troubleshooting section for issues relating to contamination, elevated back pressure and/or background conductivity, background noise and/or unstable baselines, low retention times, poor peak shape and/or resolution, and spurious peaks. If any of these problems are encountered, consult Section 6 of the manual.

Table 1. Target compounds analyzed using this method.

Analyte	Formula weight, g/mol
Hydrazine (N_2H_4)	32.00
2-Butylamine	73.14
n-Buytlamine	73.14
t-Butylamine	73.14
Diethylamine	73.14
Dimethylamine	45.08
Ethylamine	45.08
Ethylene diamine	60.10
Isoamylamine (3-methylbutylamine)	87.17
Isobutylamine (2-methylpropylamine)	73.10
Isopropylamine	59.11
Methylamine	31.06
1-Pentanamine (amylamine)	87.15
Propylamine	59.11
Trimethylamine	59.11
Triethylamine	101.19
Putrescine (1,4-diaminobutane)	88.15
Aminopyridine	94.12
Methylpyrazine	94.12
Dimethylpyrazine	108.14
Trimethylpyrazine	122.16
Tetramethylpyrazine	136.18

9.4.1.1. High system pressure can be due to blockages in column bed supports, or other hardware components. Isolate the blockage and clean or replace the part.

9.4.1.2. High background readings and/or high “noise” levels in the background can be due to a malfunctioning or contaminated CSRS, an air bubble trapped in the CSRS, contaminants in the mobile phase, contaminants in the column, or a defective proportioning valve. Check each of these possibilities, and address with guidance from the manual. If air bubbles are found, ensure that the eluent is being properly degassed, and that the reservoir is remaining under positive pressure with helium

9.4.1.3. Poor resolution can be due to column overloading, excessively low sample pH, contaminants in the system and/or column, or a damaged column. Dilute sample, check sample pH against the appropriate range for the CS17, or replace the column and/or its bed supports, as needed to isolate and fix the problem.

9.4.1.4. Poor quantitation of divalent cations (the internal standard) is most likely due to contamination in the sample loop, CSRS, or detector cell. Clean or replace these components as necessary.

9.4.2. Troubleshooting for the CD25 Conductivity Detector is addressed in Section 4 of its Operator’s Manual.

9.4.2.1. If the detector shows no response, check the following:
  9.4.2.1.1. Detector cell may be turned off.
  9.4.2.1.2. Detector may not be receiving flow (pump turned off or not working).
  9.4.2.1.3. Selected output range may be too high or too low, or no output range may be selected.
9.4.2.2. If the detector response is present but very low, check the following:
  9.4.2.2.1. Selected output range is too high.
  9.4.2.2.2. Sample may be too dilute.
  9.4.2.2.3. Detector cell may require calibration.
9.4.2.3. The following can cause unstable or noisy baselines:
  9.4.2.3.1. Leaks in the system. Check all connections for possible leaks.
  9.4.2.3.2. Rapid or significant fluctuations in temperature. Check the room housing the system for temperature variations.
  9.4.2.3.3. Pump may be out of prime. Re-prime as necessary.
  9.4.2.3.4. Air trapped in the detector cell

9.4.3. Troubleshooting for the GP50 Gradient Pump is addressed in Section 4 of its Operator’s Manual.
  9.4.3.1. If operating pressure fluctuates, re-prime the pump, check that sufficient mobile phase is available, and that the mobile phase is fully degassed. Check for blockages to inlet filters and lines, and check for dirty or defective piston seals and check valves; clean or replace as necessary.
  9.4.3.2. If pump will not stay on, check electrical connections. Verify that pressure limits (high or low) have not been exceeded. If high pressure limits have been exceeded, See Section 9.4.1.1 above.
  9.4.3.3. Leaks most commonly occur at the piston seal, proportioning valve, priming valve, and pressure transducer.

9.4.4. If either the blanks (Section 11.4), the quality assurance audits (Section 11.6), or the quality control check (Section 11.7) fail to meet their acceptance criteria, check the IC system first (as above) to make sure every parameter is correct, then do the calibration again. If the problem cannot be located and solved using the above information, technical support from the company may be needed.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.
10.2. Manage all data according to SOP B5.
10.3. Document all data and information on field data sheets, and within site logbooks with permanent ink, or in electronic field notes.
10.4. Overstrike all errors in writing with a single line. Initial and date all such corrections.

11. Quality Control and Quality Assurance

- 11.1. Reagent purity
  - 11.1.1. Use reagent-grade chemicals. Unless otherwise indicated, all reagents will conform to the specifications, if any, of the Committee on Analytical Reagents of the American Chemical Society. If any other grade of reagent is to be used, ascertain first ascertained that it is of sufficiently high purity to be used without affecting the accuracy of the determination.
  - 11.1.2. Use only ultrahigh purity, HPLC/spectrophotometric grade or equivalent solvents, and store these away from other solvents.
- 11.2. Cleaning and processing of glassware
  - 11.2.1. Rinse glassware as soon as possible after use with the last solvent used in it.
  - 11.2.2. Wash in hot water with detergent, rinse with tap water and distilled water. Drain dry.
  - 11.2.3. Heat at 400°C in a muffle furnace for 15-30 min.
    - 11.2.3.1. Solvent rinses with acetone and pesticide quality hexane may be substituted for the muffle furnace heating.
    - 11.2.3.2. Volumetric glassware should not be heated in a muffle furnace.
  - 11.2.4. When cool, glassware should be sealed and stored (inverted or capped with aluminum foil) in a clean (i.e. dust-free) environment.
- 11.3. Calibration
  - 11.3.1. Prepare a calibration curve each analysis day using a minimum of five standards that bracket the expected range of sample concentrations. One of these five should be at or below the analyte concentration which corresponds to the minimum detection limit of the project, as stated in the QAPP.
  - 11.3.2. Prepare calibration standards in filtered, degassed 0.03N H_2SO_4, the same concentration of acid as in the diluted samples.
  - 11.3.3. Analyze the calibration standards from lowest concentration to highest concentration.
  - 11.3.4. Verify that the system is clean (i.e. that there is no carryover) by analyzing a solvent blank after the highest-concentration calibration standard.
  - 11.3.5. Base calibration curves on peak area, rather than peak height.
  - 11.3.6. To be acceptable, the R^2 value for the calibration curve must be ≥ 0.98.
  - 11.3.7. Keep a control chart (SOP Q1) of calibration curve results, so that they may be compared over time to assess possible detector drift or other biases/inaccuracies that may manifest themselves over time. If the average peak area per unit concentration of any given analyte drifts from its baseline value (that at the beginning of the study) by more than ±10%, troubleshoot the system (Section 9.4) to identify and rectify the problem.
- 11.4. Blanks
  - 11.4.1. A minimum of one method blank and one trip blank (SOP V3) will be included with each batch of samples, and must be processed and analyzed along with those samples.
  - 11.4.2. To be acceptable, no target analyte may be present above its detection level in either the field or trip blank.
  - 11.4.3. Analyze column blank(s) whenever the analysis of a method blank indicates that cross-contamination may be occurring.

11.5. Reproducibility

11.5.1. Run a minimum of 20% of the samples in duplicate to assess reproducibility. Report results for these samples as mean concentrations of the duplicate analyses, with standard deviation. If the standard deviation between duplicate analyses exceeds 10%, prepare and re-analyze two new vials of the same sample with the next run.

11.6. NIST-traceable aqueous standards containing known amounts of amine analytes are available from various sources. For example, 1000-ppm standards of dimethylamine and trimethylamine are available from Alltech Associates, Deerfield, IL. Analyze these standards at the beginning of the study, and then use them for quality assurance audits of the analytical process, which are to be conducted quarterly at minimum.

11.6.1. If the analytical results are not within ±2% of the known concentration, check operating parameters (Section 9.3.1), troubleshoot the IC system (Section 9.4) and repeat the analysis. If necessary, recheck all calibration standards against the control chart (Section 11.3.7). Contact manufacturer technical support if the problem cannot be identified.

11.7. Conduct quality control checks by analyzing a solution that contains at least two of the amine analytes, at concentration(s) which are in the range of the calibration standards, but that has been prepared independently using different source(s) of amines salt than those used to prepare the calibration standards.

11.7.1. Perform this check monthly.

11.7.2. Perform this check whenever a new set of calibration standards is prepared.

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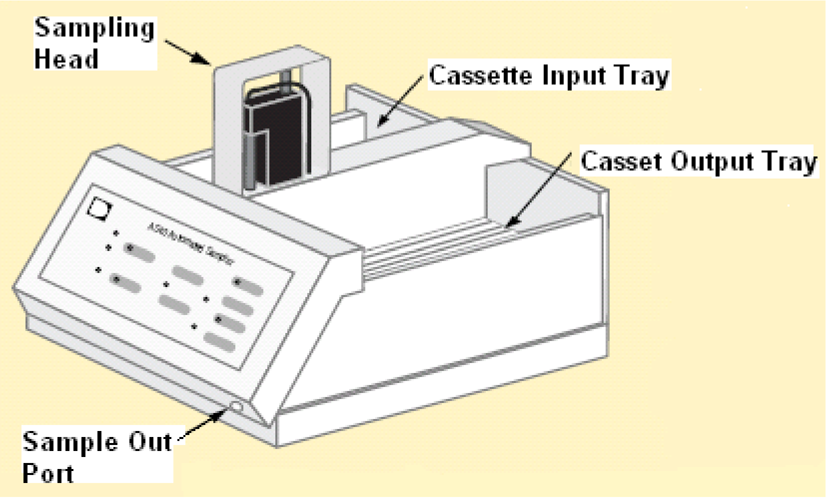

Figure1. Diagram of the Dionex AS 40 Autosampler

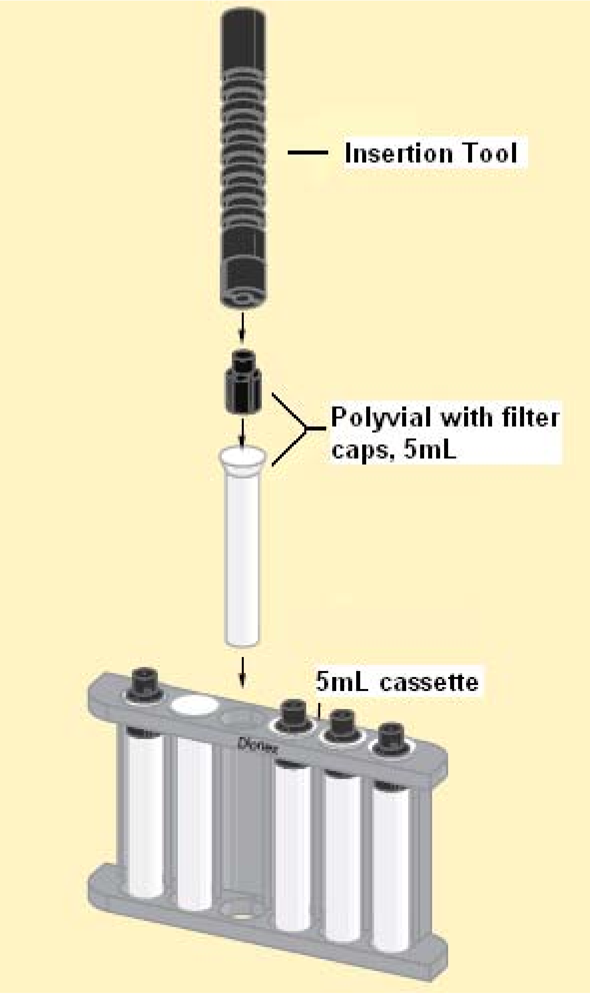

Figure 2. Autosampler vials, cassette and insertion tool used for inserting the filter caps.

GC/MS ANALYSIS OF PHENOLS AND VOLATILE FATTY ACIDS (VFAs)

COLLECTED IN SAMPLING CANISTERS

Standard Operating Procedure (SOP) V6

GC/MS ANALYSIS OF PHENOLS AND VOLATILE FATTY ACIDS (VFAs) COLLECTED IN SAMPLING CANISTERS

Standard Operating Procedure (SOP) V6

Prepared by

Bill W. Bogan and Hua Xu

Reviewed by

Albert J. Heber

Effective Date: November 6, 2006

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. This SOP describes a gas chromatography/mass spectrometry (GC/MS)-based method for detecting and quantitating volatile organic compounds (VOCs) in ambient air at livestock facilities.

1.1.1. The specific classes of VOC covered under this SOP are phenols and volatile fatty acids (VFAs), including the specific analytes listed in Table 1 below.

Table 1. Target analytes.

VFAs	Phenols
Acetic acid	Phenol
Propioic acid	p-cresol
Butyric acid	o-cresol
Isobutyric acid	m-cresol
Valeric acid	p-ethylphenol
Isovaleric acid	m-ethylphenol
Hexanoic acid	o-ethylphenol
Iso-caproic acid	Phenol
2-methylpentaoic acid	p-cresol
Heptanoic acid	o-cresol
Octanoic acid	m-cresol
Nonanoic acid	
Decanoic acid	
Undecanoic acid	
Dodecanoic acid	
Tridecanoic acid	
Tetradecanoic acid	
Benzoic acid	
Phenyl acetic acid	
3-phenylpropanoic acid	

1.2. This method analyzes VOCs collected using sampling canisters (SOP V2).

1.3. The minimum detection limit is approximately 0.5 parts per billion (ppbv) concentration in the air stream in question.

1.3.1. The detection limit will be somewhat dependent upon the degree of VOC enrichment achieved by concentrating the sample. It may be necessary to concentrate up to one liter of sample per injection to reach this detection limit for some analytes.

1.4. The methodology described in this SOP is derived from the following sources:

1.4.1. USEPA Method TO-14A – “Determination of Volatile Organic Compounds (VOCs) in Ambient Air Using Specially Prepared Canisters with Subsequent Analysis by Gas Chromatography”

1.4.2. USEPA Method TO-15 – “Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS)”

1.4.3. USEPA Method 8260B – "Volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)"
1.4.4. USEPA Method 8270C – "Semivolatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS)"
1.4.5. California EPA Air Resources Board SOP MLD 059 – "Determination of Oxygenated Hydrocarbons (OHCs) in Ambient Air by Capillary Column Gas Chromatography/Mass Spectrometry".

2. Summary of Method

Sampling canisters are used to collect VOC analytes according to SOP V2. Canisters are leak-checked after arrival in the laboratory, and are pressurized (if necessary) with humidified ultra-high-purity nitrogen. An aliquot of sample (up to 1,000 mL) is withdrawn from the canister, and introduced into a cryogenic concentrator. Water content of the sample can be reduced at this point, if necessary, by dry purging the concentrator with helium, while retaining target compounds. The analytes are thermally desorbed from the concentrator into a cryofocusing unit, which is coupled with a gas chromatograph (GC) inlet. Analytes are refocused on the trap of the cryofocusing unit, and concentrated to a very small volume. Rapid desorption of the trap follows, with transferring of the sample into the GC (Agilent Model 6890), which separates individual analytes by using a suitable GC column. Compound identification is accomplished by comparing their GC retention times and mass spectra (determined with an Agilent MSD 5975 Mass Spectrometer) with those of authentic standards. Quantitation of each compound is done by comparing the response (preferably peak area of its primary characteristic ion, but peak height may also be used) with those in a five-point calibration curve (the midpoint of which is verified by a daily calibration check).

3. Definitions

3.1. **Thermal Desorption:** The use of heat and a flow of inert (carrier) gas to extract volatiles from a solid matrix directly into the carrier gas and transfer them to a downstream system element. No solvent is required.

3.2. **Focusing Tube (Focusing Trap):** Narrow (typically < 3 mm I.D.) tube containing a small bed of sorbent, which is maintained near or below ambient temperature and used to refocus and concentrate analytes too dilute to be analyzed. Once all the VOCs have been transferred from the sorbent tube to the focusing tube, the focusing tube is heated very rapidly to transfer the analytes into the capillary GC analytical column in a narrow band of vapor (equivalent to a small injection volume), which is compatible with high resolution capillary gas chromatography.

3.3. **Cryofocusing:** Use of coolant (e.g., liquid nitrogen, liquid argon, or liquid CO2) to lower the temperature of the focusing trap and promote more rapid and complete sorption of analytes on the trap.

3.4. **Dynamic Calibration:** Calibration of an analytical system using calibration gas standard concentrations in a form identical or very similar to the samples to be analyzed and by introducing such standards into the inlet of the sampling or analytical system from a manifold through which the gas standards are flowing.

3.5. **Dynamic Dilution:** A means of preparing calibration mixtures in which standard gas(es) from pressurized cylinders are continuously blended with humidified zero air in a manifold so that a flowing stream of calibration mixture is available at the inlet of the analytical system.

3.6. **Relative Retention Time (RRT):** The ratio of the retention time of an individual analyte over the retention time of the internal standard with which the analyte is being compared for purposes of identification. RRT is a unitless quantity, as the numerator and denominator time units cancel out. For identification of the analyte peak to be valid, RRT of the sample component is within ±0.06 RRT units of RRT of the standard component (EPA Method 8260B).

3.7. **Response Factor (RF):** Instrument sensitivity towards a particular compound. The relationship between instrument output (e.g. peak height or integrated area) and analyte concentration.

3.8. **Relative Response Factor (RRF):** The comparison of the Response Factor of an analyte (i.e. a calibration standard, target compound, or surrogate) to that of an internal standard.

3.9. **MS-SCAN:** Mode of operation of a GC/MS in which all mass ions over a given mass range are swept over a given period of time.

3.10. **MS-SIM:** Mode of operation of a GC/MS in which only a single mass ion (or a selected number of discrete mass ions) are monitored.

3.11. **Total Ion Chromatogram (TIC):** Chromatogram produced from a mass spectrometer detector operating in full scan (MS-SCAN) mode.

3.12. **Extracted Ion Current Profile (EICP):** A plot showing the abundance of an ion of a particular mass, plotted as a function of retention time or scan number.

3.13. **Primary Characteristic Ion:** The particular ion, defined by USEPA or other methods, which provides the best results in terms of quantitating a particular compound.

3.14. **Target Compound:** A compound designated by the Statement of Work for analysis (qualitative or quantitative)

3.15. **Tuning Standard:** A standard used to (a) verify that the MS system is operating properly and (b) guard against reactive sites in the system (especially the injection ports, lines, and the first segments of the column) that might cause chemical breakdown or degradation of the sample

3.16. **Method Blank:** A blank sample (i.e. from a cylinder of zero air) that is treated exactly as a sample, and is processed simultaneously with other samples in the analysis batch through all steps of the analytical procedure. This is done to determine if method analytes or other potential interferences are present in the lab environment, reagents, or apparatus, and/or to check for sample carryover.

3.17. **Calibration Check Compounds (CCC):** A group of compounds used as a standard to evaluate the calibration from the standpoint of system integrity. Highly variable results with the CCCs may indicate system leaks or reactive sites on the column.

3.18. **System Performance Check Compounds (SPCC):** SPCCs are compounds that are known to have very low RFs (0.1-0.2), and that tend to decrease rapidly in response as the chromatographic system (or the standard material) begins to deteriorate. They are usually the first to show poor performance, and are therefore used to ensure that the system is performing adequately.

3.19. **Replicate Precision:** The precision determined from two canisters filled from the same air mass over the same time period. It is the absolute value of the difference between the analyses of the two canisters, divided by their average value, and expressed as a percentage.

3.20. **Duplicate Precision:** The precision determined from the analysis of two samples taken from the same canister. It is the absolute value of the difference between the analyses of the two samples, divided by their average value, and expressed as a percentage.

4. Health and Safety

4.1. Follow appropriate safety measures when working with pressurized gas cylinders. See SOP G2 for more detail.

4.2. Each chemical compound should be treated as a potential health hazard, and exposure to these chemicals will be reduced to the lowest possible level.

4.2.1. Wear protective clothing (gloves, lab coats, protective eyewear) when working with chemicals.

4.2.2. Conduct all operations involving solvents in properly-ventilated chemical fume hoods.

4.2.3. Keep analytical balances and other work areas clean; deal with spills promptly.

4.3. Maintain a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method.

4.4. Also maintain a reference file of material safety data sheets (MSDSs), which will be made available to all personnel involved in these analyses.

5. Cautions

5.1. Contact between the capillary column and GC oven wall affects chromatographic performance and column life. Do not allow column to touch the oven walls.

5.2. Carrier gas should be scrubbed to remove traces of oxygen and scrubbers should be changed regularly. If the Agilent "big universal trap" (Section 8.9.1) is used to purify helium, it should be changed after every 13th helium cylinder.

5.3. The use of a guard column between the injection port and the analytical column may help prolong analytical column performance. Use guard columns, either as part of a pre-fabricated column or separate (Section 8.2).

5.4. The period between sampling and analysis should never exceed 30 d

6. Interferences

6.1. Several loss mechanisms exist for analytes collected into sampling canisters.

6.1.1. Losses due to physical adsorption occur as equilibrium is reached between the condensed and gas phases of an analyte. These are generally considered short-term losses, (i.e., losses occurring over minutes to hours). These may be more significant with low-humidity samples.

6.1.2. Conversely, if water condenses in the canister, analytes can dissolve in this water, reducing recovery. This can be particularly significant if high-humidity samples are pressurized during dilution.

6.1.3. Losses due to chemical reactions of the VOC analytes with co-collected ozone or other reactive, unstable gas-phase species also account for some short-term losses.

6.1.4. Chemical reactions between VOCs and other, more stable substances inside the canister are generally assumed to cause the gradual decrease of concentration over time (i.e., long-term losses over days to weeks).

6.1.5. Loss mechanisms based on aqueous hydrolysis also exist.

6.1.6. Biodegradation of analytes can also occur over time.

6.1.7. Under conditions of normal usage for sampling ambient air, most VOCs can be recovered from canisters near their original concentrations after storage times of up to 30 d (Method TO-15).

6.2. Impurities in the canister pressurizing gas, calibration dilution gas (if applicable) and carrier gas, organic compounds out-gassing from the system components ahead of the trap, and solvent vapors in the laboratory can all result in contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running humidified zero air blanks.

6.2.1. Never use non-chromatographic grade stainless steel tubing, non-PTFE thread sealants, or flow controllers with Buna-N rubber components.

6.3. Use of other than inert materials (deactivated fused silica, glass lined tubing, glass, quartz and PTFE) in the sample flow path can result in degradation of some analytes.

6.4. Very volatile compounds can display peak broadening and co-elution with other species if the compounds are not delivered to the GC column in a small volume of carrier gas. Cryofocusing of the sample mitigates this problem.

6.5. Contamination by carryover can occur whenever high-concentration and low-concentration samples are sequentially analyzed. Whenever an unusually concentrated sample is encountered, follow with a suitable blank to check for cross-contamination.

6.6. When sample components are not resolved chromatographically, the result will be a mass spectrum containing ions contributed by more than one analyte. When gas chromatographic peaks obviously represent more than one sample component (i.e., a broadened peak with shoulder(s), or a valley between two or more maxima), appropriate selection of analyte spectra and background spectra is important.

6.7. When analytes coelute (i.e., only one chromatographic peak is apparent), the criteria for identification may be met, but each analyte spectrum will contain extraneous ions contributed by the coeluting compound. In these cases, examination of extracted ion current profiles of appropriate ions can aid in the selection of spectra and in qualitative identification of compounds.

6.8. Compounds that are too labile or reactive for conventional GC analysis are not suitable for this method.

6.9. Several phenolic compounds outside the scope of this SOP (e.g. 4-nitrophenol, 2,4-dinitrophenol, 4,6-dinitro-2-methylphenol, and 4-chloro-3-methylphenol) can be subject to erratic chromatographic behavior when analyzed by this method; this is especially true if the GC system is contaminated with high-boiling materials (high-molecular-weight, nonvolatile compounds).

6.9.1. It is therefore possible that phenols relevant to this SOP may also display this behavior; care should thus be taken to keep the system free of contamination of this nature. Use phenol-specific System Performance Check Compounds (SPCCs, Section 9.3.3) to guard against this.

7. Personnel Qualifications

7.1. Personnel should be trained in the use of all applicable instrumentation, and in appropriate sample-handling procedures, before performing the activities in this SOP.
7.2. Each analyst must read and understand the applicable equipment manuals and this SOP before performing these activities.
7.3. Each individual analyst must demonstrate the ability to generate acceptable results with this method (Section 11.12).

8. Equipment and Supplies

8.1. Gas chromatograph: Agilent GC6890 System
  8.1.1. Six-Port Gas Chromatographic Valve: Seiscor Model VIII, Seismograph Service Corp., Tulsa, OK (or equivalent)
  8.1.2. This GC meets the required capabilities detailed in USEPA Method 8270C, USEPA Compendium Method TO-15, and California EPA ARB SOP MLD 059.
8.2. Column: Columns that are suitable for use under this SOP are the following:
  8.2.1. Heliflex® AT-1™ms low-bleed capillary GC column (Part #935110): Alltech Associates, Deerfield, IL. Should include a 5-m “leader” span of column, which is not coated with stationary phase, and therefore functions as a guard column.
  8.2.2. DB-XLB capillary GC column, 30m × 0.25mm × 0.25µm (Part #122-1232G): Agilent Technologies, Palo Alto, CA. Should include a 10-m “DuraGuard” span of column, which functions as a guard column.
  8.2.3. An equivalent column (or column/guard column combination) may be used if equal performance can be achieved.
8.3. Mass spectrometer: Agilent 5975 Inert MSD System
  8.3.1. This MS meets the required capabilities detailed in USEPA Method 8270C, USEPA Compendium Method TO-15, and California EPA ARB SOP MLD 059.
  8.3.2. Perfluorotributylamine (PFTBA) is used as the tuning compound for electron impact tuning.
8.4. GC/MS Interface: Capillary-direct into the MS source
  8.4.1. Meets the required capabilities detailed in Methods 8270C and TO-15
8.5. Data Analysis System: A computer system that will allow continuous acquisition and storage of all mass spectra. Vendor (Agilent)’s software allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time or scan number (Extracted Ion Current Profile (EICP)). Vendor’s software also allows integrating the abundances in any EICP between specified time or scan-number limits.
  8.5.1. Use the most recent version of the EPA/NIST Mass Spectral Library.

8.6. A dynamic calibration system (Fig. 1) consists of the following components:
  8.6.1. Calibration manifold: Glass manifold (1.25 cm I.D. × 66 cm) with sampling ports and internal baffles for flow disturbance to ensure proper mixing.
  8.6.2. Humidifier: 500-mL impinger flask containing HPLC-grade deionized water.
  8.6.3. Electronic mass flow controllers: One 0 to 5 L/min and one 0 to 50 mL/min
  8.6.4. Teflon filter(s): 47 mm, for particulate control
8.7. Cryogenic/Adsorbent Concentrator, with the following components:
  8.7.1. Adsorbent trap, ca. 1/8″ (700 µL), packed with 60/80 Carbopack B, Carbopack C, and Carboxen 1000.
  8.7.2. Multi-position Stream Selector Valve
  8.7.3. Low-pressure regulator with Teflon-lined diaphragm
  8.7.4. Mass flow controller, rated at 100 cm^3/min at full scale
  8.7.5. Fixed-volume sample loop for addition of internal standard, when required
8.8. Tubing for connecting canisters to the Cryogenic/Adsorbent Concentrator
  8.8.1. The following types and sizes are appropriate: 1/8″ Teflon, 1/16″ stainless steel, or 1/16″ glass-lined tubing.
8.9. Helium cylinders - 99.999% or higher purity He as the GC carrier gas
  8.9.1. Scrubber: Use the Agilent “big universal trap” (Part # RMSH-2), or equivalent, to purify the helium carrier gas.
8.10. Nitrogen cylinders - 99.999% or higher purity N2 as the diluent gas for pressurizing canisters (Section 9.4.1)
8.11. Liquid N_2 for cooling of the GERSTEL Cooled Inlet System (CIS)
8.12. Calibration System
  8.12.1. Calibration Manifold: Stainless steel, glass, or high purity quartz manifold with sampling ports and internal baffles for flow disturbance to ensure proper mixing. The manifold should be heated to ~ 50°C.
  8.12.2. Humidifier: 500-mL impinger flask containing HPLC grade deionized water.
  8.12.3. Electronic Mass Flow Controllers: 0 to 5 L/min and 0 to 100 mL/min units
  8.12.4. Teflon Filters (47-mm) for particulate collection
8.13. Calibration standards
  8.13.1. Calibration standards must include each target analyte in a particular project. This information will be included in the QAPP and/or Statement of Work.
  8.13.2. Prepare standards in humidified zero air, using one of the methods in Section 9.1.
  8.13.3. Prepare working standard mix at a concentration (each analyte) of 10 ppmv.
    8.13.3.1. Consult the QAPP or statement of work to determine the range for each analyte.
    8.13.3.2. When reagent purity is 96% or greater, it is not necessary to use correction factors when calculating the concentration of the standard. Otherwise, use appropriate correction factors in calculating analyte concentrations.
8.14. Phenol-specific System Performance Check Compounds: A methylene chloride solution of chloromethane, 1, 1-dichloroethane, bromoform, chlorobezene, 1,1,2,2-tetrachloroethane, N-nitroso-di-n-propylamine; hexachlorocyclopentadiene; 2,4-dinitrophenol; and 4-nitrophenol, each at a concentration equal to the highest calibration standard.

9. Procedures

9.1. Standard preparation

Any one of the following four methods may be used to prepare standards under this SOP. All four are adapted from USEPA Method TO-15.

9.1.1. Dynamic dilution technique

9.1.1.1. Prepare standards by dynamic dilution of the gaseous contents of a cylinder(s) containing the gas calibration stock standards with humidified zero air using mass flow controllers and a calibration manifold.

9.1.1.1.1. Deliver the working standard from the manifold to a clean, evacuated canister using a pump and mass flow controller.

9.1.1.1.2. Alternatively, calibrate the analytical system by sampling directly from the manifold, if the flow rates are optimized to provide the desired amount of calibration standards.

9.1.1.2. Because the use of a canister as a reservoir prior to introduction into the concentration component of the analytical system resembles the procedure normally used to collect and analyze samples, this method is preferred.

9.1.1.3. Measure the flow rates of the dilution air and cylinder standards (using the same units for all), with a bubble meter or calibrated electronic flow measuring device, and calculate the concentrations of target compounds in the manifold using the dilution ratio and the original concentration of each compound, as follows:

$$\text{Manifold Concentration} = \frac{(\text{Original Concentration}) \times (\text{Standard Gas Flowrate})}{(\text{Air Flowrate}) + (\text{Standard Gas Flowrate})} \tag{1}$$

9.1.1.3.1. For example, a 1 mL/min flow of 10 ppmv standard diluted with 1,000 mL/min of humid air provides a nominal 10 ppbv mixture:

$$\text{Manifold Concentration} = \frac{(10\text{ ppm}) \times (1\text{ mL/min})}{(1000\text{ mL/min}) + (1\text{ mL/min})} = \frac{(10{,}000\text{ ppb}) \times (1\text{ mL/min})}{(1000\text{ mL/min}) + (1\text{ mL/min})} = 10\text{ ppb} \tag{2}$$

9.1.2. Static dilution bottle technique

9.1.2.1. Prepare standards in canisters by spiking the canister with a mixture of liquid components prepared in a static dilution bottle.

9.1.2.2. Determine the volume of a clean 2-L round-bottom flask (modified with a threaded glass neck to accept flexible tubing or a Mininert septum cap) by weighing the amount of water that completely fills the flask. Assume a density for the water of 1 g/mL, so the weight of the water (in g) is the flask volume (in mL).

9.1.2.3. Flush the flask with helium by attaching tubing into the glass neck to deliver the helium. After a few minutes, remove the tubing, and immediately close the glass neck with a Mininert septum cap.

9.1.2.4. Place the flask in a 60°C oven, and allow it to equilibrate at that temperature for about 15 min. Inject a predetermined aliquot of liquid standard(s) into the flask, making sure to keep the flask temperature constant at 60°C.

9.1.2.4.1. Make sure that the volume of liquid standard injected into the flask does not result in an overpressure due to the higher partial pressure produced by the standard compared to the vapor pressure in the flask.

9.1.2.5. Allow the contents of the flask to equilibrate in the oven for at least 30 min.

9.1.2.6. To avoid condensation during withdrawal of aliquots from the flask, place the syringes that will be used to make withdrawals in the oven at the same temperature to preheat them.

9.1.2.7. Withdraw sample aliquots for introduction into the analytical system, or for further dilution. Avoid taking an aliquot (or aliquots) totaling greater than 1% of the flask volume (i.e. ~ 20 mL).

9.1.2.8. Standards prepared by this method are stable for one week. Replace the septum with each freshly prepared standard.

9.1.2.9. Use the following equation to calculate the concentration of each standard component in the flask:

$$\text{Concentration (mg/L)} = \frac{(V_a)\,(d)}{V_f} \tag{3}$$

Where:
V_a = Volume of liquid neat standard injected into the flask (µL)
d = Density of the liquid neat standard (mg/µL)
V_f = Flask volume (L)

9.1.2.9.1. To obtain concentrations in ppbv, divide the gaseous volume of the injected compound by the cylinder volume (at STP) and then multiply by 10^9.

9.1.3. Standard preparation in high-pressure cylinders

9.1.3.1. Obtain standard compound(s) as gas(es) or neat liquid(s). This method is suitable for standards of ≥ 98% purity.

9.1.3.2. Flush an aluminum cylinder with high-purity nitrogen gas (Section 8.10) and evacuate it to a pressure ≤ 25 in of Hg. The cylinder should be equipped with a heated injection port and nitrogen flow to facilitate sample transfer.

9.1.3.3. Using a microliter or gastight syringe, measure predetermined amounts of each neat standard compound, and inject them into the cylinder.

9.1.3.4. Pressurize the cylinder to 1000 psig with high-purity nitrogen.

9.1.3.5. Allow the contents of the cylinder to equilibrate (~ 24 h) prior to withdrawing any aliquots for analysis.

9.1.3.6. If the neat standard is a gas, determine the cylinder concentration using the following equation (note that all volumes must be in the same units):

$$\text{Concentration (ppbv)} = \frac{\text{Volume}_{\text{standard}}}{\text{Volume}_{\text{dilution gas}}} \times 10^9 \tag{4}$$

9.1.3.7. If the neat standard is a liquid, determine the gaseous volume using the equations

$$V = \frac{nRT}{P} \quad \text{and} \quad n = \frac{(V_L)(d)}{MW} \tag{5}$$

Where:

V = Gaseous volume (L) at EPA standard temperature (25°C) and pressure (760 mm Hg)
n = Moles
R = Gas constant (0.08206 L-atm/mole °K)
T = 298°K (standard temperature).
P = 1 standard pressure, 760 mm Hg (1 atm)
V_L = Volume of liquid injected (mL)
d = Density of the neat standard (g/mL)
MW = Molecular weight of the neat standard expressed (g/mole)

9.1.3.8. Divide the gaseous volume of the injected compound by the cylinder volume (at STP), and multiply by 10^9 to obtain the concentration in units of ppb.

9.1.4. Standard preparation by water methods

9.1.4.1. Evacuate a previously cleaned canister, and pressurize to 760 mm Hg absolute (1 atm) with zero grade air.

9.1.4.2. Remove the air gauge from the canister, and connect a sparging vessel to the canister with a short length of 1/16″ stainless steel tubing.

9.1.4.2.1. Minimize dead volume to maximize analyte transfer from water to canister.

9.1.4.3. Spike a predetermined amount of the stock standard solution, and the internal standard solution, into 5 mL of water.

9.1.4.4. Transfer this water into the sparge vessel, and purge with zero grade nitrogen for 10 min at 100 mL/min, while maintaining the sparging vessel at 40°C.

9.1.4.5. Remove the sparge vessel and replace the air gauge on the canister.

9.1.4.6. Pressurize the canister with high-purity nitrogen to 1500 mm Hg absolute pressure (approximately 29 psi absolute).

9.1.4.7. Allow the canister to equilibrate overnight before use.

9.2. System settings

9.2.1. Use the general GC/MS operating conditions (Table 2), taken from USEPA Methods 8270C and TO-15, as guidance for setting the various GC/MS parameters:

Table 2. GC-MS operating settings and parameters.

Mass range	35-500 amu
Scan time	1 s/scan
Initial temperature	40ºC, hold for 4 min
Temperature program	40-270ºC at 10 ºC/min
Final temperature:	Highest temperature in above gradient, hold for 5 min
Injector temperature	250-300ºC**
Transfer line temperature	250-300ºC**
Source temperature	According to manufacturer's specifications
Injector	Grob-type, splitless*
Injection volume	1-2 µL
Carrier gas	Helium (30 cm/s)
Ion trap only	Set axial modulation, manifold temperature, and emission current to manufacturer's recommendations

* Split injection is allowed if the sensitivity of the mass spectrometer is sufficient.

** These temperatures should be higher than highest temperature in the temperature program.

9.3. Initial tuning, initial calibration, and system performance check

9.3.1. Initial tuning and calibration

9.3.1.1. Use Perfluorotributylamine (PFTBA) as the tuning compound along with a built-in calibrant delivery system to perform Autotune (standard spectra tune) as initial tuning or after any maintenance.

9.3.1.2. Quicktune should be performed daily at the beginning of each batch of samples (i.e. once per 24-h time period of operation).

9.3.1.3. Use the following as tuning acceptance criteria for the PFTBA standard:

9.3.1.3.1. The ratio of the ion at *m/z* 69 to that at *m/z* 70 must be 1 percent (± 0.50 %).

9.3.1.3.2. The ratio of the ion at *m/z* 219 to that at *m/z* 220 must be 5 percent (± 1.25 %).

9.3.1.3.3. The ratio of the ion at *m/z* 502 to that at *m/z* 503 must be 10 percent (± 1.0 %).

9.3.1.3.4. The peak width at half-height for the ions at *m/z* 69, 219, and 502 must be 0.5 amu (± 0.2 amu).

9.3.1.3.5. The mass assignments for the ions at *m/z* 69, 219, and 502 must be correct to within 0.1 amu (e.g ., 69.0 amu ± 0.1 amu).

9.3.1.4. Alternatively, use other documented tuning criteria (e.g. manufacturer's instructions), provided that performance is not adversely affected.

9.3.1.5. Special Autotune can be performed to meet the tuning criteria of decafluorotriphenylphosphine (DFTPP) and 4-bromofluorobenzene (BFB) required by EPA for semivolatiles and volatiles.

9.3.1.6. Do not begin analyses until the tuning criteria are met.

9.3.2. Injection port inertness check

9.3.2.1. Prepare a methylene chloride solution containing 50 ng/µL each of 4,4'-DDT, Pentachlorophenol, and benzidine to verify injection port inertness and GC column performance. Store solution at -10°C (or below) when not in use.

9.3.2.2. Use the DDT, pentachlorophenol, and benzidine in this standard to assess column performance and injection port inertness. Degradation of DDT to DDE and DDD should not exceed 20%. Benzidine and pentachlorophenol should be present at their normal area or height responses, and no peak tailing should be visible.

9.3.2.2.1. If DDT breakdown is > 20% and/or poor chromatography is noted, the injection port may require cleaning. Repeat until the above criteria are met.

9.3.2.2.2. Calculate DDT breakdown as follows (EPA Method 8081A):

$$\%\ \text{breakdown of DDT} = \frac{\text{sum of degradation peak areas (DDD + DDE)}}{\text{sum of all peak areas (DDT + DDE + DDD)}} \times 100$$

Equation (6)

9.3.3. System performance check

9.3.3.1. Perform a system performance check daily to ensure that minimum average RFs are met before the calibration curve is used. For this SOP, the System Performance Check Compounds (SPCCs) are: chloromethane, 1, 1-dichloroethane, bromoform, chlorobezene, and 1,1,2,2-tetrachloroethane (volatitiles);N-nitroso-di-n-propylamine; hexachlorocyclopentadiene; 2,4-dinitrophenol; and 4-nitrophenol (semivolatiles).

9.3.3.2. These SPCCs typically have very low RFs (0.1-0.2), and tend to decrease in response as the chromatographic system (or the standard material) begins to deteriorate. They are usually the first to show poor performance. Calculate RF for each of the four SPCCs; the minimum acceptable average RF is 0.050. This check must be met before sample analysis begins.

9.3.3.3. If the minimum response factors are not met, evaluate the system and take corrective action before sample analysis begins. Possible problems include:

9.3.3.3.1. Standard mixture degradation

9.3.3.3.2. Injection port inlet contamination

9.3.3.3.3. Contamination at the front end of the analytical column

9.3.3.3.4. Reactive (i.e. non-inert) sites in the column and/or system

9.4. Sample analysis

9.4.1. Dilution

9.4.1.1. Samples collected according to SOP V2 will have a final vacuum of 7 in. of Hg, based on a collected volume of 4.55 L.

9.4.1.2. Pressurize the canister to 1 atm (29.92 in. of Hg) above ambient, using ultrahigh-purity N_2 gas (Section 8.10).

9.4.1.3. This introduces a dilution factor of 2.61 (RESTEK Canister Guide 2002):

$$(29.92 + 29.92)/(29.92 - 7) = 2.61$$

- 9.4.1.4. Adjust calculations accordingly if the final (i.e. post-sampling) vacuum of a canister is other than 7 in. of Hg.

9.4.2. Connect the sample canister to the inlet of the GC/MS system (through the six-port chromatographic valve).

- 9.4.2.1. Place a mass flow controller on the canister, open the canister valve, and vent the canister flow past a tee inlet to the analytical system at a flow of 75 mL/min. Pull approximately 35 mL/min through the Nafion® dryer to the six-port valve.
  - 9.4.2.1.1. Flow rate is not as important as acquiring a sufficient, accurate sample volume.

9.4.3. Preconcentration

- 9.4.3.1. Cool the Cryogenic/Adsorbent Concentrator (Section 8.7) to its set point (-100 to 150°C). Once it has reached this point, turn the six-port chromatographic valve to the "fill" position to initiate sample collection.
- 9.4.3.2. Collect sample for the appropriate amount of time necessary to concentrate the desired volume.
- 9.4.3.3. After the sample is fully loaded onto the preconcentrator trap, dry purge the concentrator with He.
- 9.4.3.4. Cycle the six-port GC valve to the "inject" position and heat the trap to 250°C (with a ramp time of approximately 1 min). The trapped analytes thermally desorb into the cryofocusing trap of the CIS, which is initially set to -30 to -50°C.

9.4.4. Sorption to and isolation of cryofocusing trap

- 9.4.4.1. Allow three (3) min of gas flow through the heated Cryogenic/Adsorbent Concentrator and onto the cooled cryofocusing trap.
- 9.4.4.2. Close the valve between the Cryogenic/Adsorbent Concentrator and the cryofocusing trap, and purge the Concentrator with He.

9.4.5. Secondary desorption

- 9.4.5.1. Rapidly (e.g. a ramp of 40°C/sec) heat the focusing trap to 250 to 300°C, and apply a flow of at least 3 mL/min of pure helium carrier gas.
- 9.4.5.2. Desorb analytes from the focusing trap in "backflush" mode, with the gas flow through the trap in the opposite direction from that used during the focusing step.
- 9.4.5.3. The GC run is initiated based on a programmed time delay after the start of thermal desorption.

9.4.6. GC/MS analysis

- 9.4.6.1. Appropriate operating conditions for the GC columns listed in Section 8.2 when used under this specific SOP are in Table 3:

Table 3. Operating conditions for the GC column.

Initial temperature	40ºC, hold for 3 min
Temperature program	40-220 ºC at 10ºC/min
Final temperature:	220ºC, hold for 3 min
Carrier gas	Helium (20 mL/min)

- 9.4.6.2. Operate the GC/MS system to scan the atomic mass range from 35 - 300 atomic mass units (amu).
- 9.4.6.3. Acquire at least ten scans per chromatographic peak.
- 9.4.6.4. Selected ion monitoring (SIM) is acceptable for applications requiring detection limits below the normal range of electron impact mass spectrometry. However, SIM may provide a less definitive compound identification, unless multiple ions are monitored for each analyte.

9.4.7. Qualitative analysis (peak identification)

- 9.4.7.1. Identify compounds by (a) comparing retention time and (b) comparing the sample mass spectrum (after any necessary background correction) with a reference mass spectrum (Method 8270C). Conditions that must be met for identification of compounds are as follows:
  - 9.4.7.1.1. The relative retention time (RRT) of the analyte in a sample must be within ± 0.06 RRT units of the RRT of the corresponding analyte in the standard.
  - 9.4.7.1.2. The intensities of the characteristic ions of a compound must maximize in the same scan or within one scan of each other. For the purposes of this SOP, peak selection is done by a data system target compound search routine based on the presence of a target peak, containing ions specific for the target compound, at a compound-specific retention time.
    - 9.4.7.1.2.1. The characteristic ions from the reference mass spectrum are defined as the three ions of greatest relative intensity, or any ions over 30% relative intensity, if less than three such ions occur in the reference spectrum.
  - 9.4.7.1.3. The relative intensities of the characteristic ions in the spectrum of the sample component must agree within 30% of the relative intensities of the same ions in the reference spectrum.
    - 9.4.7.1.3.1. For example: If an ion has an abundance of 50% in the reference spectrum, the abundance of the same ion in a sample spectrum can range between 20% and 80%.
- 9.4.7.2. Identify structural isomers with very similar mass spectra as individual isomers only if they have sufficiently different GC retention times.
  - 9.4.7.2.1. Sufficient GC resolution is achieved if the height of the valley between two isomer peaks is less than 25% of the sum of the two peak heights.
  - 9.4.7.2.2. If this criterion is not met, identify structural isomers as isomeric pairs.
- 9.4.7.3. Use a library search to tentatively identify sample components not matching any calibration standard (e.g. unknown or unidentified components). Guidelines for tentative identification are:
  - 9.4.7.3.1. The molecular ion(s) and all major ions in the reference spectrum (ions > 10% of the most abundant ion) should also be in the sample spectrum.
  - 9.4.7.3.2. The relative intensities of the major ions should agree within ± 20%. As an example, an ion with an abundance of 50% in the spectrum of the standard must have an abundance in the sample of between 30 and 70%.
  - 9.4.7.3.3. Ions present in the sample spectrum but not in the reference spectrum should be reviewed to determine if they may be due to background contamination or the presence of coeluting compounds.

9.4.7.3.4. Ions present in the reference spectrum but not in the sample spectrum should be reviewed for possible subtraction from the sample spectrum because of background contamination or coeluting peaks. Data system library reduction programs can sometimes create these discrepancies.

9.4.8. Quantitative analysis

9.4.8.1. Once a compound has been identified, base its quantitation upon the integrated abundance of the primary characteristic ion from the EICP.

9.4.8.2. Estimate the concentration of analytes that can be identified, but that are not included in the calibration standards, using the formula given in Section 11.4.8.

9.4.8.2.1. Take the area A_s from the total ion chromatograms, and assume the RF for the compound to be 1.

9.4.8.2.2. Report all concentrations derived in this way as estimates, and note which internal standard was used in the calculation for each analyte.

9.4.8.3. Quantitate structural isomers that produce very similar mass spectra as individual isomers if they have sufficiently different GC retention times.

9.4.8.3.1. Sufficient GC resolution is defined as the height of the valley between two isomer peaks being less than 25% of the sum of the two peak heights.

9.4.8.4. Quantitate structural isomers that do not meet this criterion for separation together as isomeric pairs.

10. Data and Records Management

10.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on laboratory data sheets, and within logbooks with permanent ink, or in electronic notes files. Initial and date all corrections.

11. Quality Control and Quality Assurance

11.1. Carrier gas

11.1.1. Use inert, 99.999% or higher purity helium as the carrier gas.

11.1.2. Use only stainless steel or copper carrier gas lines.

11.1.3. Install oxygen and organic filters on the carrier gas lines supplying the analytical system. Replace these filters regularly, according to the manufacturer’s instructions.

11.2. Reagent purity

11.2.1. Use only reagent-grade chemicals in all tests.

11.2.2. Unless otherwise indicated, ensure that all reagents conform to the specifications of the Committee on Analytical Reagents of the American Chemical Society, where such specifications are available.

11.2.3. If any other grade of reagent is to be used, ascertain first that it is sufficiently pure that it will not decrease the accuracy of the determination.

11.2.4. Use only pesticide-quality (or equivalent) solvents.

11.3. Storage of working standards
  11.3.1. Working standards prepared in canisters may be stored for 30 d in an atmosphere free of potential contaminants. Do not exceed this storage time.
  11.3.2. Keep a storage logbook to document the date that any canister working samples are prepared, so their storage time can be tracked.
11.4. Full calibration
  11.4.1. Do a full calibration during initial instrument setup, whenever the analytical method parameters are substantially changed, or whenever significant maintenance is performed on the system. Significant maintenance includes:
    11.4.1.1. Ion source cleaning or repair
    11.4.1.2. Injection port cleaning (e.g. change septa, o-ring, liner, and/or gold-plated seal)
    11.4.1.3. Column replacement
  11.4.2. Do a full calibration whenever the system fails the daily single-point calibration check (Section 11.5) twice in one day.
  11.4.3. Set up the dynamic calibration system (Fig. 1).
  11.4.4. Analyze a sample of humidified zero air.
  11.4.5. After the zero air check, begin the multipoint calibration. For each desired concentration, meter the contents of the working standard cylinder (2 mL/min) into the manifold's heated mixing chamber, where they are diluted and mixed with humidified zero air. For example, to calibrate the system at a nominal 10 ppbv, zero air flow rate would be 2 L/min. Calibrate the system at five concentrations, spanning the monitoring range. The lowest point on the calibration curve must be below the lowest concentration that meets the data quality objectives of the project, and close to the detection limit for the analyte. For example, if the range of interest is 2 to 20 ppbv, standards of 1, 2, 5, 10 and 25 ppbv are appropriate.
    11.4.5.1. One point of the full calibration curve must correspond to the concentration in the daily single-point calibration check standard (Section 11.5).
    11.4.5.2. Run the lowest concentration on the calibration curve first, and the highest last.
    11.4.5.3. Allow each working standard/zero air mixture to flow and equilibrate for 30 min before taking a sample for GC/MS analysis.
  11.4.6. Run a second zero air sample, to re-check the system cleanliness and check the potential for sample carryover.
  11.4.7. Using the primary ions for each compound (unless interferences are present, in which case a secondary ion is used), quantitate all analytes in the calibration curve.
  11.4.8. Calculate relative response factors (RRFs) for each target compound in each standard, by dividing detector response by the nominal concentration of the analyte:

$$\mathrm{RRF} = \frac{A_s}{C_s} \tag{7}$$

Where:
A_s = Peak area (or height) of the analyte or surrogate
C_s = Concentration of the analyte or surrogate (ppbv)

    11.4.8.1. Calculate mean RRF (using all five standards), standard deviation and %RSD.

11.4.9. Calculate mean RT (using each of the five concentrations in the standard curve), as well as the standard deviation and %RSD.
11.4.10. Tabulate the area response (Y) of the primary ion for each compound and the corresponding concentration for each compound and internal standard.
11.4.11. Calculate the mean area response for each internal standard compound over the entire calibration range.
11.4.12. Technical acceptance criteria for the initial calibration are as follows:
  11.4.12.1. The calculated %RSD for the RRF for each compound in the calibration table must be less than 30%. There may be at most two exceptions with %RSDs up to 40%. No compounds may have an RRF %RSD greater than 40%.
  11.4.12.2. The RTs for each target compound at each individual calibration level must be within 6% of the mean RT for the compound.
  11.4.12.3. The RTs for each target compound at each individual calibration level must be within 6% of the mean RT for the compound.
  11.4.12.4. For each internal standard component, the retention time at each concentration must be within 20 s of the mean retention time over the initial calibration range.
11.4.13. Initial calibration acceptance criteria must be met before analyzing field samples.
  11.4.13.1. If the initial calibration technical acceptance criteria are not met, inspect the system for problems. It may be necessary to clean the ion source, change the column, or take other corrective actions.
11.4.14. Do not report quantitative results for target compound(s) not included in the calibration standard(s), unless they are noted as estimates (Section 9.4.8.2).
11.5. Daily (single-point) calibration checks
11.5.1. Perform a check of the calibration curve once every 24 h – after the GC/MS system has met the tuning criteria for PFTBA, but before any actual samples are run.
11.5.2. Analyze the mid-level concentration from the calibration curve as the standard for the calibration check.
  11.5.2.1. Introduce this standard through the dynamic calibration system.
  11.5.2.2. Alternatively, the standard can be added from a certified canister that has been filled (from the dynamic calibration system) with the diluted working standard.
    11.5.2.2.1. If this option is chosen, allow the gas flow to properly equilibrate (Section 11.4.5.3) before filling the canister.
    11.5.2.2.2. Do not use calibration check standards that are > 30 d old (Section 6.1.7.1).
11.5.3. Perform the following calculations:
  11.5.3.1. Calculate a relative response factor (RRF) for each analyte (Section 11.4.8).
  11.5.3.2. Calculate the percent difference in the RRF of the daily RRF compared to the mean RRF in the most recent full calibration. Calculate the %D for each target compound using the following equation:

$$\%D = \frac{\left(RRF_c - \overline{RRF_i}\right)}{\overline{RRF_i}} \times 100 \qquad (8)$$

Where:
RRF_c = RRF of the target compound in the daily calibration check run
$\overline{RRF_i}$ = Mean RRF of the target compound in the most recent full calibration

11.5.4. Acceptance criteria for daily calibration checks are as follows:

11.5.4.1. The %D for each target compound in a daily calibration sequence must be within ±30% in order to proceed with the analysis of samples and blanks.

11.5.4.2. Maintain a control chart showing %D values for each daily calibration check. Values for %D that steadily increase over time, although still within the acceptable range, may indicate that maintenance will soon be needed.

11.5.5. If the daily calibration technical acceptance criteria are not met, it may be necessary to clean the ion source, change the column, or take other corrective action(s).

11.5.5.1. Rerun the daily calibration check standard. If the %D criterion still cannot be met, more thorough corrective action may be needed.

11.5.5.1.1. In this case, rerun the full calibration (Section 11.4).

11.6. Method TO-15 also advises analyzing one calibration check standard roughly every tenth sample during an extended analytical sequence, to check system performance.

11.6.1. For runs containing more than 15 samples, a calibration check standard may be run near the middle of the batch, and evaluated as per Section 11.5.4. For runs longer than approximately 30 samples, consider adding two calibration check standards.

11.7. Check each analytical run for saturation. The level at which a compound saturates the detection system is a function of system sensitivity and the mass spectral characteristics of that compound. Denote any analyte(s) in a particular sample that are found to be saturated as "above the quantitation limit" (with the limit identified) in that sample.

11.8. Use secondary ion quantitation only when there are sample matrix interferences with the primary ion. If secondary ion quantitation is performed, document the reasons.

11.9. Blanks

11.9.1. **Laboratory blanks** are identically prepared (cleaned and certified) canisters, with similar histories and conditioned at the same time as those used for sampling, pressurized to 1 atm with N_2 gas.

11.9.1.1. Include at least two laboratory blanks per sampling event.

11.9.1.2. Store laboratory blanks in clean controlled conditions prior to use.

11.9.1.3. Analyze laboratory blanks at the same time as the samples (after the calibration check) - one at the beginning and one at the end of the sequence of runs.

11.9.1.4. Add any internal standard to laboratory blanks in the same mass and volume added to samples.

11.9.1.5. Acceptance criteria for laboratory blanks are as follows:

11.9.1.5.1. The blank should not contain any target analyte at a concentration greater than its quantitation level (three times the MDL, Section 11.10).

11.9.1.5.2. The blank should also not contain any additional (non-target) compounds with retention times and mass-spectral features that would interfere with identification and measurement of a method analyte.

11.9.1.6. If the blanks do not meet the technical acceptance criteria, investigate the source of the contamination and take (and document) appropriate corrective measures before proceeding with further sample analysis.

11.9.1.7. Whenever a particularly concentrated sample is encountered (i.e., one outside the calibration range), analyze a blank canister immediately after the sample is completed, as a check against carryover effects.

11.9.2. **Field blanks** are the same as laboratory blanks; however, they are transported to and from the monitoring site. They do not actually receive air.
  11.9.2.1. Take one field blank canister for every ten canisters included in a sampling event, with the exception that no less than two field blanks may be included, however small the study.
  11.9.2.2. Distribute field blanks evenly throughout the run when the canisters are analyzed.

11.10. Method detection limits
  11.10.1. Determine the method detection limit for each compound on a particular GC/MS system by making seven replicate measurements of the compound of interest at a concentration near (within a factor of five) the expected detection limit. Calculate the standard deviation for the seven replicate concentrations, and multiply it by 3.14 (the Student's *t* value for 99 percent confidence for seven values).

11.11. System precision checks
  11.11.1. Test analytical system precision using six calibration check standard canisters.
  11.11.2. Conduct system precision checks once every tenth batch of samples or once every three months, whichever happens first.
  11.11.3. Conduct system precision checks whenever the analytical method is modified.
  11.11.4. Include the report produced from the most recent precision test with the report generated for each batch of samples.

11.12. Initial demonstration of analyst proficiency
  11.12.1. Whenever new analysts are trained to conduct the analyses described in this SOP, they will be required to successfully complete all of the calibrations, performance checks, and verifications outlined in this SOP prior to generating actual data.

11.13. Modifications or changes to the system
  11.13.1. If any changes are made to the system (e.g., the column is changed, a septum is changed), the following guidance (from Section 8.2 of USEPA Method 8000B) dictates whether or not recalibration of the system is necessary.
    11.13.1.1. The following procedures will automatically require recalibration of the system:
      11.13.1.1.1. Changing, replacing, or reversing the column
      11.13.1.1.2. Cleaning the MS source
      11.13.1.1.3. Changing the electron multiplier, ion source chamber, or injector port
    11.13.1.2. The following procedures will probably not require recalibration of the system, but must still be followed by a calibration check standard analysis:
      11.13.1.2.1. Changing septa or split seals
      11.13.1.2.2. Changing compressed gas cylinders and/or PTFE transfer lines
      11.13.1.2.3. Changing syringes
      11.13.1.2.4. Changing moisture, hydrocarbon, or oxygen traps
      11.13.1.2.5. Changing column fittings, inlets, or filaments
      11.13.1.2.6. Cleaning the inlet port
      11.13.1.2.7. Breaking off or changing a guard column

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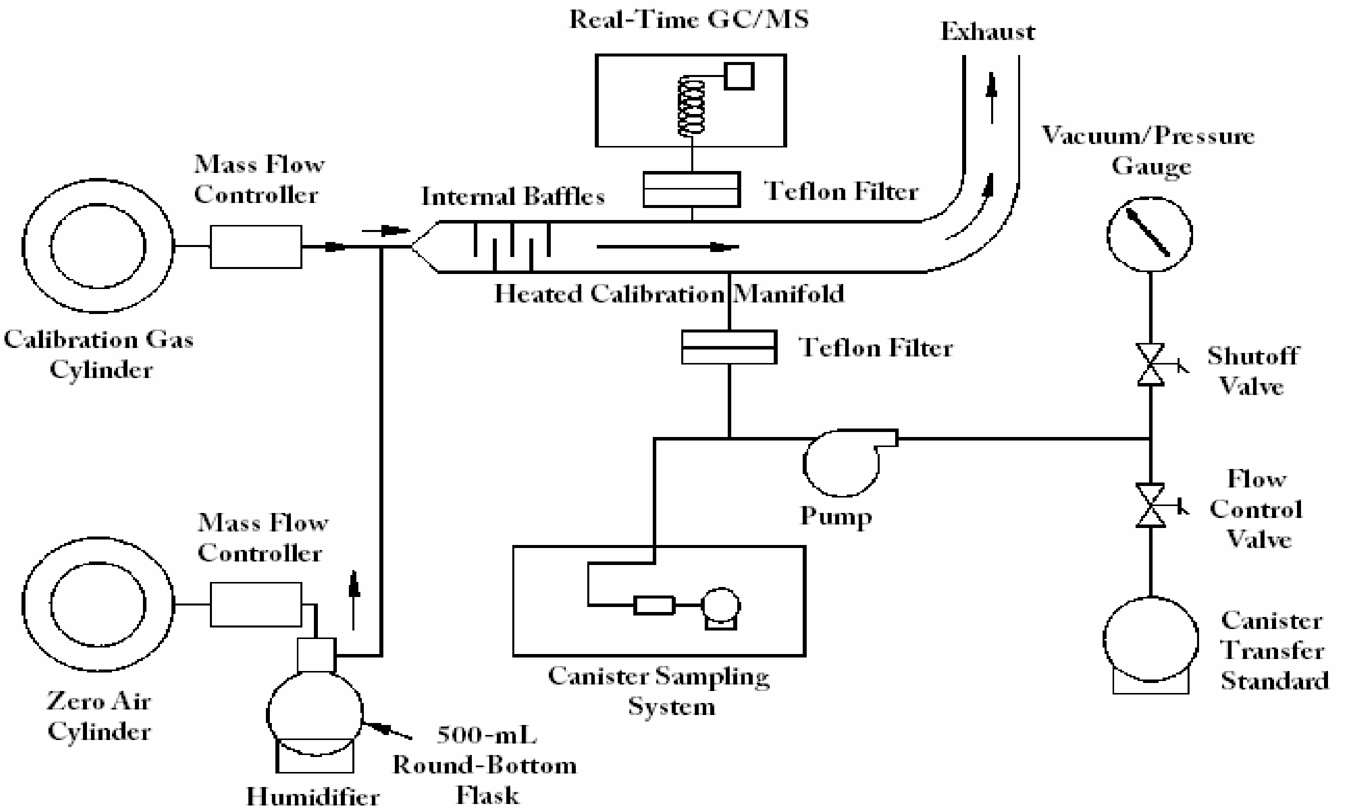

Figure 1. Schematic representation of a dynamic calibration system, which can be used for testing cleanliness of a sampling train (See SOP V7), calibrating the GC/MS (This SOP), or preparing canister transfer standards through dynamic dilution (Section 9.1.1). Adopted from USEPA Compendium Method 14A.

CLEANING, CERTIFICATION AND PRE-SAMPLING PREPARATION OF SAMPLING CANISTERS

Standard Operating Procedure (SOP) V7

CLEANING, CERTIFICATION AND PRE-SAMPLING PREPARATION OF SAMPLING CANISTERS

Standard Operating Procedure (SOP) V7

Prepared by

Hua Xu and Bill W. Bogan

Reviewed by

Albert J. Heber

Effective Date: November 13, 2007

PURDUE AGRICULTURAL AIR QUALITY LABORATORY (PAAQL)
Agricultural and Biological Engineering, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. A common method for sampling of volatile organic compounds (VOCs) utilizes canisters, which are evacuated to sub-atmospheric pressure in the laboratory, and then opened in the field to collect an air sample containing air pollutants of interest. Sample collection at barns and livestock buildings using this method is described in SOP V2. Analysis of the samples, including a list of target analytes which can be quantitated using these methods, is provided in SOP V6.

1.2. The canister must be very clean prior to sampling in the field. This SOP describes the protocols for cleaning canisters, for verifying their acceptability using GC/MS (certification), and record-keeping practices for tracking canister status.

1.3. This protocol is adapted from USEPA Methods TO-14A and TO-15, and ASTM Standard D5466-01.

2. Summary of Method

Fig. 1 presents a flowchart of the preparation of canisters and sampling trains for use in air sampling. Procedures for the sampling itself are described in SOP V2.

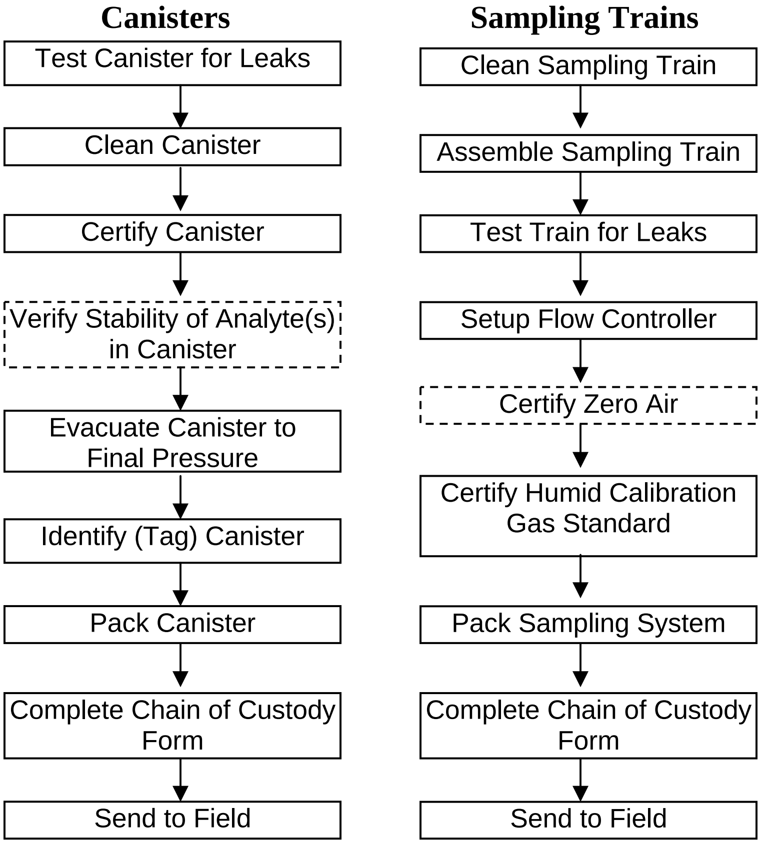

Figure 1. VOC sampling flowchart, adopted from USEPA Method TO-15. Dashed procedures are optional, or are done periodically.

3. Definitions

3.1.	ASTM	American Society for Testing and Materials
3.2.	Certification	The process of demonstrating with humid zero air and humid calibration gases that the sampling systems components and the canister will not change the concentrations of sampled and stored gases
3.3.	COC	Chain of custody
3.4.	GC/MS	Gas chromatography/mass spectrometry
3.5.	HPLC	High-performance liquid chromatography
3.6.	Internal standard	A pure analyte which is added to a sample (or standard) in a known amount, and is used to measure the relative responses of target compounds in the solution. The internal standard(s) must not already be present in the sample.
3.7.	ppbv	Parts per billion (volume basis)
3.8.	"Practice" Canister	A canister used to calibrate the mass flow controller.
3.9.	psi	Pounds per square inch
3.10.	QAPP	Quality Assurance Project Plan
3.11.	sccm	Standard cubic centimeters per minute
3.12.	Target analyte	A compound designated by the QAPP or Statement of Work for analysis (qualitative or quantitative)
3.13.	Tuning standard	A standard which is used to (a) verify that the MS system is operating properly and (b) guard against reactive sites in the system (especially the injection ports, lines, and the first segments of the column) which might cause chemical breakdown or degradation of analytes in the sample
3.14.	VOC	Volatile organic compound(s)

4. Health and Safety

4.1. Release or evacuate air from a canister to a fume hood or to outside.

4.2. Because some suppliers send canisters in a pressurized state, always wear safety glasses when handling canisters.

4.3. To avoid burns, exercise care when using heat bands or jackets in the canister-cleaning process.

5. Cautions

5.1. New or reconditioned canisters should be filled with humidified Ultra High Purity (UHP) air or nitrogen and then analyzed after 24 h to evaluate cleanliness. Although the 24-h period is not a method requirement, new and reconditioned canisters have a higher potential for contamination due to the manufacturing processes, and it is therefore prudent to allow the humidified UHP air or nitrogen to remain in the canister for a longer period to ensure that contaminants are desorbed from active sites.

5.2. Avoid impurities from:
  5.2.1. Calibration gas(es)
  5.2.2. Internal or tuning standard dilution and/or carrier gas(es)
  5.2.3. Organic compounds outgassing from system components ahead of the canister
  5.2.4. Solvent vapors in the laboratory

5.3. Never use non-chromatographic grade stainless steel tubing, non-PTFE thread sealants, or flow controllers with Buna-N rubber components.

5.4. Dust particles can obstruct the canister orifice, compromise the leak integrity of the valve, and possibly damage the valve.

5.5. Clean sampling train parts with solvents in a place that guarantees no cross-contamination of the cleaned parts (i.e., inside a lab hood or in a room other than the room where the sampling train parts are assembled).

5.6. Once the flow rate of a sampling train has been set and certified, the train must be handled carefully, to avoid disturbing that flow rate.

6. Interferences

6.1. The following loss mechanisms for analytes collected into sampling canisters are generally considered (USEPA Method TO-15) to be short-term, and could affect the stability of analytes over the time periods relevant to this SOP (i.e. the two weeks required to assess analyte stability in Section 11.8). In general, however, most VOCs can be recovered from canisters near their original concentrations up to 30 d.
  6.1.1. Reactive sites on the internal surface(s) of the canister and/or sampling train can cause loss of analytes.
  6.1.2. Losses of analytes due to physical adsorption can occur. These slow as equilibrium is reached between the condensed (adsorbed) and gas phases of an analyte. These are generally considered to occur over minutes or hours, and may be more significant with low-humidity samples.
  6.1.3. Conversely, if there is any water condensed in the canister, analytes can be lost as they dissolve in this water. This can be particularly significant if high-humidity samples are pressurized, leading to condensation.
    6.1.3.1. Loss mechanisms based on aqueous hydrolysis also exist.
  6.1.4. Chemical reactions between VOCs and other, more stable substances inside the canister are generally assumed to cause the gradual decrease of concentration over time (i.e., long-term losses over days to weeks).

6.2. Biodegradation of analytes can also occur over time.

6.3. Impurities in the canister pressurizing gas, dilution gas (if used in the introduction of analytes during stability checks) and carrier gas, organic compounds out-gassing from the cleaning system components after cryogen traps, and solvent vapors in the laboratory can all result in contamination problems. The analytical system must be demonstrated to be free from contamination under the conditions of the analysis by running humidified zero air blanks, which must be shown (Section 11.1) to have less than 0.2 ppbv of any target analyte.

7. Personnel Qualifications

7.1. Each person working with sampling canisters must read and understand this SOP.

8. Equipment and Supplies

8.1. Equipment

8.1.1. Stainless steel canister(s): Leak-free stainless steel pressure vessels of desired volume with valve and specially prepared (passivated) interior surface. For the purposes of this SOP, SilcoCan® canisters (or equivalent) will be used.

8.1.2. Canister mass flow controller (Veriflo™ Flow Controller Model SC423XL, RESTEK Corporation, Bellefonte, PA, or equivalent). Capable of maintaining a constant flow rate (± 10%) over a sampling period of up to 24 h and under conditions of changing temperature (20°C – 40°C) and humidity. Veriflo™ controllers contain built-in critical orifices, and the exact part number depends upon the desired flow rate of sample into the canister (SOP V2).

8.1.2.1. The flowrate can be calculated (SOP V2) by

$$F = \frac{P \times V}{T \times 60 \text{ (min-atm/hour)}}$$

Where:
F = flowrate, mL/min
P = final canister absolute pressure
V = volume of canister, mL
T = sample period, h

8.1.3. Vacuum gauge (RESTEK Catalog #24269, or equivalent)

8.1.4. Leak-free stainless steel valve for vacuum/pressure gauge

8.1.5. In-line filter cartridge (2-µm pore size, sintered stainless steel in-line filter, Nupro Co., OH, Model SS-2F-K4-2, or equivalent)

8.1.6. Sample inlet

8.1.6.1. 1/4″ nut to serve as a “rain cap” at the end of the sampling inlet

8.1.7. Passivated stainless steel sampling tube, typically 1/4″ ID,

8.1.8. A canister-cleaning system (Fig. 2) consisting of the following components:

8.1.8.1. UHP gas cylinders (1), with appropriate regulators (SOP G2). Use humidified UHP nitrogen for SilcoCans®, and humidified zero air for SUMMA® canisters; In this SOP, since SilcoCan® will be used, UHP nitrogen is appropriate. The QAPP for a particular project will specify a source/distributor if a specific product is to be used.

8.1.8.1.1. Note: All UHP gas cylinders must be certified as clean (less than 0.2 ppbv of any target VOC) before they can be used in the canister-cleaning procedure.

8.1.8.2. A vacuum pump capable of evacuating canister(s) to an absolute pressure of <0.002 in Hg (50 mTorr) (DuraVane Two Stage High Vacuum Rotary Vane Pump (7.5×10^{-3} Torr), Part #DERVR003H, LACO Technologies)

8.1.8.3. Stainless steel manifold with connections for six (6) canisters

8.1.8.4. Shut-off valves: Swagelok plug valves
8.1.8.5. Stainless steel vacuum gauge: Capable of measuring vacuum in the manifold to an absolute pressure of 0.002 in Hg (50 mTorr) or less. All the wetted surfaces of the sensor must be of passivated stainless steel.
8.1.8.6. Cryogenic traps (1): Stainless steel Dry Ice Trap (Part #LIT-10025, LACO Technologies, UT), to capture contaminants (e.g. oil from vacuum pump)
8.1.8.7. Vacuum guage (Part #KJL-205, Lesker, PA) which can measure absolute pressure less than 50 mTorr.
8.1.8.8. Humidification chamber (Part #24282, Restek, PA): Pressurizable water bubbler containing high performance liquid chromatography (HPLC)-grade deionized water and capable of withstanding pressure up to 90 psi.
8.1.8.9. Insulated heat jackets, bands, or equivalent, that can heat canisters to 140°C (optional)
8.1.9. If canister samples are loaded directly to the GC/MS, a dynamic calibration system (Fig. 3) consisting of the following components is required:
8.1.9.1. Glass calibration manifold: 1.25-cm I.D. × 66 cm, with sampling ports and internal baffles to ensure proper mixing by flow disturbance
8.1.9.2. Humidifier: 500-mL impinger flask containing HPLC-grade deionized water.
8.1.9.3. Electronic mass flow controllers (2) with 5 L/min and 50 mL/min ranges.
8.1.9.4. Teflon filter(s) (47-mm dia), to filter particulate matter
8.1.10. Vacuum oven (optional) capable of holding a temperature of 50 or 100°C
8.1.11. Certified mass flow meter to verify sampling train flow controller
8.1.12. Vacuum gauge (capable of measuring manifold vacuum to an absolute pressure of 0.00197 in Hg (0.000967 psi) or less).
8.1.13. A “practice” canister to check the flow controller
8.1.14. 9/16″ wrench
8.1.15. 3-mm Hex (Allen) wrench
8.2. Supplies
8.2.1. 2-micron sintered stainless steel in-line particulate matter filter
8.2.2. Methanol and hexane for cleaning sampling train parts
8.2.3. HPLC-grade deionized water (MilliQ water)
8.2.4. UHP nitrogen
8.2.4.1. Must be certified (through GC/MS analysis) to have < 0.2 ppbv of each individual target analyte.
8.2.5. GC/MS system (SOP V6)
8.2.5.1. Gas chromatograph (Agilent GC6890 System, or equivalent)
8.2.5.2. Column: Columns that are suitable for use under this SOP are the following:
8.2.5.2.1. Rtx®-1 60 m × 0.32 mm × 1.0 µm capillary column (Restek Part #10157).
8.2.5.2.2. An equivalent column (or column/guard column combination) may be used if equal performance can be achieved.
8.2.5.3. Mass spectrometer (Agilent MSD5975 System, or equivalent)
8.2.5.4. Capillary GC/MS Interface into the MS source from the GC
8.2.5.5. A computer system that allows the continuous acquisition and storage of all mass spectra. Vendor (Agilent)’s ChemStation software allows searching any GC/MS data file for ions of a specified mass and plotting such ion abundances versus time

or scan number (Extracted Ion Current Profile (EICP)). Vendor's software also allows integrating the abundances in any EICP between specified time or scan-number limits.

8.2.5.5.1. The most recent version of the EPA/NIST Mass Spectral Library will be utilized.

8.2.5.6. Helium cylinders - 99.999% or higher purity He as the GC carrier gas

8.2.5.6.1. A scrubber ("Big Universal Trap", Part # RMSH-2, Agilent), or equivalent should be used to purify the carrier gas.

8.2.6. Dry ice and isopropanol

8.2.7. Low-level standard gas mix of target analytes (approx. 10 ppmv in N_2) for stability checks, and for certifying the sampling train(s)

8.2.7.1. Prepare standards according to one of the methods outlined in Section 9.1 of SOP V6, using certified clean zero air as the diluent.

8.2.8. Chain-of-custody (COC) forms (original and field and lab copies) and canister identification tags

9. Procedure

9.1. Sampling train preparation

9.1.1. Cleaning sampling system components

9.1.1.1. Disassemble the sampling train to clean individual components.

9.1.1.2. Rinse all nonmetallic parts with HPLC-grade deionized water, and dry them in a vacuum oven at 50°C for 12 to 24 h.

9.1.1.3. Clean all stainless steel parts and fittings by placing them in a beaker of methanol in an ultrasonic bath for 15 min. Repeat, with hexane as the solvent.

9.1.1.4. Rinse the parts with HPLC-grade deionized water and dry them in a vacuum oven at 100°C for 12 to 24 h.

9.1.1.5. Thoroughly clean the particle filter.

9.1.1.5.1. Disassemble the filter.

9.1.1.5.2. Remove the larger particles from the frit by blowing particle-free nitrogen through the frit from the outlet surface toward the inlet surface.

9.1.1.5.3. After larger particles are removed, sonicate or rinse filter parts in methanol.

9.1.1.5.4. Bake the parts in an oven at 130°C to remove any residual organic vapors.

9.1.1.6. Clean orifice and flow controller using either of the following two methods:

9.1.1.6.1. Disassemble the flow controller and clean all the metal parts with methanol to remove any high boiling compounds that condensed onto the wetted areas of the controller. Heat the cleaned metal parts in an oven at 130°C to remove any residual organic vapors.

9.1.1.6.2. A simpler flow controller cleaning method is to use a heating jacket or heat gun to heat the components of the sampling train, while purging the system with nitrogen.

9.1.1.7. Assemble the sampling train (Section 9.1.2).

9.1.1.8. Purge the entire system with humid UHP nitrogen for 24 h.

9.1.2. Assemble the sampling train

9.1.2.1. Use a 9/16″ wrench to assemble the sampling train components. Tighten the parts by hand and then apply a ¼ turn with the wrench. Do not overtighten the fitting. Verify that the sampling train parts cannot be rotated by hand. Fig. 4 shows the proper assembly of the sampling train components; additional instructions pertaining to each individual component follow.

9.1.2.2. Sampling inlet
  9.1.2.2.1. If assembling the sampling train for shipment to the field:
    9.1.2.2.1.1. Make sure that the entrance of the sampling inlet faces downward to avoid the entrance of raindrops.
    9.1.2.2.1.2. Install a nut at the entrance of the inlet to prevent rain droplets from accessing the inlet edge where they can enter the sampling train with the air sample.
  9.1.2.2.2. If the sampling train will be used indoors, these precautions are unnecessary.

9.1.2.3. Particle filter
  9.1.2.3.1. EPA Compendium Methods TO-14A and TO-15 recommend a sintered stainless steel in-line filter with 2-micron pores (Section 8.1.5).
  9.1.2.3.2. Attach the particle filter to the lower end of the sampling inlet, before the critical orifice (located in the Veriflo™ flow controller).

9.1.2.4. Critical orifice and flow controller
  9.1.2.4.1. Verify that the chosen Veriflo™ controller has a critical orifice of the correct diameter for the desired sample flow rate (as calculated in SOP V2). For example, for a 6-L canister sampling during a 24-h period, the orifice diameter is 0.0012″ for a flow rate range of 2 to 4 sccm (note that the specific flow rate calculated in SOP V2 for these conditions was 3.19 sccm). This will ensure an accurate and valid sample. The critical orifice fitting should have a marking indicating the orifice size.
  9.1.2.4.2. Attach the flow controller to the in-line filter, and set the flow of this assembly according to Section 9.1.2.5. If the critical orifice is included with the flow controller, follow the recommendations of the manufacturer.

9.1.2.5. Setting the flow rate with the flow controller
  9.1.2.5.1. Remove the protective cap from the back of the Veriflo™ Flow Controller SC423XL body.
  9.1.2.5.2. Connect either an evacuated canister or a vacuum source to the outlet of the sampling train (i.e. the bottom of the Veriflo™ controller).
  9.1.2.5.3. Connect a calibrated (NIST-traceable) flow meter (Allicat Scientific, M-50 sccm, air), rotameter, or equivalent to the inlet of the train.
  9.1.2.5.4. Apply a vacuum by opening the canister and/or turning on the vacuum source.
  9.1.2.5.5. With a 3-mm hex (Allen) wrench, adjust the piston gap screw to achieve the desired flow rate. Wait for the flow to equilibrate between adjustments.
  9.1.2.5.6. Replace protective cap on the back of the Veriflo™ Flow Controller body.
  9.1.2.5.7. Remove the vacuum source or evacuated canister.

9.1.2.6. Vacuum gauge

9.1.2.6.1. Install a vacuum gauge to monitor canister filling. The flow controller has a minimum pressure that needs to be considered to assure that the flow is stable. This minimum pressure is 7 in. Hg (3.44 psi) for the Veriflo^{TM} Model SC423 XL Flow Controller.

9.1.2.6.2. Verify that the gauge indicates zero upon arrival.

9.1.2.6.3. If the indicator does not read zero, there are two possible causes.

9.1.2.6.3.1. The gauge may need to be equilibrated. This is done by taking out the rubber plug on top of the gauge.

9.1.2.6.3.2. The gauge may be damaged, in which case it must be returned to the manufacturer and replaced.

9.1.2.7. The sampling train is now completely assembled, and ready to be leak tested, certified, or attached to a canister for shipment to the field, as appropriate.

9.1.3. Leak test of sampling train – can be done either of two ways:

9.1.3.1. Sampling train pressure change

9.1.3.1.1. Cap the inlet, attach the sampling train to an evacuated canister, open the valve on the canister and evacuate the sampling train.

9.1.3.1.2. Close the valve and monitor any pressure change in the static sampling train. If the pressure of the static sampling train remains stable for 1-2 min, the sampling train is sufficiently leak-free, and may be used.

9.1.3.1.3. If the sampling train is leak-free, set the desired sampling flow rate.

9.1.3.1.4. If the sampling train does leak, check every connection again, tightening as necessary, and repeat the procedures in Sections 9.1.3.1.1 and 9.1.3.1.2.

9.1.3.2. Helium leak detection

9.1.3.2.1. Pass helium gas through the flow controller and use a sensitive helium leak detector to test for leaks.

9.1.4. Certifying sampling train cleanliness: UHP nitrogen certification

9.1.4.1. Certify the train by passing a humidified, UHP nitrogen stream through the train, concentrating the exit gas on the trap, and analyzing by GC/MS (SOP V6).

9.1.4.1.1. The UHP nitrogen cylinder must be certified as clean (Section 8.2.4.1).

9.1.4.2. Assemble the calibration system and manifold (Fig. 3). Connect the sampler (without a canister) to the manifold, and open the UHP nitrogen cylinder to generate a humid gas stream to the calibration manifold. The flow rate should be ~2 L/min.

9.1.4.3. Pass the humid zero gas stream through the calibration manifold and the sampling train (without a canister) to the GC/MS analytical system at 75 mL/min, so that 35 mL/min is pulled through the six-port valve of the GC and routed through the cryogenic trap at the GC inlet at the appropriate time. Vent the rest of the sample.

9.1.4.4. Following the procedures given in SOP V6, concentrate approximately 1000 mL of sample, and route this concentrated sample to the column. Conduct analysis as described in SOP V6.

9.1.4.5. For the sampling train to pass certification, the analytical system (GC/MS) must not detect any target VOC analyte at or above a concentration corresponding to 0.2 ppbv in the original air stream.

        - 9.1.4.5.1. If more than 0.2 ppbv is detected for any target compound, repeat the procedures 9.1.1 to 9.1.5.
        - 9.1.4.5.2. If the sampling system is certified clean with zero air, it must then be tested with standards of gas in the range of concentrations expected in the field. This is done by dynamic dilution, as discussed in the following section.
- 9.1.5. Verify cleanliness of the canister(s) and their associated sampling system(s) using one of the following two methods:
    - 9.1.5.1. Sampler system certification with sorbent tubes
        - 9.1.5.1.1. Pressurize the canister(s) to be certified with UHP nitrogen.
        - 9.1.5.1.2. Connect the sampling system(s) to the canisters
        - 9.1.5.1.3. Connect a sorbent tube containing the appropriate packing material (SOP V1) to each canister/sampling system combination.
        - 9.1.5.1.4. Open the canister valve, and allow approximately 2.0 – 2.5 L of the canister contents to pass through the sorbent tube at a rate of 50 – 100 mL/min.
        - 9.1.5.1.5. Analyze the sorbent tube (SOP V4) and determine the concentration(s) of any target compound(s) detected. If any target compound is present at 0.2 ppbv or greater, the canister(s) in question must be re-cleaned and re-tested.
    - 9.1.5.2. Sampler system certification with humid calibration gas standards from a dynamic calibration system
        - 9.1.5.2.1. Assemble the dynamic calibration system and manifold (Fig. 3).
        - 9.1.5.2.2. Verify that the calibration system is clean (less than 0.2 ppbv of any target compounds) by sampling a humidified gas stream (SOP V2), without gas calibration standards (e.g. ultra-high purity zero air or nitrogen), with a canister that has been previously certified as clean. Subject this collected sample to GC/MS analysis according to SOP V6.
            - 9.1.5.2.2.1. The assembled dynamic calibration system is certified clean if less than 0.2 ppbv of any target VOC compound is found in the collected sample.
        - 9.1.5.2.3. For generating the humidified calibration standards, attach calibration gas cylinder(s) (Section 8.2.7) to the calibration system as illustrated in Fig. 3. Open the gas cylinders (gas calibration standards and zero air) and pass the gas mixtures through 0 to 10 mL/min certified mass flow controllers to generate ppb levels of calibration standards. Relative flow rates from the two gas cylinders will depend on the concentration(s) of analyte(s) in the standard.
        - 9.1.5.2.4. After equilibrating approximately 5 min, attach sampling system (containing an evacuated canister that has been certified as clean) to the manifold (Fig. 3).
        - 9.1.5.2.5. Sample the dynamic calibration gas stream (SOP V2).
        - 9.1.5.2.6. Concurrent with the sampling system operation, real-time monitoring of the calibration gas stream is accomplished by the on-line GC/MS analytical system (Fig. 3) to provide reference concentrations of generated VOCs.
        - 9.1.5.2.7. After the sampling period (normally the same length of time used for field sampling), analyze an aliquot taken from the sampling system canister (SOP V6). Compare results to reference (real-time) GC/MS analyses to determine if the sampling system changed the concentration(s) of target VOC(s).
        - 9.1.5.2.8. A recovery of between 90% and 110% is expected for all targeted VOCs.

9.1.5.2.9. The percent of recovery is calculated:

$$\% \text{ Recovery} = \frac{Y - X}{X} \times 100$$

Where:
X = concentration of VOC analyte from calibration gas (determined by real-time GC/MS), ppbv.
Y= concentration of VOC targeted compound recovered from sampler, ppbv.

9.1.6. Sampling train packing
  9.1.6.1. Carefully pack the certified sampling train in aluminum foil or in a clean container for storage, or for shipment to the field site.
  9.1.6.2. Packing is critical. Careless handling could affect the preset flow rate.
9.1.7. Complete the chain of custody form.
  9.1.7.1. Include the original COC and the field copy in the box with the sampling train. Keep a copy in the laboratory canister file.

9.2. Canister preparation
9.2.1. Canister cleaning
  9.2.1.1. Assemble a canister cleaning system (Fig. 2), consisting of the components listed in Section 8.1.3.
  9.2.1.2. Add cold trap to the vacuum pump trap
    9.2.1.2.1. Add 5 lb (2.3 kg) dry ice (crushed into small cubes) to the 3.3-L cold well of cold trap.
    9.2.1.2.2. Add 946 mL isopropanol (at least 90% strength) to make a dry ice slurry, which can typically last for 8 h.
  9.2.1.3. Connect the desired number of canister(s) to the manifold.
  9.2.1.4. Open the vent shut-off valve and the canister valve(s) to release any remaining pressure in the canister(s).
  9.2.1.5. Heat canisters to 120°C-140°C. (optional)
    9.2.1.5.1. If using heat bands, position them around the equator of the canister(s) according to manufacturer’s instructions. Note that the valve area of the canister will not be directly heated; however, the amount of radiant heat generated at the valve by heating the canister equator to this temperature should be sufficient to decontaminate the valve (Restek Corporation 2002)
    9.2.1.5.2. Heat jackets can be customized to cover the canister valve.
  9.2.1.6. Start the vacuum pump, close the vent shut-off valve, and open the vacuum shut-off valve.
  9.2.1.7. Once the canister(s) reaches the target temperature, evacuate the canister(s) to <0.002 in Hg (50 m Torr) and maintain them at this pressure for at least 1 h.
  9.2.1.8. Close the vacuum and vacuum/pressure gauge shut-off valves and open the UHP nitrogen shut-off valve to pressurize the canister(s) with humidified nitrogen. Pressurize all canister(s) to approximately 60.8 in. Hg (30 psi).Wait for 30 min.

- 9.2.1.9. Close the UHP nitrogen shut-off valve and allow the canister(s) to vent down to atmospheric pressure through the vent shut-off valve.
- 9.2.1.10. Close the vent shut-off valve.
- 9.2.1.11. Repeat Sections 9.2.1.1 through 9.2.1.10 two additional times for a total of three (3) evacuation/pressurization cycles for each set of canisters.
  - 9.2.1.11.1. Note: It is possible that canisters used under some conditions (e.g. high levels of pollutant(s) in the air stream) may need to be subjected to a higher number of cycles. Use the canister log (Section 10.4) to help evaluate whether this is likely based on how many cycles were required to clean the canister(s) after sampling similar atmospheres in the past.
- 9.2.1.12. After the required number of pressurization/heating/evacuation cycles, pressurize the canister(s) to 60.8 in. Hg (30 psig) with humid nitrogen. Initiate a leak check (Section 9.2.2) immediately.
- 9.2.1.13. Clean cold trap
  - 9.2.1.13.1. Release pressure or vacuum.
  - 9.2.1.13.2. Warm the trap to room temperature.
  - 9.2.1.13.3. Remove center well from the chamber.
  - 9.2.1.13.4. Properly dispose of the slurry.
  - 9.2.1.13.5. Wipe outside of the cold well to achieve its original pristine sheen.
  - 9.2.1.13.6. Mild soap can be used to clean the cold well, but it should be rinsed with deionized water.
  - 9.2.1.13.7. Clean acrylic lid and o-ring, using only a damp or dry cloth.
  - 9.2.1.13.8. Apply small amount of vacuum grease to o-ring

9.2.2. Canister leak check

- 9.2.2.1. After pressurizing to 60.8 in. Hg (30 psig), record the initial pressure.
- 9.2.2.2. Close the canister valve.
- 9.2.2.3. Check the final pressure after 24 h.
- 9.2.2.4. To be acceptable, the final pressure must not vary by more than ± 4.08 in. Hg (± 2 psi) over the 24 h.

9.2.3. Canister certification

- 9.2.3.1. Assessing canister cleanliness
  - 9.2.3.1.1. Allow a minimum of 12 h of "aging" between the final pressurization step of the cleaning process (Step 9.2.2.14) and the analysis.
  - 9.2.3.1.2. Analyze the contents of the canister(s) by a GC/MS following SOP V6.
  - 9.2.3.1.3. Do not use any canister that has not tested clean (< 0.2 ppbv each of targeted compounds). Repeat the cleaning process in Section 9.2.2 until the canister achieves the required cleanliness.
    - 9.2.3.1.3.1. Note in the canister log (Section 10.4) each time a canister requires more than the normal number of cycles to clean. Comparison with the sampling history can help to identify cases in which canisters will require more extensive cleaning in the future, and will streamline the cleaning/certification process.
  - 9.2.3.1.4. Once tested clean, re-evacuate the canister(s) to < 0.002 in Hg (50 mTorr), close the canister valve(s), and keep the canister(s) in the evacuated state until used.

9.2.3.1.4.1. Use an accurate vacuum gauge (Section 8.1.12) to ensure that the required vacuum is obtained. Attach the vacuum gauge to the sample inlet, and open the canister valve to double-check the reading displayed on the canister's vacuum gauge (Fig. 4).

9.2.3.1.5. Remove the canister from the cleaning system and cap the canister connection(s) with stainless steel fitting(s).

9.2.3.2. The canister is now ready for collection of an air sample.

9.2.4. Canister identification

9.2.4.1. Attach an identification tag to each canister. This tag includes, at minimum, spaces for the following information, which must match information on the COC:

9.2.4.1.1. Canister serial number
9.2.4.1.2. Sample number (will be filled out in the field)
9.2.4.1.3. Location (will be filled out in the field)
9.2.4.1.4. Date (will be filled out in the field)
9.2.4.1.5. Initial/final pressure (will be filled out in the field)

9.2.5. Canister packing for shipment

9.2.5.1. Pack canister carefully. Several canisters can be packed in one box.

9.2.6. Canister Chain of Custody

9.2.6.1. Complete the canister COC form.
9.2.6.2. Include the original and field copies in the box with the canister.
9.2.6.3. Keep a copy in the lab canister file.

9.3. Troubleshooting

9.3.1. If there is no flow through the sampling train:

9.3.1.1. Check that the filter is not clogged with particles. Clean (Section 9.1.1.5) if necessary.

9.3.1.2. Check the orifice to verify it is not obstructed with particles. This is more critical when using very small orifices.

10. Data and Records Management

10.1. Maintain all lab records in a worksheet of the electronic field notes spreadsheet designated for this method. Supplement this electronic record by a bound record book designated for the method, which should contain copies of the electronic record.

10.2. Manage all data according to SOP B5.

10.3. Document all data and information on field (or laboratory) data sheets, and within site (or laboratory) logbooks with permanent ink, or in electronic field notes.

10.4. Maintain a permanent log for each individual canister and sampling system, which must include, at minimum, the following information:

10.4.1. Dates and parameters of all cleanings (i.e. temperature applied, number of cycles required to achieve certification)
10.4.2. Certification dates
10.4.3. Data (i.e. chromatograms) on which each certification of cleanliness is based
10.4.4. Dates and results of all leak tests
10.4.5. Dates and results of all analyte stability checks

10.4.6. Dates and locations of all sampling events, as well as analytical results obtained from each sample

10.4.7. Dates and results of all dynamic calibration tests for sampling systems

11. Quality Control and Quality Assurance

11.1. The analytical system must be certified clean at the initiation of a project. Using a volume of UHP nitrogen equivalent to the maximum sample volume expected to be used, a GC/MS run (conducted according to SOP V6) must result in less than 0.2 ppbv of each individual target analyte.

11.2. Test each new UHP nitrogen cylinder to ensure that it meets this same level of purity (less than 0.2 ppbv of each individual target analyte). Otherwise, do not use the cylinder for any procedure in this SOP.

11.3. Calibrate and leak-check all flow controllers annually.

11.4. Subject all sampling trains to a cleanliness check with zero air (Section 9.1.4) before their initial use. The required level of purity is less than 0.2 ppbv of each individual target analyte

11.5. Subject all sampling trains to a dynamic calibration test (Section 9.1.5) before their initial use. Recoveries of all targeted VOCs must be between 90% and 110%. Otherwise, the field sampler must be removed from use, cleaned, and recertified according to the initial certification procedures (Sections 9.1.4 and 9.1.5).

11.6. Perform leak checks on every canister (Section 9.2.2) and every sampling train (Section 9.1.3) after every cleaning. Pressurized canisters must not change pressure by more than ± 4.08 in. Hg (± 2 psi) over a 24-h period, and sampling trains attached to evacuated canisters must display a stable pressure for a minimum of 1-2 minutes.

11.7. Calibrate all mass flow meters at the beginning of the project using an ISO-certified outside lab or NIST-traceable airflow calibrators, and maintain the certificates or documentation of calibration for the duration of the project.

11.8. Incorporate "spot-checks" into canister and sampling train certifications

11.8.1. Initially (i.e. at the start of a project), check all canisters individually by GC/MS during certification, and certify all sampling trains (Sections 9.1.4 and 9.1.5).

11.8.2. After the cleanup system has been proven reliable, spot-check a lower percentage of canisters and sampling systems, and certify the entire batch.

11.8.2.1. Check at least 10% of any given batch of canisters, where "batch" refers to the group of canisters cleaned together in a given session.

11.8.2.2. Canisters in a batch which is to be spot-checked should have contained similar contaminant levels as a result of their most recent sample collection. If some canisters in a batch are known to have contained higher levels of contaminants than others, give preference to checking some (or all) of these.

11.8.2.3. Re-check each sampling system after every tenth use, using both the zero-air and dynamic calibration tests.

11.9. Verify analyte stability on all new canisters (after dynamic calibration), and on each canister after every tenth sampling event using that canister.

- 11.9.1. Introduce a low working concentration of a characterized test mix into the canister. The test mix must contain all or most of the target analytes, and be prepared according to one of the methods described in SOP V6 (Section 9.1).
- 11.9.2. Analyze an aliquot of the contents of the canister immediately after introducing the test mixture and after 5, 10, 20 and 30 days.
- 11.9.3. Responses (i.e. the concentrations of any single target analyte) should not decrease more than 20% over this period.
  - 11.9.3.1. Re-clean and retest any canister that fails this test.
  - 11.9.3.2. Remove from service any canister that, while certified clean, fails the test twice.

11.10. Measure the pressure of the canister at the following events:

- 11.10.1. In the lab, before it is sent to the field. Pressure should be 0.002 in Hg (50 mTorr) or less. Check this value in the field (SOP V2) to ensure that no leaks occurred in transit.
- 11.10.2. When the canister is returned to the lab after sampling, the vacuum should be the same as the value reported in the field (i.e. noted on the COC form). If it is not, invalidate the canister, as a leak occurred during transport to the lab.

12. References

12.1. ASTM Method D5466-01. 2006. Standard Test Method for Determination of Volatile Organic Chemicals in Atmospheres (Canister Sampling Methodology). ASTM International, West Conshohocken, PA.

12.2. EPA Method TO-14A. 1999. Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition (EPA/625/R-96/010b). Center for Environmental Research Information, Office of Research and Development, USEPA, Cincinnati, OH.

12.3. EPA Method TO-15. 1999. Determination of Volatile Organic Compounds (VOCs) in Air Collected in Specially-Prepared Canisters and Analyzed by Gas Chromatography/Mass Spectrometry (GC/MS). In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition (EPA/625/R-96/010b). Center for Environmental Research Information, Office of Research and Development, USEPA, Cincinnati, OH.

12.4. EPA Method TO-12. 1999. Method for the Determination of Non-Methane Organic Compounds (NMOC) in Ambient Air Using Cryogenic Preconcentration and Direct Flame Ionization Detection (PDFID). In Compendium of Methods for the Determination of Toxic Organic Compounds in Ambient Air, Second Edition (EPA/625/R-96/010b). Center for Environmental Research Information, Office of Research and Development, USEPA, Cincinnati, OH.

12.5. RESTEK Catalog 59977B. 2002. A guide to Passive Air Sampling Using Canisters. RESTEK Corporation, Bellefonte, PA. Online at http://www.restek.com/restek/images/external/59977A.pdf. Accessed on 3/20/06.

12.6. SOP B5. 2006. Data Management for Barns. Standard Operating Procedure B5. Purdue Ag Air Quality Lab.

12.7. SOP G2. 2006. Compressed Gas Cylinders. Standard Operating Procedure G2. Purdue Ag Air Quality Lab.
12.8. SOP V2. 2006. VOC Sampling Using Canisters. Standard Operating Procedure V2. Purdue Ag Air Quality Lab.
12.9. SOP V6. 2006. GC/MS Analysis of Phenols and Volatile Fatty Acids (VFAs) Collected in Sampling Canisters. Standard Operating Procedure V6. Purdue Ag Air Quality Lab.

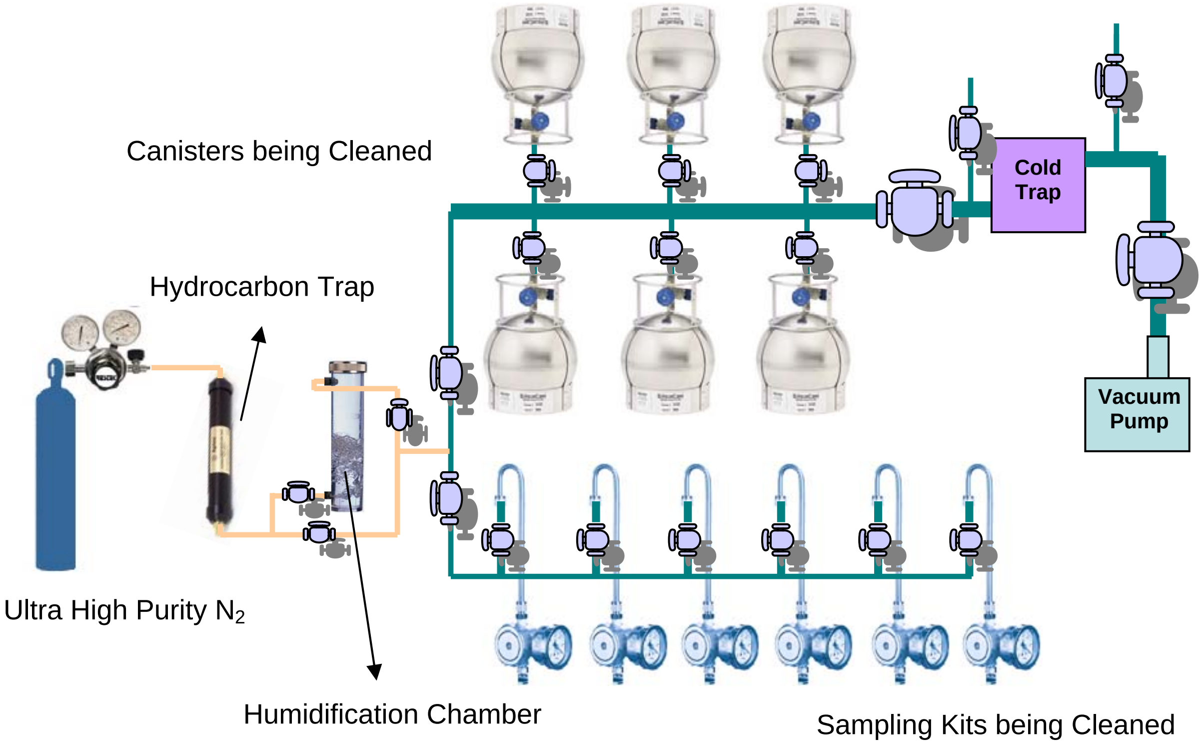

Figure 2. Schematic of canister-cleaning system.

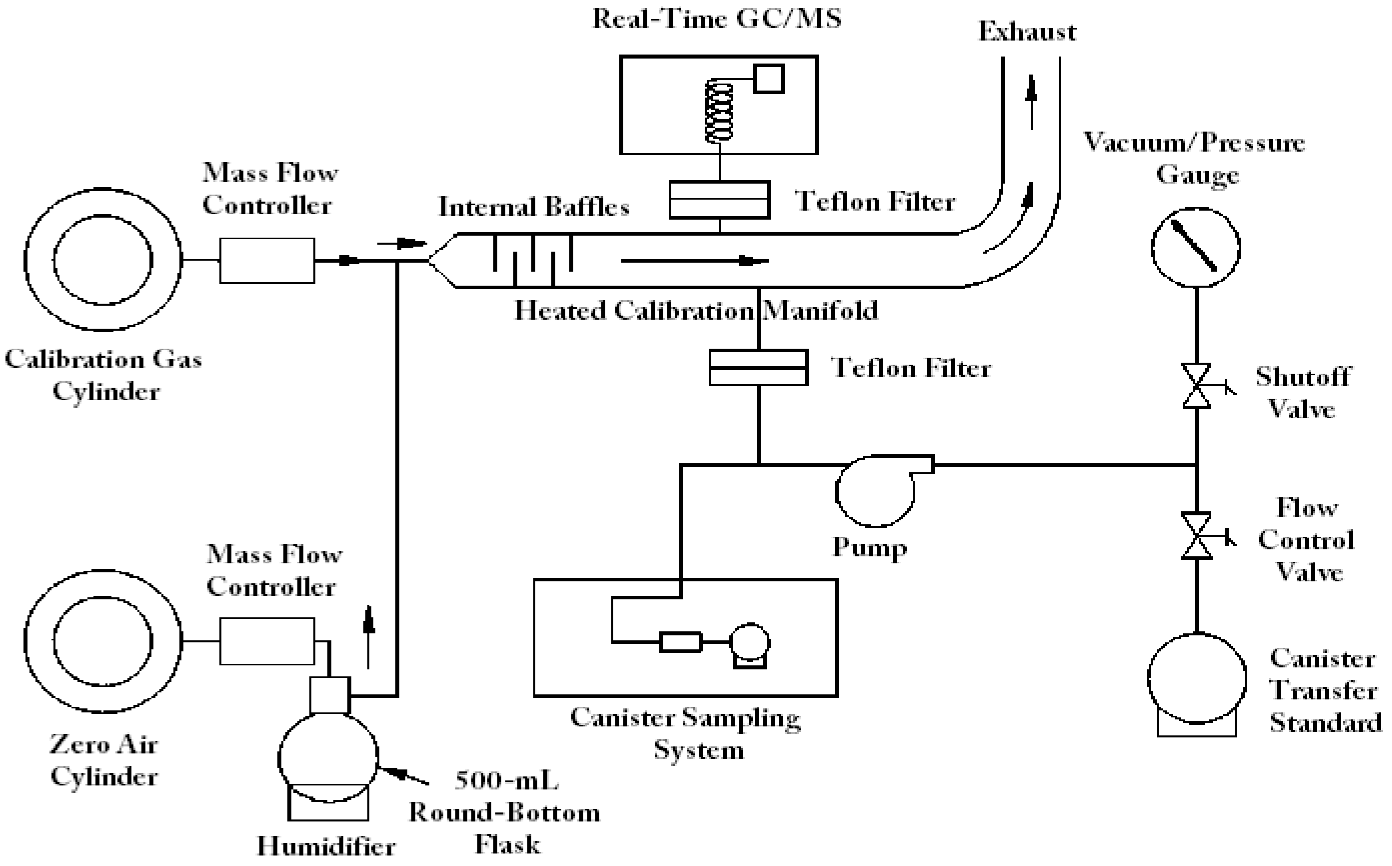

Figure 3. Schematic of a dynamic calibration system, which can be used for testing cleanliness of a sampling train (Section 9.1.5), calibrating the GC/MS (Section 11.1 and SOP V6), or preparing canister transfer standards through dynamic dilution (SOP V6). Adopted from USEPA Compendium Method TO 14A.

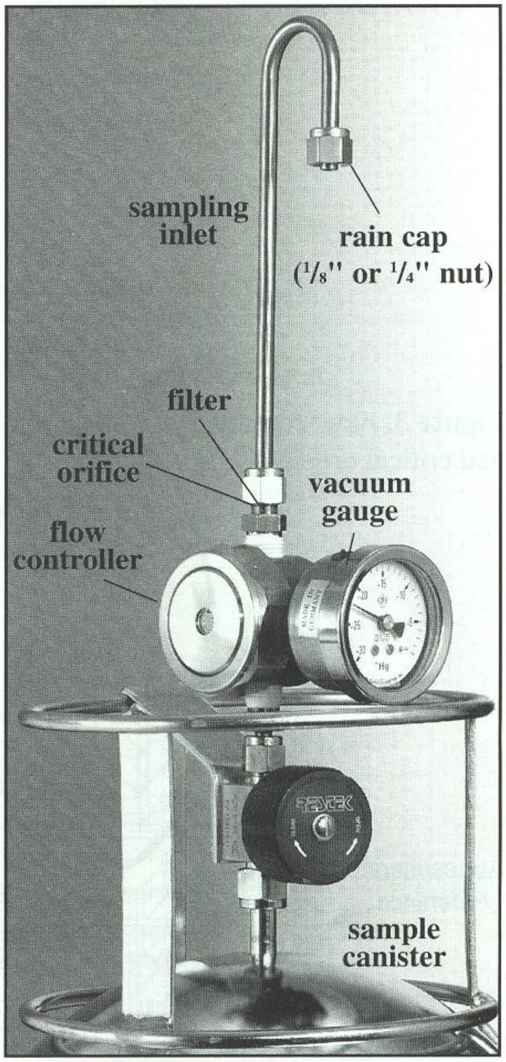

Figure 4. Proper assembly and attachment to a canister of a sampling train. Source: RESTEK Corporation (Reference 12.5).

MEASUREMENT OF WIND WITH THE RM YOUNG MODEL 81000 3-DIMENSIONAL SONIC ANEMOMETER

Standard Operating Procedure (SOP) W2

MEASUREMENT OF WIND WITH THE RM YOUNG MODEL 81000 3-DIMENSIONAL SONIC ANEMOMETER

Standard Operating Procedure (SOP) W2

Prepared by

Richard H. Grant

Reviewed by

Albert J. Heber and Bill W. Bogan

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PURDUE APPLIED METEOROLOGY LABORATORY (PAML)
Agronomy, Purdue University
West Lafayette, IN 47907

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1. Scope and Applicability

1.1. The measurement of the directional components of wind is used in the gaseous emissions measurement methodologies.

1.1.1. Statistical values of instantaneous wind components and the virtual temperature are used in the backward Lagrangian Stochastic method of emission measurement (SOP O1).

1.1.2. Statistical values of instantaneous horizontal wind components are used in the radial plume method of emission measurement (SOP O2).

1.2. The difference in time required for sound to travel through the moving air is a fast response method of measuring each directional component of the wind.

1.3. The detection limit of the method described in this SOP is 0.05 m/s.

1.4. The range of wind speeds which can be measured under this SOP is 0.05 to 40 m/s.

1.5. For wind speed, the manufacturer-reported sensor accuracy is 0.02 m/s, while the manufacturer-reported sensor precision (rms) is 0.05 m/s for speeds of 0 to 5 m/s, 1% of reading for speeds from 5 to 30 m/s and 3% of reading for speeds from 30 to 40 m/s.

1.6. This procedure applies only to the RM Young Model 81000 Ultrasonic Anemometer.

2. Summary of Method

The RM Young Model 81000 measures three-dimensional wind velocity and speed of sound based on the transit time of ultrasonic acoustic signals at 4Hz to 32 Hz. Sonic temperature is derived from speed of sound which is corrected for crosswind effects. Measurement data are available as serial output using RS-232 or RS-485 connections. Operating parameters may be edited via simplified menus using an ordinary serial communication program like HyperTerminal ®. All parameters are stored in non-volatile memory. Superior environmental resistance is achieved by using UV stabilized thermoplastic, stainless steel, and anodized aluminum components.

3. Definitions

COM port	A serial communications port of a computer
HyperTerminal®	A Windows® program that provides communication through a serial communications port of a computer
PAAQL	Purdue Agricultural Air Quality Laboratory
PAML	Purdue Applied Meteorology Laboratory
QAPP	Quality Assurance Project Plan
RS-232	A serial communications protocol
RS-485	A serial communications protocol

4. Health and Safety

4.1. The sensor has electrical components, and proper care should be used as with all electrical equipment.

5. Cautions

5.1. The sensor is acoustical and therefore cannot be dropped without damage.
5.2. Be sure that the sensor is properly grounded.
5.3. Tilt of sensor induces an error in the measurement of approximately 6% in the correlations of wind deviations and 3% in the derived friction velocity with 1^o tilt.

6. Interferences

6.1. Wakes from obstructions such as buildings, storage piles, trees and other vegetation which are closer than ten times the sensor height.
  6.1.1. Incorrect siting of the anemometer will cause greater uncertainties in the data due to failure of assumptions of homogeneity and stationarity.
6.2. Sensor response under high winds can result in extreme values.
6.3. The sensor does not respond under conditions of accumulated freezing rain, heavy frost and snow on the transducers.
6.4. Wake flow around support struts reduces sensor performance.

7. Personnel Qualifications

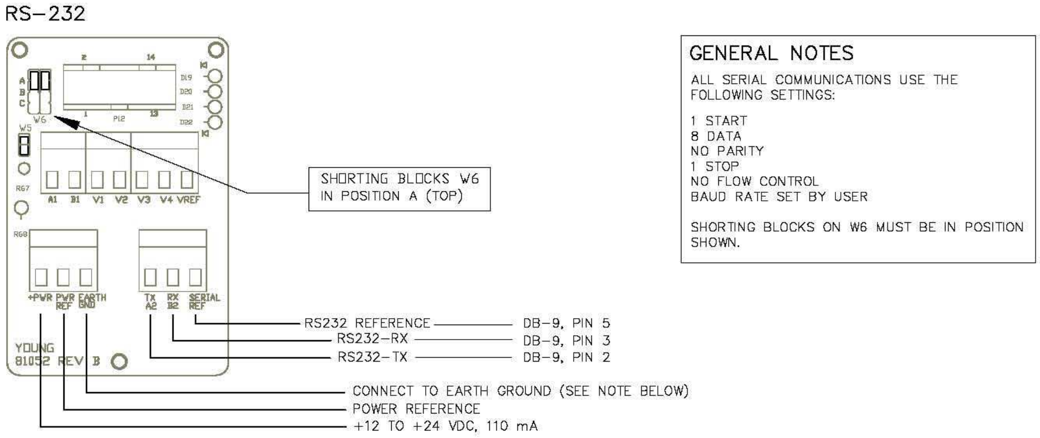
7.1. Read and understand the sensor instruction manual and this SOP before operating this sensor.

8. Equipment and Supplies

8.1. 3-D sonic anemometer
8.2. #2 common head screwdriver
8.3. 1/8″ slotted screwdriver
8.4. Anechoic box
8.5. Laptop computer
8.6. DB9 modem cable
8.7. Labview software
8.8. XStream® RS-232/485 RF Modem
8.9. Sonic anemometer intercomparison stand

9. Procedures

9.1. Instrument acceptance
  9.1.1. Carefully unpack the unit and inspect for physical damage. Report any damage to the shipper. The sensor arrives fully calibrated and ready to use.
  9.1.2. Remove junction box cover. Connect power and signal wires to terminals as in the wiring diagram below. Connect serial cable to computer COM port.
    9.1.2.1. Supply power must be in the range of 12 to 24 VDC **at the sensor junction box terminals** in order for the sensor to operate properly.



9.1.3. Start HyperTerminal® on the computer with baud rate at 38400 and flow control set to NONE.

9.1.4. Apply power to the 81000 sensor. There will be a 4-s delay for initialization; then, the unit will begin to output data at 4 Hz using the following format: speed (m/s), azimuth (deg), elevation (deg), speed-of-sound (m/s), and sonic-temperature (°C). Verify that all values are present on the display. Typical output is:

```
0.00    0.0    0.0  346.70    25.14
0.00    0.0    0.0  346.68    25.11
0.00    0.0    0.0  346.76    25.25
0.00    0.0    0.0  346.80    25.30
0.00    0.0    0.0  346.82    25.35
```

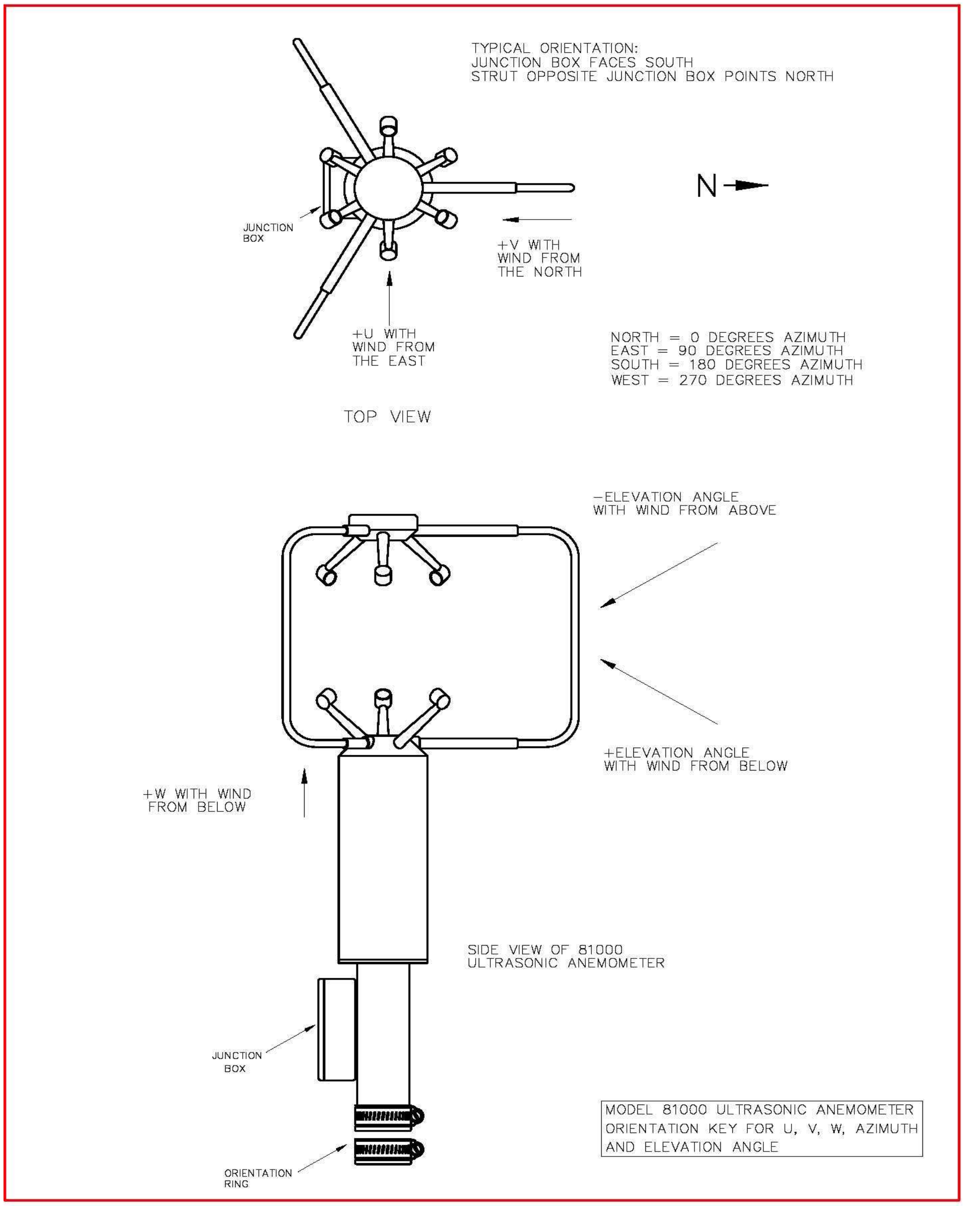
Wind below the 0.05 m/s detection limit is output as 0.00 m/s. Azimuth may be any value from 0.0 to 359.9 degrees. When wind speed is below threshold, azimuth output is maintained at the last value read before wind speed went below threshold. Elevation remains zero until threshold is exceeded. Speed of sound ranges from 300 m/s to 360 m/s, depending on temperature. At 20°C, the value is ~ 344 m/s. Sonic temperature may be compared to a standard Celsius thermometer and should agree within ±2°C. If values appear questionable or any value is not displayed, remove power and check all wiring connections. If the problem cannot be corrected, contact service support (Section 13.1).

9.1.5. Verify sensor response by gently blowing through the measuring section. Wind from the north side (marked “N”), should produce a positive SPEED response and an AZIMUTH display corresponding to North (i.e.: values around 359.9 or 0.0). Wind from the opposite direction should produce AZIMUTH values indicating south, (around 180) and so forth. Downward wind produces negative ELEVATION values, upward wind produces positive values.

9.2. Instrument installation

9.2.1. Mount the sensor securely on top of a mast or tower such that it will not twist, rotate, or sway, according to SOP U5.

9.2.2. Mount the sensor with the following orientation:



9.2.3. Attach earth ground for proper operation.

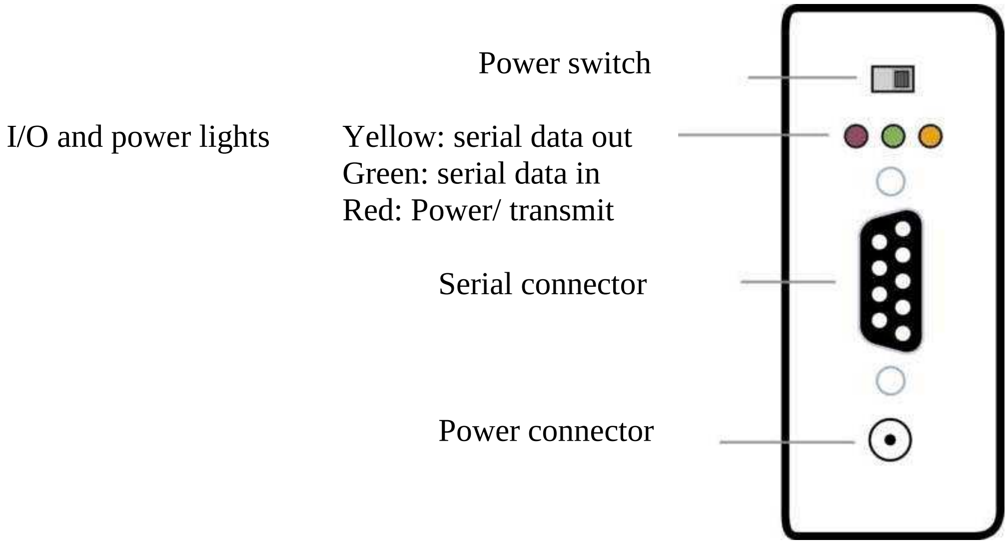
9.3. Instrument operation

9.3.1. Connect a serial cable from the XStream RS-232/485 RF Modem to the COM port of a laptop computer.

9.3.2. Connect antenna to RF Modem.

9.3.3. Provide power to radio modem by connecting power cable to power connector and switching on power switch (See figure below)

9.3.4. Verify power to radio modem by checking red light on modem indicated below:



9.3.4.1. Using X-CTU® program on the laptop computer, verify configuration of Modem (8 data bits, 1 stop bit, no parity, 19200 baud), in accordance with SOP U5.

9.3.5. Connect the serial cable from XStream RS-232/485 RF Modem serial output connector (See figure in Section 9.3.5) to the anemometer, according to figure in Section 9.1.2.

9.3.5.1. Test communication link to the computer in the trailer.

9.3.6. Establish communications with the sensor, according to Sections 9.1.3 and 9.1.4.

9.3.7. Provide power to sensor, and wait 4-s for initialization.

9.3.8. Using the HyperTerminal® window, send the ESC character (ASCII 27) three times in quick succession. This takes the unit out of OPERATE mode and causes the COMMAND MENU to appear:

```
COMMANDS (VERSION 6.6.07)
 -------------------------
R) REPORT
S) SETUP
X) EXIT TO OPERATE MODE
```

9.3.9. Go to SETUP. The SETUP menu appears as follows:

```
SET PARAMETERS
 -------------------------
 A) AVERAGING
 B) BAUD
 E) ERROR HANDLING
 N) SCALING MULT
 O) OUTPUT RATE
 P) POLL CHARACTER (ADDR)
 S) SER OUT FORMAT
 T) THRESHOLD
 U) UNITS
 V) V OUT FORMAT
W) WAKE CORRECTION
 X) EXIT TO MAIN MENU
```

9.3.9.1. Set AVERAGING at 0.
9.3.9.2. Set ERROR HANDLING to “`INCLUDE INVALID DATA`”.
9.3.9.3. Set OUTPUT RATE at 16-Hz
9.3.9.4. Set SER OUT FORMAT as “CUSTOM”. The following appears:

```
CURRENT SERIAL OUTPUT FORMAT:
[       ]
CONSTRUCT AN OUTPUT FORMAT BY SELECTING FROM THE LIST BELOW.
ELEMENTS MAY BE IN ANY ORDER. REFER TO MANUAL FOR DETAILS.
5) UVW
6) 2D SPEED
7) 3D SPEED
8) AZIMUTH
9) ELEVATION
A) SOS
B) Ts
E) ERR CODE
V) INTERNAL VOLTAGE


ENTER CUSTOM STRING (12 CHARACTERS MAX):
```

9.3.9.4.1. Enter Custom string as “5BE”.
9.3.9.5. Set WAKE CORRECTION to “YES”.
9.3.9.6. Exit to main menu and return to OPERATE mode.
9.3.9.7. Locate the appropriate input serial channel on the computer in trailer (SOP U4) and evaluate output for reasonable values.
9.3.9.8. Check output of sensors on the instrument trailer computer.
9.3.9.8.1. If output is not providing three wind vectors, a temperature and an error code, in accordance with the manual, re-enter setup menu and correct problem, starting anew at Section 9.3.5.

9.4. Instrument calibration

9.4.1. The sensor response under constant wind is calibrated at the factory.

9.4.2. The sensor cannot be calibrated for turbulence components.

9.4.3. <u>Standard intercomparison</u>: Compare the output of all three in-use sensors with that of three unused sensors (Standard Triad). This is done after every 6 mos.

9.4.3.1. Locate the sensors to minimize wind interference given prevailing winds.

9.4.3.2. Conduct measurements with the sensors for a period of 24-48 h, so that a variety of atmospheric conditions are included. Then, reverse the locations of the sensors and sample for another 24-48 h.

9.4.3.3. Compare the measurements obtained from the three sensors of the Standard Triad to ensure that the mean wind speed agrees to within 0.2 m/s. If the sensors agree within this amount, then use the average of all 3 sensors of the Triad as the standard. If one of the sensors lies outside this range, then use the average of the two remaining sensors as the standard.

9.4.3.3.1. Troubleshoot any Standard sensor that is out of agreement with other sensors, and resolve problem (Section 9.5).

9.4.3.4. Compare the mean wind speed from each used sensor with the standard set obtained above. If the mean difference is less than 0.2 m/s, then the used sensor being compared is in good working order. If the mean difference is greater than 0.2 m/s, then the used sensor being compared is defective

9.4.3.4.1. Troubleshoot defective sensor and resolve problem (Section 9.5).

9.4.4. <u>In-field intercomparison</u>: Compare the sensor with two identical units which are in routine use.

9.4.4.1. Locate all sensors next to each other on the sonic anemometer intercomparison stand. Orient the stand so that it is perpendicular to the wind, to minimize interference among the instruments.

9.4.4.2. Conduct measurements with all sensors for a one-hour period. Record the mean wind speeds for the three sensors over this period on the Field Intercomparison Form (Appendix B).

9.4.4.3. Determine the three paired differences between the sensors' measurements.

9.4.4.3.1. If all paired differences are less than 0.2 m/s, then the sensors are in good working order.

9.4.4.3.2. If one of the sensor's measurement differs by more than 0.2 m/s from the other sensors' measurements, then conduct tests for another one-hour period. If the difference remains greater than 0.2 m/s, then the sensor is defective, and must be returned to the factory for repair or replacement. Otherwise, if the difference in the second hour is less than 0.2 m/s, then the differences in the first hour were likely due to unsteady wind conditions.

9.4.4.3.2.1. If a sensor fails this test, inspect all measurements made since the sensor last passed to determine the time of failure. Invalidate measurements made after that time.

9.4.4.3.2.2. Contact PM for sensor replacement.

9.5. Troubleshooting
  9.5.1. If no measurements are reported at computer:
    9.5.1.1. Check for obstructions in the acoustic path. Invalid measurements occur when the acoustic path of the sonic signal is blocked or internal circuits fail.
      9.5.1.1.1. Acoustic blockage may be caused by rain drops, ice, snow, or other debris, and is indicated by the output error code (see Section 11).
    9.5.1.2. Check communications.
      9.5.1.2.1. Verify communications link between radio modems (Yellow and Green lights intermittently lit during communications) on modems; (See figure in Section 9.3.3).
      9.5.1.2.2. Verify firm connections for power, signal, and antenna for serial communications.
        9.5.1.2.2.1. Correct as needed.
      9.5.1.2.3. Verify power at modems in trailer and at anemometer, as indicated by a lit red light on the modems (See figure in Section 9.3.3).
        9.5.1.2.3.1. If not within acceptable range, check continuity of wires and tightness of cable connections and correct as needed.
          9.5.1.2.3.1.1. If all connections are tight and of good continuity, send sensor to manufacturer for repair and/or replacement of the appropriate modem.
      9.5.1.2.4. Verify Destination Address of radio modems (SOP W6), and correct as needed.
      9.5.1.2.5. Check that the correct baud rate is selected (See Section 9.1.3) and correct as needed.
    9.5.1.3. Sensor troubleshooting
      9.5.1.3.1. Verify power at anemometer by voltage measurement with multimeter: Voltage should be 12 to 24 VDC **at the sensor junction box terminals** (See figure in Section 9.1.2).
        9.5.1.3.1.1. If voltage is not within acceptable range, check continuity of wires and tightness of cable connections.
          9.5.1.3.1.1.1. Correct as needed.
          9.5.1.3.1.1.2. If all connections are tight and of good continuity, send sensor to manufacturer for repair or replacement.

9.6. Data acquisition, calculations & data reduction requirements
  9.6.1. Data are collected on the LAN server (SOP D1).
  9.6.2. Corrections for wake effects are internally conducted.
  9.6.3. Identify spikes in 16-Hz values of U, V, W, T using 100-s mean filter and dynamically calculated standard deviation.
    9.6.3.1. Calculations are made by a computer program on the LAN server (SOP D1).
    9.6.3.2. Spikes are defined as data points with values more than 3 standard deviations away from running mean.
      9.6.3.2.1. Spike data are omitted.
    9.6.3.3. Count spikes and calculate their mean value.
    9.6.3.4. Inspect and flag data falling outside of acceptable limits based on spike counts.
      9.6.3.4.1. Write to a data file the spike count, as well as the mean value of spikes, over a 5-min interval.

9.6.3.4.2. If spike count is greater than 160 for any variable, then the 5-min measurement period for that variable is flagged and investigated.

9.6.3.4.2.1. Do not calculate the derived variables in Sections 9.6.4 and 9.6.5 using any invalidated variables as dependencies.

9.6.3.4.3. If spikes count is less than 160 for a variable, then that variable passes the spike test.

9.6.3.4.3.1. Store instantaneous U, V, W, T and corresponding qc flags (See table in Section 11.4.1) in temporary data file.

9.6.3.4.3.2. Store 16-Hz sampling of instantaneous values of wind components *u'* and *w'* from 2 m and 16 m anemometers over the period from 12:00 PM to 12:30 PM in a data file (for spectral analysis on LAN server).

[NOTE: There is no correction for tilt of the sensor since inhomogeneities of the surface type (lagoon vs. land surrounding lagoon) and terrain elevation (lagoon berm) create streamlines assumed to be variable with wind direction].

9.6.4. Mean horizontal winds derived from 2-s periods of 16-Hz sampling of instantaneous wind components *u'* and *v'*.

9.6.4.1. Computations are made by computer program on the LAN server (SOP D1).

9.6.4.2. Compute the means of U, V ($\overline{U}, \overline{V}$). Computed values are used in the radial plume method of emission measurement (SOP O2).

9.6.5. Turbulence statistics derived from 5-min periods of 16-Hz sampling of instantaneous wind components *u'*, *v'*, *w'* and *T'*.

9.6.5.1. Computations are made by computer program on the LAN server (SOP D1).

9.6.5.2. Compute the means of U, V, W, and T ($\overline{U}, \overline{V}, \overline{W}, \overline{T}$). Computed values are used in the quality assurance routines and the backward Lagrangian Stochastic emissions measurement (SOP O1).

9.6.5.3. Compute the variance of the three orthogonal wind components σ_u^2, σ_v^2, σ_w^2 and σ_T^2 ($\overline{u'u'}, \overline{v'v'}, \overline{w'w'}, \overline{T'T'}$). Computed values are used in the Quality Control and Assurance checks (Section 11) and the backward Lagrangian Stochastic emissions measurement (SOP O1).

9.6.5.4. Compute averaged correlations of instantaneous deviations in wind components *u'*, *v'*, *w'* and the temperature *T'* derived from the speed of sound: $\overline{u'w'}, \overline{u'v'}, \overline{v'w'}, \overline{u'T'}, \overline{w'T'}, \overline{v'T'}$. Computed values are used in the Quality Control and Assurance checks (Section 11) and the backward Lagrangian Stochastic emissions measurement (SOP O1).

9.6.6. Mean horizontal winds derived from 5 and 30-min periods of 16-Hz sampling of instantaneous wind components *u′* and *v′*.

9.6.6.1. Computations are made by computer program at PAML.

9.6.6.2. Computed values are used to characterize wind conditions.

9.6.6.3. Compute mean vector wind speed ($\overline{S}$) according to the following:

$$\overline{S} = \sqrt{\overline{U}^2 + \overline{V}^2}$$

9.6.6.4. Compute mean wind direction ($\overline{\Theta}$) according to:

$$\overline{\Theta} = \left\{ \begin{array}{cc} 0^\circ & \text{if } \overline{\mathrm{U}} = 0 \text{ and } \overline{V} > 0 \\ 180^\circ & \text{if } \overline{\mathrm{U}} = 0 \text{ and } \overline{V} < 0 \\ -\tan^{-1}\left(\overline{V}/\overline{U}\right) + 90^\circ & \text{if } \overline{\mathrm{U}} > 0 \\ -\tan^{-1}\left(\overline{V}/\overline{U}\right) + 270^\circ & \text{if } \overline{\mathrm{U}} < 0 \end{array} \right\}$$

The convention for the sonic anemometer output is that U is positive for wind from the east, and V is positive for wind from the north. The directions obtained from the above formula are 0° for wind from the north, 90° for wind from the east, and so on.

9.6.7. Turbulence statistics derived from 5 and 30-min periods of 16-Hz sampling of instantaneous wind components *u'*, *v'*, *w'* and virtual temperature *T'*.

9.6.7.1. Computations are made by computer program at PAML.

9.6.7.2. Re-compute LAN-computed variances σ_u^2, σ_v^2, and σ_w^2 and correlations $\overline{u'w'}, \overline{u'v'}, \overline{v'w'}, \overline{u'T'}, \overline{w'T'}, \overline{v'T'}$ with rotated coordinates so that mean wind is in the u direction.

9.6.7.2.1. Rotated values are used in the stationarity and homogeneity quality assurance tests (Sections 11.3.2, 11.3.3)

9.6.7.3. Compute the friction velocity (u_*):

$$u_* = \sqrt[4]{\overline{u'w'}^2 + \overline{v'w'}^2} \qquad \text{(Flesch et al. 2005)}$$

9.6.7.3.1. Computed values are used to characterize wind conditions, and to qualify backward Lagrangian Stochastic emission measurements (SOP O1).

9.6.7.4. Compute the characteristic temperature:

$$T_* = \overline{w'T'} / u_* \qquad \text{(Kaimal and Finnigan 1994)}$$

9.6.7.4.1. Computed values are used to characterize wind conditions.

9.6.7.5. Compute the Obukov length (*L*):

$$z/L = \frac{-kzg\overline{w'T'}}{\overline{T}u_*^3} \qquad \text{(Flesch et al. 2005)}$$

Where:
z = Sensor height (m)
k = von Karman’s constant (0.4)
g = Acceleration due to gravity (9.8 m/s)

9.6.7.5.1. Computed values are used to characterize wind conditions and qualify backward Lagrangian Stochastic emission measurements (SOP O1).

9.6.7.6. The program estimates the roughness length (z_o) as the average value of the three heights of wind measurement, each calculated as:

$$z_o = \frac{(z-d)}{e^{kU/u_* - \psi_m}} \quad \text{(Flesch et al. 2005)}$$

Where (Flesch et al. 2004, Businger et al. 1971, Paulson 1970):
ψ_M = 4.7 (z-d)/L for $z/L > 0.0001$
ψ_M = 0 for $0.0001 > z/L > 0.0001$
ψ_M = $-2\, ln[(1+x)/2]\, -ln\, (1+x^2)/2\,]+ 2\tan^{-1} x - \pi/2$ and
X = $(1-15(z\text{-d})/L\,)^{1/4}$ for $z/L > 0.0001$

9.6.7.6.1. Computed values are used to characterize wind conditions.

9.6.7.7. Estimate dissipation rate ε:

$$\varepsilon = \frac{u_*^3}{kz}\varphi_\varepsilon \quad \text{(Flesch et al. 2004)}$$

Where:
$\varphi_\varepsilon = 1 + 5z/L$ for $L>0$
$\varphi_\varepsilon = \dfrac{b_w^4(1-3z/L)^{1.33}+1}{(b_w^4+1)(1-3z/L)^{0.33}(1-6z/L)^{0.25}}$ for $L<0$

9.6.7.7.1. Computed values are used to characterize wind conditions.

9.6.8. Write values of $\overline{U}, \overline{V}, \overline{W}, \overline{T}, \overline{S}, \overline{\Theta}$, $\sigma_u^2(\overline{u'u'})$, $\sigma_v^2(\overline{v'v'})$, $\sigma_w^2(\overline{w'w'})$ u_*, T_*, z/L, z_o, ε and corresponding qc flags (Table 1) to data file

9.7. Computer hardware & software

9.7.1. Using electrical wires, attach sensor serial port to an XStream® RS-232/485 RF Modem.

9.7.2. A computer in the instrumentation trailer will receive the data using an identically addressed XStream® RS-232/485 RF Modem on a COM port.

9.7.3. Computer will record and process the data, and store it using LABView software.

10. Data and Records Management

10.1. Manage data according to SOP D1.

10.2. Document all data and information checked in the field on field data sheets and in site logbooks with permanent ink, or in electronic notes.

10.3. Overstrike errors in writing with a single line; date and initial all such corrections.

11. Quality Control and Quality Assurance

11.1. Physical inspection

11.1.1. Inspect sensor support arms for dents or deep scratches in the metal.

11.1.1.1. If present, conduct an in-field intercomparison (Section 9.4.3).

11.2. Zero check

11.2.1. Enclose sensor within an anechoic box and check for non-zero values on all wind components (similar to ASTM 2001).

11.2.1.1. Record sensor biases in the *U*, *V*, and *W* components on an audit form similar to the one in Appendix A of this SOP.

11.2.1.2. If sensor does not indicate values of less than 0.2 m/s in all three components, then send it back to the factory for repair or replacement.

11.3. Path obstruction check

11.3.1. The instrument's internal processing determines individual invalid measurements due to a path obstruction (e.g. debris, dew, mist, ice, or snow) preventing or radically altering acoustic transit time measurement. Instrument output includes invalid data and an error code, the sum of values for the following conditions:

2	Zero samples on at least one acoustic path
4	Path A speed < -50 m/s
8	Path A speed > +50 m/s
16	Path B speed < -50 m/s
32	Path B speed > +50 m/s
64	Path C speed < -50 m/s
128	Path C speed > +50 m/s

11.3.1.1. If less than 10% of the sampling interval has non-zero error codes, the measurement period is considered valid and computation on the valid data beginning at section 9.6 will be conducted.

11.3.1.2. If greater than 10% of the sampling interval has a non-zero error code, the measurement period is given an error code (Table 1).

11.3.2. <u>Stationarity check</u> Determine stationarity in the time series by comparing 5-min covariances of u' and w' and w' and T_v' (Section 9.6.6.2) with the 30-min covariance (Section 9.6.5) where i and j are different variables:

$$\sum \left[\left(\overline{u'_i\, u'_j}\right)_{5\,\min} - \left(\overline{u'_i\, u'_j}\right)_{30\,\min}\right] \Big/ \left(\overline{u'_i\, u'_j}\right)_{30\,\min}$$ (Foken and Wichura 1996)

where the 5-min periods included in the sum are sequential within the 30-min interval. Computations are done by computers at PAML.

11.3.2.1. If greater than 0.30 with the inclusion of any 5-min period to the sum, the 5-min period of data is given a QA/QC error code (Table 1).

11.3.3. <u>Homogeneity check</u>: Given values computed according to Section 9.6.6.2, check for homogeneity of turbulence during 30-min sample periods (six sequential 5-min periods) by comparing the theoretically derived and measured integral turbulence scales of w', u' and T' (u_* and T_*) to the standard deviation of w' and T'. Computations are done by computers at PAML.

11.3.3.1. The theoretically-derived values are computed according to (Foken and Wichura 1996):

z/L	<-1	-1...-0.0625	-0.0625...<0	>=0
$\frac{\sigma_w}{u_*}$	$2.00(-z/L)^{1/6}$	$2.00(-z/L)^{1/8}$	1.41	1.25
$\frac{\sigma_u}{u_*}$	$2.83(-z/L)^{1/6}$	$2.83(-z/L)^{1/8}$	1.99	2.4
$\frac{\sigma_T}{T_*}$	$1.00(-z/L)^{1/3}$	$1.00(-z/L)^{1/4}$	$0.50(-z/L)^{1/2}$	

11.3.3.2. Compute the differences between theoretical and measured values as:

$$\sum\left[\frac{\sigma_w}{u_*}-\left(\frac{\sigma_w}{u_*}\right)_{theory}\right]\Big/\left(\frac{\sigma_w}{u_*}\right)_{theory}$$

$$\sum\left[\frac{\sigma_u}{u_*}-\left(\frac{\sigma_u}{u_*}\right)_{theory}\right]\Big/\left(\frac{\sigma_u}{u_*}\right)_{theory}$$

$$\sum\left[\frac{\sigma_T}{T_*}-\left(\frac{\sigma_T}{T_*}\right)_{theory}\right]\Big/\left(\frac{\sigma_T}{T_*}\right)_{theory}$$

11.3.3.2.1. If the value of any of these is greater than 0.30, the 30-min period is given a QA/QC error code (Table1).

11.4. Turbulence structure check: Conduct spectral turbulence checks of the 16-Hz sampling of instantaneous wind components *u'*and *w'* collected over an approximately 30-min period between 12:00 AM and 12:30 PM. Computations are done by computers at PAML.

11.4.1. Store instantaneous values of wind components *u'*, *v'* and *w'* from all anemometers in a data file for processing at PAML.

11.4.2. Calculate spectral statistics of *u'*and *w'*:

11.4.3. Calculate the spectral density function of the first 32,384 values at the all heights by fast Fourier transform.

11.4.4. Using u_* calculated for the 30-min period, calculate the spectral density function normalized to u_*^2 and plot as

$fS(f)/u_*^2$ by f for both measurement heights.

- 11.4.5. Compare shape of spectra and evaluate similarity.
  - 11.4.5.1. If more than one peak in the spectra for either height, flag period values as suspect (Table 1).
  - 11.4.5.2. If the peak spectral density in the 16-m height spectra is at a higher frequency than that for the 2-m height, flag period values as suspect (Table 1).

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13. Contact Information

13.1. Anemometer manufacturer:

R. M. Young Company, 2801 Aero Park Drive, Traverse City, MI, 49686, USA,
email: met.sales@youngusa.com
Customer support and repair: 231-946-3980, Fax 231-946-4772

13.2. Modem manufacturer:

Maxstream, Inc., 355 South 520 West, Suite 180, Lindon, UT 84042
Phone: (801) 765-9885
Fax: (801) 765-9895
email: rf-xperts@maxstream.net

Table 1. Data QA/QC conditions.

Individual measurements

Condition
Value not suspect
Value missing (>10% of records in 5 min period)
Value below minimum or above maximum or value is +/- infinity
Spike count >160
Value has variance >10 m^2/s^2 (u, v, w) or 10 C^2 (T)
> 10% of sampling interval has path obstruction

Combinational measurements

$u'w'$ not stationary (30-min period)
$w'T'$ not stationary (30-min period)
σ_u inhomogeneous turbulence in 5-min period
σ_w inhomogeneous turbulence in 5-min period
σ_T inhomogeneous turbulence in 5-min period

APPENDIX A
AUDIT FORM

SOP W2 RM YOUNG MODEL 81000 3-DIMENSIONAL SONIC ANEMOMETER

Date/time Yymm/dd hhmm-hhmm	Bias in U (m/s)	Bias in V (m/s)	Bias in W (m/s)	Auditor

APPENDIX B
FIELD INTERCOMPARISON FORM

SOP W2 RM YOUNG MODEL 81000 3-DIMENSIONAL SONIC ANEMOMETER

Date/time Yymm/dd hhmm-hhmm	Mean Speed (m/s)			Auditor
	Sensor 1	Sensor 2	Sensor 3	

MEASUREMENT OF WETNESS WITH THE CAMPBELL SCIENTIFIC MODEL RESISTANCE GRID

Standard Operating Procedure (SOP) W3

MEASUREMENT OF WETNESS WITH THE CAMPBELL SCIENTIFIC MODEL RESISTANCE GRID

Standard Operating Procedure (SOP) W3

Prepared by

Juan Carlos Ramirez and Richard H. Grant

Reviewed by

Bill W. Bogan and Albert J. Heber

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Rev. 1.0 Effective Date: February 6, 2008

PURDUE APPLIED METEOROLOGY LABORATORY (PAML)

Agronomy, Purdue University

West Lafayette, IN 47907

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1. Scope and Applicability

1.1. Electrical resistance grids are useful for the determination of surface wetness.
1.2. Surface wetness measurements indicate precipitation, an important weather variable.
1.3. This procedure applies only to the Campbell Scientific Model 237 Leaf Wetness Sensor Resistance Grid, to be used coated with white latex ceiling house paint.
1.4. This device is used as a wet/dry sensor in this application. Sensor readings in between wet and dry are simply interpreted as "Conditions other than wet or dry".
  1.4.1. If measuring resistance with a multimeter, connect the leads to the red and black sensor leads. The sensor lead has a built-in 100,000–Ω, resistor in series with the sensor that must be included in any resistance calculations. See R1 in Fig. 1 of the Model 237 manual. The resistance (including the 100,000-Ω resistor) will be approximately 120,000 Ω – 500,000 Ω when wet, and above 3,100,000 Ω when dry.

2. Summary of Method

2.1. The 237 Leaf Wetness Sensor design emulates the surface area of a leaf. The dimensions of the sensor are 2.75″ W x 3″ L x 0.25″ D, and its weight is 0.5 lb. Surface wetness is detected using a resistance grid (see Fig. 1 at right) of interlaced gold-plated copper etched 'fingers' on an electronic circuit board. Condensation connects the etched 'fingers' of the board, resulting in a resistance change. The change in resistance is detected by change in voltage of a half bridge of fixed resisters (built into sensor cable) excited by AC current.

Figure 1.
Leaf Wetness Sensor

3. Definitions

3.1.	CS	Campbell Scientific, Inc
3.2.	NEMA	National Electrical Manufacturers Association
3.3.	PAAQL	Purdue Agricultural Air Quality Laboratory
3.4.	PAML	Purdue Applied Meteorology Laboratory
3.5.	QAPP	Quality Assurance Project Plan
3.6.	SOP	Standard operating procedure

4. Cautions

4.1. Be careful when connecting the sensor cable to the data logger, being sure the connections are tight and made according to SOP W6.
4.2. Replace the sensor if the cable should become detached from the sensor (do not attempt to resolder it to the sensor), as the cable contains built-in components (a half bridge of fixed resistors) specifically designed to make the sensor operate correctly.
4.3. As with any electrical device, use proper care when crimping cables and connectors.

5. Interferences

5.1. Dust will reduce the sensitivity of the sensor to drying conditions.
5.2. Fingerprints and grease will reduce the sensitivity of the sensor to wetting conditions.

6. Personnel Qualifications

6.1. Each member of the field staff must read the sensor instruction manual and this SOP before operating this equipment.
6.2. Personnel must be trained in the use of the handheld multimeter before initiating the procedure. Training requires 10 min.

7. Equipment and Supplies

7.1. Leaf Wetness Sensor (Campbell Scientific, Model 237, Logan, Utah)
7.2. #2 common head screwdriver
7.3. 1/8″ slotted screwdriver
7.4. Bottle of distilled water for cleaning and testing sensor
7.5. Multimeter

8. Procedures

8.1. Preparation for use
  8.1.1. Clean the Model 237 Leaf wetness sensor thoroughly using acetone; allow to dry.
  8.1.2. Coat the sensor with a single coat of standard Latex exterior house paint; allow to thoroughly dry.
8.2. Acceptance
  8.2.1. Attach multimeter probes to red and black wires of sensor cable.
  8.2.2. Set multimeter to measure resistance.
    8.2.2.1. Read sensor response on multimeter when sensor is dry.
      8.2.2.1.1. Value should be greater than 3,100,000 Ω.
      8.2.2.1.2. If less than 3,100,000 Ω, allow sensor to dry in a warm environment for a minimum of 24 h. If the sensor still reads less then 3,100,000 Ω, return sensor to manufacturer.
    8.2.2.2. Wet sensor with tap water and read sensor response on multimeter.
      8.2.2.2.1. Value should be in the range of 120,000 – 500,000 Ω (±40,000 Ω).
      8.2.2.2.2. If wet resistance is <80,000 Ω or >540,000 Ω, return sensor to manufacturer.
8.3. Calibration check
  8.3.1. Note that this device is not a precision instrument, and exact resistance readings may vary considerably, depending on a wide variety of conditions including the mineral content of the distilled test or rain water.
  8.3.2. Attach red and black sensor wires to probe wires of multimeter.
  8.3.3. Set multimeter to measure resistance.
    8.3.3.1. Read sensor response on multimeter when sensor is dry.

- 8.3.3.1.1. Record value on calibration check sheet (Appendix A). If resistance is over-range on the multimeter's highest resistance scale, record resistance as infinite.
- 8.3.3.1.2. Value should be greater than 3,100,000 Ω.
- 8.3.3.1.3. If not, return sensor to manufacturer.

8.3.3.2. Wet sensor with distilled water and read sensor response on multimeter.

- 8.3.3.2.1. Record value on calibration check sheet (Appendix A)
- 8.3.3.2.2. Value should be within 120,000 Ω – 500,000 Ω (wet resistance tolerance is not critical).
- 8.3.3.2.3. If after one minute, resistance value is less than 80,000 Ω, or over 1,000,000 Ω, return sensor to manufacturer.

8.4. Installation

8.4.1. Mount sensor on the 3-m (10-ft) meteorological mast (SOP U5) at 2-m (6.6-ft) height, according to SOP W6.

8.4.2. Pass cable along ground to weatherproofed NEMA 4X box (SOP W6) and through specified knockout.

8.4.3. Attach sensor wires to data logger according to SOP W6 using the 1/8″ slotted screwdriver.

8.4.3.1. Connect black wire to 5 VAC excitation, purple wire to ground, clear wire to ground, and red wire to analog single ended measurement channel.

8.4.3.2. Data logger will log voltage returned from the wetness sensor's output wire (red wire) as a ratio of the measured voltage divided by the excitation voltage (Vs/Vx). The datalogger applies 5 VAC to the sensor's exciter (black) wire.

- 8.4.3.2.1. Sensor resistance (Rs) is recorded as a voltage ratio using the following calculation: Vs/Vx=R2/(R2+R1+Rs).
- 8.4.3.2.2. R1 and R2 are fixed values; R1=100,000 Ω and R2=1,000 Ω (Fig. 1 of Model 237 manual).
- 8.4.3.2.3. For example, if the sensor resistance is 101,200 Ω, the voltage ratio recorded would be 0.0049455 (1000(R2)/(102,200(R2+R1+Rs)).

8.4.3.3. This logged voltage will indicate the condition the sensor is currently detecting.

8.4.3.4. Values from 4.524 mV to 1.663 mV (120,000 Ω < Rs < 500,000 Ω will indicate "Wet" conditions.

8.4.3.5. Values less than 0.3124 mV (Rs >3,100,000 Ω) will indicate "Dry" conditions.

8.4.3.6. Values between 1.663 mV and 0.3124 mV 500,000 Ω < Rs < 3,099,999 Ω) will indicate transition "Conditions other then wet or dry".

8.4.4. While sensor is dry, check to see that data logger is indicating "Dry" conditions. Check wiring connections for error if response is incorrect.

8.4.5. Rinse the wetness grid with tap water and verify data logger's proper "Wet" response. Check wiring connections for error if response is incorrect.

8.5. Troubleshooting

8.5.1. If readings are noisy or erratic, check for poor connections.

8.5.2. If sensor does not respond to wetness, check for broken wires or connections.

8.6. Data acquisition, calculations & data reduction requirements

8.6.1. Analog input is monitored by the datalogger.

- 8.6.1.1. Ratio of excitation to sensor resistance is recorded and then calculated at PAML to be "Wet", "Dry" or "Conditions other then wet or dry", based on sensor resistance calculated from recorded voltage ratio.
- 8.6.2. Datalogger will record measurements every 5 minutes.
- 8.7. Computer hardware & software.
  - 8.7.1. Attach the sensor to a Campbell Scientific datalogger through electrical wires that will extract data from the instruments.
  - 8.7.2. The Campbell Scientific data logger will record the data and store it.
  - 8.7.3. Datalogger operates using on-board BASIC-like programming.
    - 8.7.3.1. The general program for measurements is stated in the Model 237 Manual.

9. Data and Records Management

- 9.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method, and in a record book designated for meteorological sensors.
- 9.2. Manage all data according to SOP D1.
- 9.3. Document all data and information on field notes with permanent ink, or in electronic notes. Overstrike errors in ink with a single line, then initial and date the overstrike.

10. Quality Control and Quality Assurance

- 10.1. Daily check from PAML
  - 10.1.1. If value is -6999, flag with "1".
    - 10.1.1.1. Voltages over the maximum measurable input are indicated by data logger as -6999, and indicate sensor failure (short circuit). Dispatch personnel to check sensor and sensor wiring on site.
  - 10.1.2. Check weather data from an outside source for the area such as http://www.crh.noaa.gov/iwx/index.php?mystation=KLAF (Lafayette, IN). If indicated data does not match conditions shown by outside weather sources on two or more days:
    - 10.1.2.1. Flag recorded value with a "2" as invalid.
    - 10.1.2.2. Dispatch personnel to check sensor and sensor wiring on site.
      - 10.1.2.2.1. If damage is indicated, repair or replace as indicated in Section 8.4.
- 10.2. Perform the following checks at the beginning and end of each measurement period.
  - 10.2.1. Check to be sure probe surface is clean.
    - 10.2.1.1. If dirty, clean with distilled water and cloth.
  - 10.2.2. Check integrity of the plastic casing of the signal cable.
    - 10.2.2.1. If damaged slightly, repair with heat-shrink tubing.
    - 10.2.2.2. If damaged significantly, replace sensor and return sensor to manufacturer for repair.
  - 10.2.3. Wet sensor with tap water.
    - 10.2.3.1. Check datalogger for value corresponding to a wet sensor
    - 10.2.3.2. If data logger does not indicate wet conditions, check wiring (Section 8.2).
  - 10.2.4. Dry sensor.
    - 10.2.4.1. Check datalogger for value corresponding to a dry sensor.

10.2.4.2. If data logger does not indicate dry conditions, check wiring (Section 8.2).

10.2.5. Record results of checks on the site logbook and electronic spreadsheet.

11. References

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11.2. SOP D1. 2006. Management of Weather and Lagoon-Characterization Data. Standard Operating Procedure D3. Purdue Applied Meteorology Lab.
11.3. SOP U5. 2006. The Installation of Open-source Measurement Equipment. Standard Operating Procedure U5. Purdue Applied Meteorology Lab.
11.4. SOP W6. 2006. Establishment, Data Acquisition and Control of Weather and Lagoon Characterization Hardware. Standard Operating Procedure W6. Purdue Applied Meteorology Lab.

12. Contact Information

12.1. Distributor: Campbell Scientific, Inc., 815 West 1800 North, Logan, Utah, 84321

12.1.1. Technical support: 435-753-2342

Appendix A

Calibration Check Form: Campbell Scientific Resistance Grid Wetness Sensor

Instrument Serial Number:________________________________ Location:__________________________________

Date (D-M-Y)	Time		Resistance (Ω)		Action Taken (Adjust, Replace)	Analyst
	Begin	End	Dry	Wet		

THE MEASUREMENT OF BAROMETRIC PRESSURE WITH THE SETRA MODEL 278 (CAMPBELL SCIENTIFIC CS100) BAROMETER

Standard Operating Procedure (SOP) W5

THE MEASUREMENT OF BAROMETRIC PRESSURE WITH THE SETRA MODEL 278 (CAMPBELL SCIENTIFIC CS100) BAROMETER

Standard Operating Procedure (SOP) W5

Prepared by
Richard H. Grant

Reviewed by
Albert. J. Heber and Bill W. Bogan

Effective Date: November 6, 2006

PURDUE APPLIED METEOROLOGY LABORATORY (PAML)
Agronomy, Purdue University
West Lafayette, IN 47907

Table of Contents

1. Scope and Applicability

1.1. Barometric pressure measurements are needed to determine the mass concentration of gases from volume concentration measurements.
1.2. The resonant frequency of silicon is a useful means of measuring pressure.
1.3. The lower detection limit for the instrumentation described in this SOP is 600 hPa.
1.4. The range of the instrument, under normal atmospheric conditions, is from 600 to 1100 hPa.
1.5. Sensor response is 5mV / hPa.
1.6. Sensor accuracy is ±3 hPa
1.7. This procedure applies only to the Setra model 278 barometric pressure sensor, purchased as CS100 Barometric Pressure Sensor
1.8. This procedure applies to the open source portion of the National Air Emissions Study.

2. Summary of Method

Barometric pressure is measured using two closely-spaced, parallel, electrically-isolated metallic surfaces, one of which is essentially a diaphragm capable of slight flexing under applied pressure. The surfaces are mounted to allow slight mechanical flexing by small changes in pressure. Changes in the gap between the surfaces change the electrical capacitance of the gap, which is detected and converted to a proportional high level analog signal. The Setra model 278 sensor is used under this SOP because it is well-suited to long-term environmental applications, as its housing and all of its wettable parts are constructed of stainless steel or polyester. The sensor itself is enclosed in a thermally stable, low-hysteresis glass fused ceramic capsule which minimizes temperature effects on pressure readings.

3. Definitions

ARM	Atmospheric Radiation Monitoring Network
CS	Campbell Scientific, Inc
hPa	The S.I. unit of pressure is Pascal. The worldwide meteorological community uses the hectopascal(hPa) i.e. a hundred Pascals, which is the metric equivalent of a millibar. “Standard atmospheric pressure=1013 hPa = 101,325 Pa= 101.3 kPa=760 mm Hg=14.696 psi.”
NEMA	National Electrical Manufacturers Association
PAAQL	Purdue Agricultural Air Quality Laboratory
PAML	Purdue Applied Meteorology Laboratory
QAPP	Quality Assurance Project Plan
VDC	Direct Current voltage

4. Cautions

4.1. Static charge damages the sensor. To avoid damage, take adequate anti-static measures when handling.
  4.1.1. Wear an antistatic wrist strap that is properly connected to earth ground when in contact with the sensor.
  4.1.2. If an antistatic wrist strap is not available, discharge static electricity by touching a grounded metal object before touching the sensor itself.

5. Interferences

5.1. Failure to provide an open vent at the bottom of the NEMA 4X box will interfere with barometric measurements by blocking the sensor's ability to sense atmospheric pressure changes.
5.2. Failure to protect sensor from condensation or liquid water may cause permanent damage. See Section 8.2.2 for proper installation to avoid condensation. Place desiccant inside the NEMA box to absorb any moisture which does occur.

6. Personnel Qualifications

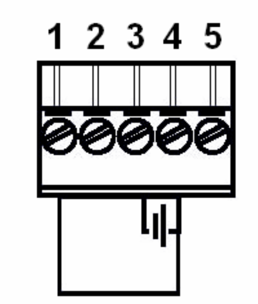
6.1. Personnel must be trained in the use of the handheld frequency multimeter before initiating the procedure. Training requires 10 min.
6.2. Personnel must be trained in the use of the power supply before initiating the procedure. Training requires 10 min.
6.3. Each staff member must read and understand the sensor instruction manual and this SOP before operating this sensor.

7. Equipment and Supplies

7.1. Multimeter
7.2. #2 Phillips head screwdriver
7.3. 1/8" slotted screwdriver
7.4. 2-inch length of jumper wire
7.5. 12 VDC power supply
7.6. 2-in. section of plastic tubing
7.7. Toothbrush
7.8. Electrical cleaner
7.9. Fortin Barometer (kept at PAML)
7.10. CS100 Barometric Pressure Sensor
7.11. NEMA 4X Box
7.12. Campbell Scientific Data Logger

8. Procedures

8.1. Acceptance



8.1.1. Connect terminal 4 to positive terminal of 12 VDC supply and terminal 3 to power supply ground (See diagram at right).
8.1.2. Connect a jumper across terminals 1 and 4.
8.1.3. With multimeter off, connect terminal 2 to negative terminal of multimeter and terminal 5 to positive terminal of multimeter.
8.1.4. Turn multimeter on and set to mV DC.
8.1.5. After 2 s, read measured voltage on multimeter.
8.1.6. Voltage should be approximately 1-2.25 VDC (800-1050 hPa).
  8.1.6.1. If values are less than 1V or greater than 2.25 VDC, the sensor is defective, and should be returned to the manufacturer for replacement or repair.

8.2. Setup

8.2.1. Mount the instrument on the inside of the NEMA 4X box on the 10-foot mast according to SOP U5.
8.2.2. Mount the sensor with the pneumatic connector pointing vertically downwards to prevent condensation collecting on the pressure cavity and ensure that water cannot enter the sensor. Place fork lug under the mounting screw for grounding.
8.2.3. Using the 1/8”slotted screwdriver, connect the red wire to 12 VDC supply, black to power ground, yellow to signal ground, clear to shield, green to the external trigger (control terminal), and blue to a single-ended analog terminal of the data logger, according to SOP W6.
8.2.4. On power-up, the sensor requires less than 1 second of warm-up time.
8.2.5. The voltage across the blue and yellow wires (when terminals 1 and 4 are jumper wired as in Step 8.1.2) should be approximately 1-2.25 VDC (800-1050 hPa).
  8.2.5.1. If values are less than 1 VDC, the sensor is defective, and should be returned to the manufacturer for replacement or repair.

8.3. Calibration

8.3.1. Calibrate the sensor every 6 mos., or at a different frequency if specified by the QAPP for a particular project.
8.3.2. Calibrate the sensor system (sensor and data logger) against a Fortin Barometer at PAML.
  8.3.2.1. Follow the procedures for reading and adjusting the Fortin barometer documented in Appendix A of this SOP.
  8.3.2.2. Read instantaneous measurements from datalogger/ sensor system at the time of each Fortin Barometer reading.
8.3.3. Conduct six paired measurements over a two–day period, average mean of their respective readings are taken out and if this matches then it is calibrated.
8.3.4. Record the results of the calibration on the sensor lab notebook form (Appendix B).
  8.3.4.1. If the mean difference between Fortin barometer and senor/datalogger measurement is less than or equal to 2 hPa, then the sensor passes calibration and the drift is back-corrected according to Equation 1.

$$P_{corr}(t) = P(t)\left[1 - \frac{\overline{P_{measured}(i) - P_{\exp ected}(i)}}{\overline{P_{\exp ectd}}}\right]\left(\frac{t}{p}\right) \qquad \text{(Equation 1)}$$

Where:
P_{corr} = Back-corrected value at time t into the last measurement period
$P(t)$ = Original measured value at time t
$P_{measured}$ = Measured barometric pressure during calibration comparison
$P_{expected}$ = Barometric pressure indicated by the Fortin barometer during calibration comparison
p = Length of time between calibrations

8.3.4.2. If the mean difference between Fortin barometer and senor/datalogger measurement is >2 hPa, return sensor to manufacturer for repair or replacement.
  8.3.4.2.1. If the mean difference is <6 hPa, adjust measurements since the last passed calibration linearly over time to the current calibration to account for the drift according to Equation 1. Correction coefficients determined at this point can be entered into the PAML computers to correct data collected during the next measurement period; the QAPP for a particular project will specify whether or not this is to be done.
  8.3.4.2.2. If the mean difference is >6 hPa, invalidate barometric pressure measurements over the preceeding measurement period.

8.4. Troubleshooting
  8.4.1. If pressure measurements vary widely over 24 h, check that the NEMA box is not ‘hermetically sealed’. A hermetic seal is evident when air is distinctly forced out at the sides of the opening when the box is closed.
  8.4.2. Be sure there is no condensate in the NEMA box.
  8.4.3. Visually inspect the casing for damage.
  8.4.4. Ensure there is a secure, clean ground connection.
  8.4.5. Ensure that the pneumatic connection and tubing are secure and undamaged.
  8.4.6. Replace desiccant in the NEMA box as needed.

8.5. Data acquisition, calculations & data reduction requirements
  8.5.1. Monitor the analog voltage output with a Campbell Scientific datalogger or equivalent data acquisition system (See SOP W6).
  8.5.2. Take measurements every 5 min
  8.5.3. Report voltage data to five significant digits.

8.6. Computer hardware & software
  8.6.1. Attach the sensors through electrical wires to a Campbell Scientific datalogger (or equivalent data acquisition system) that will extract data from the instruments.
  8.6.2. The logger program for reading the sensor is written in a version of BASIC language.
    8.6.2.1. The program converts the sensor voltage to hPa using the following formula:

$$\text{hPa} = 600 + 0.2\ \text{mVDC} \qquad \text{(Equation 2)}$$

8.6.2.2. The sensor units are logged as hPa.

8.6.3. Record and store the data with the datalogger.

9. Data and Records Management

9.1. Maintain all laboratory records in a worksheet of the electronic field notes spreadsheet designated for this method, as well as in a bound record book designated for meteorological sensors.

9.2. Manage data according to SOP D1.

9.3. Record the calibration information on the form provided in Appendix B.

9.3.1. Maintain a separate record sheet for each individual sensor.

9.4. Document all data and information on field data sheets and in site logbooks with permanent ink, or in electronic notes.

9.5. Overstrike errors in writing with a single line. Initial and date all corrections.

10. Quality Control and Quality Assurance

10.1. Daily

10.1.1. If value is missing, flag with “1”.

10.1.2. If value is less than 600 hPa or greater than 1100 hPa (i.e. outside the range of the sensor), then flag value with “2”.

10.1.3. Calculate the altitude-adjusted barometric pressure from the nearest National Weather Service Weather Station.

10.1.3.1. Correct NWS measured pressure to height of measurement location according to Equation 2 (Holton, 1979):

$$P_{site} = P_{NWS} e^{-(Z_{site} - Z_{NWS})/H} \qquad \text{(Equation 3)}$$

Where:

P_{site} = Height-adjusted NWS pressure for site

P_{NWS} = Pressure at NWS station

Z_{site} = Site elevation

Z_{NWS} = NWS station elevation

H = $287(T_{NWS})/9.80665$

T_{NWS} = Absolute temperature (ºK) at NWS station.

10.1.4. If the altitude-adjusted difference between the barometric pressure at the sampling site and the nearest local weather station is > 4 hPa , then flag the day’s data with “3”.

10.1.4.1. Further investigation of the cause for the difference (such as synoptic weather front over the area) will be conducted.

10.2. Repeat the Acceptance Check (Section 8.1) before beginning a measurement period (i.e. during the setup of equipment at a site).

10.3. Do the following at the beginning and end of each measurement period:

10.3.1. Visually inspect the casing for damage.

10.3.1.1. Replace sensor if damaged.

- 10.3.2. Ensure there is a good secure and clean ground connection.
  - 10.3.2.1.Secure ground if needed.
- 10.3.3. Ensure that the pneumatic connection and tubing is secure and undamaged.
  - 10.3.3.1.Replace tubing if needed.
- 10.3.4. Check dessicant in the NEMA box.
  - 10.3.4.1. Replace as needed.
- 10.3.5. Check cleanliness of connectors.
  - 10.3.5.1.If corroded, clean with toothbrush and electrical cleaner.

11. References

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11.7. SOP W6. 2006. Establishment, Data Acquisition and Control of Weather and Lagoon Characterization Hardware. Standard Operating Procedure W6. Purdue Applied Meteorology Lab.

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11.11. USEPA. 2000. Meteorological Monitoring Guidance for Regulatory Modeling Applications, EPA-454/R-99-005.

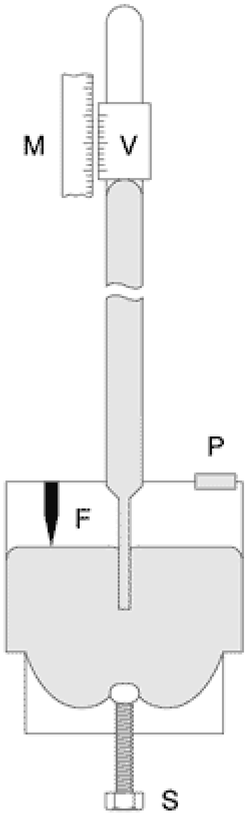
12. Contact Information

- 12.1. Distributor: Campbell Scientific, Inc., 815 West 1800 North, Logan, UT, 84321
  - 12.1.1. Technical support: 435-753-2342
- 12.2. Manufacturer: Setra Systems, Inc., 159 Swanson Road, Boxborough, MA 01719
  - 12.2.1. Repair Dept. Fax: 978-266-2158/Phone: 978-266-2194

Appendix A. Fortin Barometer Operation

The correct procedure for measuring pressure with a Fortin Barometer is:

- Adjust the cistern mercury surface to within a small distance of the fiducial point.
- Tap the barometer (to achieve a stable meniscus).
- Set the fiducial point.
- Set the vernier.
- Measure the barometer's temperature (and add calibration correction).
- Read the vernier.
- Apply the calibration correction for the barometer.
- Apply the temperature and gravity corrections (from tables or formula).



Fortin barometers should be used with their axis of rotation vertical - such that a setting of the mercury surface to the fiducial point remains correct after axial rotation through any angle.

<u>Setting the Fiducial Point (F in diagram at right)</u>

The lower mercury surface in a Fortin barometer has to be set to a datum level before adjusting its vernier (see schematic diagram) and the accuracy of pressure measurement depends crucially upon proper setting.

To achieve this, the mercury surface should first be lowered until it is clearly *below* the fiducial point (F in diagram at right). After tapping the barometer, the level-adjusting screw (S in diagram at right) should be turned slowly until the thin background of light between the mercury surface and the point just disappears, while viewed along a horizontal line of sight. To confirm proper setting, observe the point of contact at an angle of elevation of about 30° and determine whether or not the fiducial point is making an indentation in the mercury.

When the setting is correct there should be no more than the slightest dimple where the fiducial point makes contact with the mercury surface. If the surface is bright and the setting correct, the tip of the point will appear to coincide with its reflected image in the mercury surface. Correct setting is achieved when the mercury surface is *raised* to the fiducial point but not lowered - if the mercury surface overshoots the point it should be lowered and then raised again.

<u>Setting the vernier</u>: With suitably bright background illumination (using flashlight aimed at the white plastic background for the vernier), and taking care to correctly align the front and back setting edges, the vernier cursor (V in diagram at right) should be lowered until it appears on the

summit of the mercury meniscus. Proper setting can be aided by making small 'pecking' head movements to ensure that both cursor edges just meet the meniscus. Read the vernier.

Measuring temperature: Mercury barometers have a temperature coefficient of nearly 0.2 hPa per °C so it is important to ensure that their thermometers respond to ambient temperature changes in the same fashion as the barometer. Read the temperature off the thermometer attached to the barometer case.

Calculation of pressure from barometer readings: Three corrections to the measured barometric pressure must be made:

- Temperature correction
- Calibration correction
- Gravity correction

Theoretically, the corrections are made according to the following equations:

$$t = (t` - 32) * 5/9$$

$$\text{Pressure} = \frac{g}{9.806\,65}\left\{R + c - R\frac{(b-a)\,t}{(1+bt)}\right\}$$

where R is the barometer reading (in inches Hg)
c is its calibration correction (+.003 in Hg for barometer at PAML)
g is the acceleration due to gravity at the level of the barometer in m/s^2 (see below)

b is the coefficient of expansion of mercury (taken to be 0.000 181 8 $°C^{-1}$ for meteorological purposes)
a is the coefficient of linear expansion of the scale (taken to be 0.000 018 4 $°C^{-1}$ for brass)
t is the temperature of the barometer in °C
$t`$ is the temperature of the barometer in °F

and $g = 9.780\,318\,4\,(1 + A\sin^2 L - B\sin^2 2L) - 3.086\times10^{-6}\,H$

where A = 0.005 302 4
B = 0.000 005 9
L = Latitude (40.5)
H = height of barometer meters above sea level (197 m)

At West Lafayette, g = 9.80153, so the gravity correction is 9.80153 / 9.80665 = 0.999.

The correction terms involving a, b, and c were combined in the following table. To correct for the barometer local gravity and temperature, multiply the measured value by the value from the following tables and subtract from the measured value, then multiply by 0.999.

deg. F	correction	deg. F	correction	deg. F	correction
50	0.001631	70	0.003436	90	0.005234
50.5	0.001676	70.5	0.003481	90.5	0.005279
51	0.001721	71	0.003526	91	0.005324
51.5	0.001767	71.5	0.003571	91.5	0.005369
52	0.001812	72	0.003617	92	0.005414
52.5	0.001857	72.5	0.003662	92.5	0.005459
53	0.001902	73	0.003707	93	0.005504
53.5	0.001947	73.5	0.003752	93.5	0.005548
54	0.001993	74	0.003797	94	0.005593
54.5	0.002038	74.5	0.003842	94.5	0.005638
55	0.002083	75	0.003887	95	0.005683
55.5	0.002128	75.5	0.003932	95.5	0.005728
56	0.002173	76	0.003977	96	0.005772
56.5	0.002219	76.5	0.004022	96.5	0.005817
57	0.002264	77	0.004067	97	0.005862
57.5	0.002309	77.5	0.004111	97.5	0.005907
58	0.002354	78	0.004156	98	0.005952
58.5	0.002399	78.5	0.004201		
59	0.002444	79	0.004246		
59.5	0.002489	79.5	0.004291		
60	0.002535	80	0.004336		
60.5	0.00258	80.5	0.004381		
61	0.002625	81	0.004426		
61.5	0.00267	81.5	0.004471		
62	0.002715	82	0.004516		
62.5	0.00276	82.5	0.004561		
63	0.002805	83	0.004606		
63.5	0.00285	83.5	0.004651		
64	0.002896	84	0.004696		
64.5	0.002941	84.5	0.004741		
65	0.002986	85	0.004786		
65.5	0.003031	85.5	0.004831		
66	0.003076	86	0.004875		
66.5	0.003121	86.5	0.00492		
67	0.003166	87	0.004965		
67.5	0.003211	87.5	0.00501		
68	0.003256	88	0.005055		
68.5	0.003301	88.5	0.0051		
69	0.003346	89	0.005145		
69.5	0.003391	89.5	0.00519		

Appendix B.

Calibration Record: Setra 278 Barometric Pressure Sensor

Instrument Serial Number:________________________________ Location:_________________________________

Date (D-M-Y) Time: Begin-End (HHMM-HHMM)	Temp. (°C)	Manometer pressure (in. Hg)	Hg Temp. correction (in. Hg)	Pressure			Difference hPa	Action*	Analyst
				Corrected		Measured			
				in. Hg	hPa**	hPa			

* Sensor adjustment or replacement made after the measurement, if necessary. If action is taken, next entry should show result of re-calibration following that action.

**1hPa = 0.02953 in Hg

APPENDIX D

EMISSIONS DATA FROM TWO BROILER CHICKEN HOUSES IN CALIFORNIA
Final Report for Site CA1B
of the
National Air Emissions Monitoring Study

EMISSIONS DATA FROM TWO BROILER CHICKEN HOUSES IN CALIFORNIA

Final Report for Site CA1B

of the

National Air Emissions Monitoring Study

Submitted to

John Thorne, Executive Director
Agricultural Air Research Council
C/O Crowell and Moring, LLP
1001 Pennsylvania Avenue, NW
Washington, DC 20004

and

Bill Schrock, Environmental Engineer
U.S. EPA Office of Air Quality Planning and Standards
Mail Code E143-03, 4930 Page Road
Durham, NC 27703

by

Albert J. Heber, Professor and NAEMS Science Advisor
Agricultural and Biological Engineering, Purdue University
225 S. University St., West Lafayette, IN 47907
Phone: 765-494-1214 Email: heber@purdue.edu.

July 2, 2010

Contributors

Ruihong Zhang, Xing Jun Lin, Shumei Jiang
Biological and Agricultural Engineering
University of California
One Shields Avenue
Davis, CA 95616

Erin L. Cortus
Agricultural and Biosystems Engineering
South Dakota State University
Box 2120
Brookings, SD 57007

Albert J. Heber, Juan Carlos Ramirez, Jiqin Ni, Claude Diehl, Changhe Xiao, Bill W. Bogan
Agricultural and Biological Engineering
Purdue University
225 S. University St.
West Lafayette, IN 47907

Teng T. Lim
Agricultural Systems Management
University of Missouri
220 Agricultural Engineering Building
Columbia, MO 65211

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Table of Contents

1. INTRODUCTION AND OBJECTIVES

1.1. Overview of NAEMS

The primary goals of the National Air Emissions Monitoring Study (NAEMS) were to: 1) quantify aerial pollutant emissions from dairy, pork, egg, and broiler production facilities, 2) provide reliable data for developing and validating emissions models for livestock and poultry production and for comparison with government regulatory thresholds, and 3) promote a national consensus on methods and procedures for measuring emissions from livestock operations. Emissions measurements were conducted at a total of 15 different barn monitoring sites and ten open source sites in the continental US.

The NAEMS was managed by Purdue University, in its role as Independent Research Contractor (IRC) to the Agricultural Air Research Council. Purdue selected equipment and methods in consultation with the U.S. EPA, and subcontracted with other universities to operate the monitoring sites. The University of California-Davis (UCD) maintained and calibrated equipment, collected samples, and conducted all other on-site activities. Purdue provided rapid feedback (generally within 2-4 business days) to catch aberrations in the data, and later conducted final processing of the data. Both UCD and Purdue participated in reviews of the analyzed data.

The overall objective of this report is to present the quality-assured measurements of ammonia (NH3), hydrogen sulfide (H2S), non-methane hydrocarbons (NMHC), ethanol (EtOH), particulate matter (PM) and volatile organic compounds (VOCs) from two broiler houses at the California chicken growout facility. The specific objectives of the report are to:

1. Describe the farm, and the monitored buildings,
2. Describe the monitoring methods and quality assurance, and
3. Present tabulated daily averages of emissions.

2. CONFINED ANIMAL FEEDING OPERATION

2.1. Farm

This 336,000-bird broiler ranch (CA1B) was located in California. Other livestock or poultry sources near the ranch were a hatchery just over 1.6 km west of the ranch, a 10-house broiler ranch approximately 1.2 km to the north-northwest, and a large dairy about 0.8 km to the northwest.

The production facility had a total capacity of 336,000 broiler chickens and consisted of 16 mechanically-ventilated houses that were oriented east-west (Figure 1). Birds were fed a pelleted corn and soy based diet. All litter was removed from the houses after three flocks, and taken off-site within 2-3 d of cleanout. Between each flock, the top 20 to 25% of the litter was removed the entire length of the house. Bird genetics were 60% Cobb, 40% Ross.

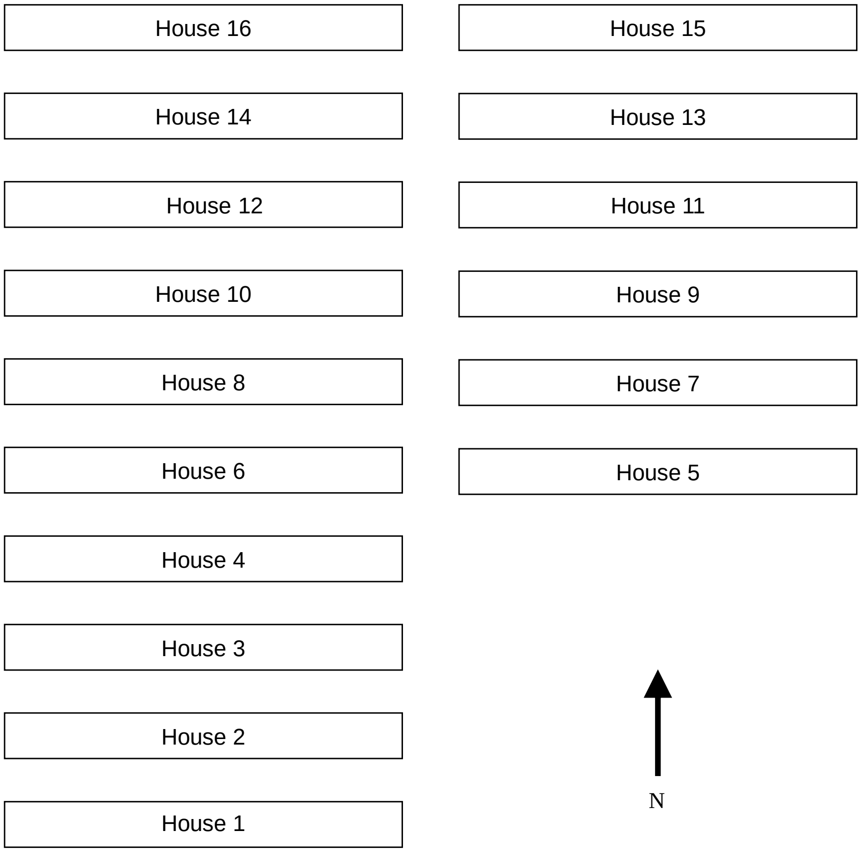

Figure 1. Facility layout. Monitored buildings were houses 10 and 12

2.2. Monitored Buildings

Houses 10 and 12 (H10 and H12) were spaced 12.2 m apart. The roofs had a 4:12 slope with sidewall heights of 2.3 m. Each house was 125 m long x 12.2 m wide and housed 21,000 birds that grew from 0.05 to 2.4 kg. Six to seven flocks of birds were raised in each house every year, and all houses were on the same grow-out cycle. During cooler weather, the front half of the house was heated by 12.3 kW Radiant Brooders, while the rest of the house was heated by 52.7 kW White Convection LP heaters. During warmer conditions, supplemental cooling was provided by evaporative pads, which were located at the east ends of the houses. These were Munters pads made of a paper product, and were 1.2 m high, 0.2 m deep and 0.3 m wide.

Birds were fed a pelleted diet consisting of corn, soybeans, protein, and poultry fat. Four feed rations were used, specially formulated for weeks 1 and 2, weeks 3 and 4, and week 5 and week 6. Feed was delivered by auger. Water consumption was recorded by an automatic water meter. The lights were shut off for several hours each night. A standby generator supplied power for critical systems during power outages.

Ventilation air entered the house through pressure-adjusted baffled air inlets at the eaves. The air was exhausted out the west end of the house where there were ten, 122-cm diameter belted exhaust fans (Model 48318-235, Chore-Time, Milford, IN) located in banks of five fans on the north and south sidewalls. The fans within each bank of fans on the north and south walls were 20 cm apart. The 122-cm fans were powered by 746-W fan motors (General Electric Model # 5KCR49UN0462AT). The five fans located on the south sidewall (Figure 2) were numbered 3 thorough 7, and the five fans located on the north wall were numbered 8 thorough 12. In addition, there was one 91-cm diameter belted exhaust fan (Model AT365Z1CP, Aerotech, Mason, MI) located on the west wall at the back of the house. This fan was designated as fan 2, and had a 373-W motor (Aerotech Model # 177509-01) (Figure 2). Finally, there was one other 91-cm diameter belted exhaust fan (Model AT365Z1CP, Aerotech, Mason, MI), designated fan 1, located on the east wall; however, this fan was disabled and inactive during the study. The house had six temperature sensors. Fan relay control regimes included eight strategies, which depended on the age of the birds and the maximum temperature. The transition temperature between strategies was 24ºC. Eight of the 10 fan relays controlled single fans, while relays 6 and 10 each controlled two 122-cm fans (Table 1).

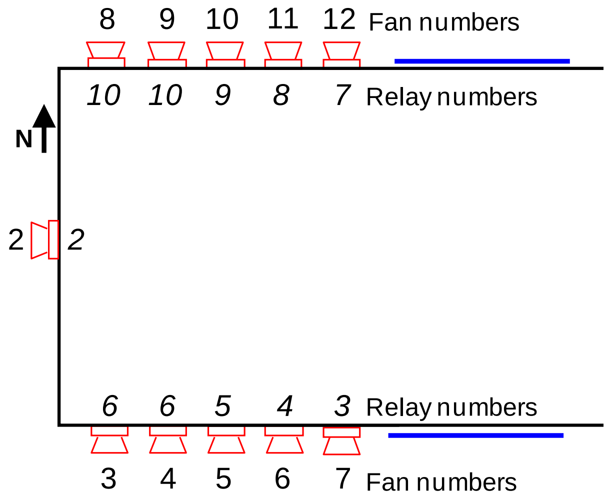

Figure 2. Relay assignments to control fans. Relays 6 and 10 each control two adjacent fans.

All litter was removed from the houses after three flocks, and was taken off-site to a fertilizer plant within 2-3 d (Table 2). Prior to being removed from the site, manure remained in piles to the west of the houses. Between each flock, the top 20 to 25% of the litter was removed the entire length of the house in a decaking operation using a commercial poultry litter cleanout machine (Housekeeper, Lewis Brothers, Baxley, GA). After decaking, the remaining litter at the front of the house was moved to the back of the house and 34.4 m^3 of rice hulls were placed in the front using a 3.8 m^3 Soil Mover. The birds were concentrated in the east end of the houses during the first 10 d of each cycle.

2.3. **Significant Events and Modifications**

Chicken genetics remained the same and there were no significant weather, management, or construction events that impacted the monitoring period.

The ventilation fans were maintained by the producer as required. On 4/20/08, the belts were replaced on all fans.

Table 1. Fan relay control for the various stages of the eight temperature control regimes.

Fan relays running	% on	Scheme[1]							
		1	2	3	4	5	6	7	8
Tunnel Ventilation									
3,4,5,6,7,8,9,10									■
3,4,5,6,7,10									■
3,4,5,6,7,8									■
3,4,5,7,8,9								■	■
3,4,5,7,8							■	■	■
3,4,7,8						■	■		
3,4,7						■			
3,7					■				
3,2					■				
Power Ventilation									
3,4,5,7,8				■					■
3,4,5,6				■					
3,4,7,8						■	■	■	■
3,4,7,2						■			
3,4,7						■	■	■	■
3,7,5				■					
3,7,2				■					
3,7,2						■	■	■	
3,7						■	■	■	■
3,7	100		■	■					
3,7	80			■					
3,7	80								■
3,7	60							■	
3,2	100	■	■	■	■	■	■		
3,2	80					■	■		
3,2	75			■					
3,2	50			■		■	■		
3,2	35			■		■	■		
3,2	20			■					
3,2	10			■					
3,2	50	■	■						
3,2	30	■	■						
3	100	■	■		■				
3	75	■	■		■				
3	50	■	■		■				
3	35	■	■		■				
3	20	■	■		■				
3	10	■	■		■				

[1] Scheme numbers: 1 = Days 1-9, 2 = Days 10-28, 3 = Days 28-ship, 4 = Days 1-9 (T>24), 5 = Days 10-14 (T>24), 6 = Days 15-24 (T>24), 7 = Days 25-29 (T>24), 8 = Days 29-ship (T>24).

Table 2. Flock and manure removal schedule.

Flock	Hatch date, m/d/y	Ship out date, m/d/y	Cycle length, d	Empty house, d	Manure cleanout method
1	09/20/07	11/4/2007	45	11	Load out
2	11/15/07	1/1/2008	48	4	Decaking
3	01/05/08	2/21/08	47	7	Decaking
4	02/28/08	4/15/08	47	7	Load out
5	04/22/08	6/6/08	45	8	Decaking
6	06/14/08	8/1/08	48	10	Decaking
7	08/11/08	9/27/08	47	23	Load out
8	10/20/08	12/4/08	45	8	Decaking
9	12/12/08	1/28/09	47	12	Decaking
10	02/09/09	3/28/09	46	13	Load out
11	04/10/09	5/27/09	47	8	Decaking
12	06/04/09	7/21/09	47	9	Decaking
13	07/30/09	9/14/09	46	12	Load out
14	09/26/09	11/10/09	45		
Mean			46	12	

3. MONITORING AND SAMPLING METHODS

3.1. General Approach

Equipment installation and preliminary testing began on 5/29/07 and was completed on 9/27/07. The site setup and equipment installation followed an approved site monitoring plan, a quality assurance project plan, and instrument or method-specific standard operating procedures.

The monitoring period began on 9/27/07 and concluded on 10/21/09. Target pollutants were NH_3, H_2S, NMHC, EtOH, PM (PM_{10}, TSP, and $PM_{2.5}$), and VOC. Appendix A lists the target pollutants, and all measured supporting variables and monitored metadata. The monitoring schemes for the two structures are shown in Figure 3. **Error! Reference source not found.** lists the major equipment.

3.2. Instrument Shelter

The on-farm instrument shelter (OFIS) was located at the far west end of the space between houses 10 and 12, with a north-south orientation to minimize interference with vehicular traffic along the driveway west of the houses. The OFIS was positioned off-center between the houses to provide access for mowing equipment. Heated raceways were used to connect the OFIS with each house, to avoid condensation in the sampling lines during cold weather.

The OFIS was supplied with 3-wire, single-phase, 120/240-volt, 100 A at 240 V power by the farm. A copper ground rod was installed at the location of the OFIS and connected to the OFIS ground. The HVAC system of the OFIS maintained inside temperatures within the operating range of the analyzers, and created a positive pressure with a filtered outside air intake to minimize entry of unfiltered outside air.

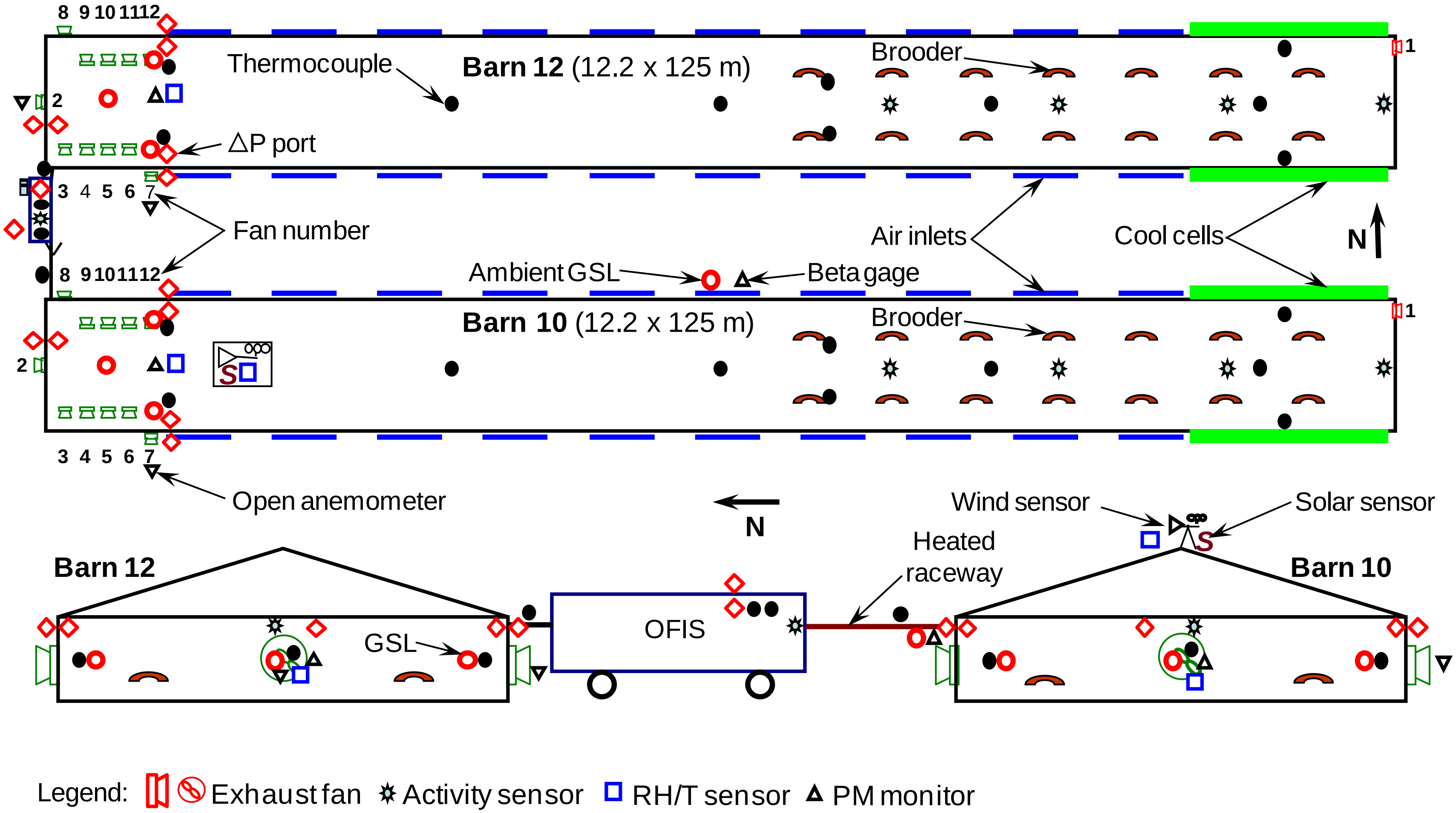

Figure 3. **Overhead and endwall view of sensor and air sampling locations at the building monitoring site.**

One set of gas analyzers () in the OFIS measured gas concentrations as the gas sampling system (GSS) sequenced through all the gas sampling locations (GSLs). Vacuum pumps and controllers for the PM monitors were located in the OFIS. A personal computer collected all site monitoring data using a data acquisition and control program AirDAC.

Table 3. Major instrumentation.

Analyzer/Instrument	Serial number
INNOVA 1412 Multi-gas analyzer	710-209
TEI 450i H_2S analyzer	709220684
Environics 4040 dilutor	3920
TEOM 1 (House 10)	263760609
TEOM 2 (House 12)	265160702
TEI FH 62C14 (Beta Gauge)	E-1300

3.3. Data Acquisition and Control System

The data acquisition and control system consisted of a personal computer, custom software (AirDAC) written in a commercial programming language (LabVIEW, National Instruments, Austin, TX), distributed I/O hardware (National Instruments FieldPoint modules), and Universal Serial Bus (USB) devices by National Instrument (NI) and Measurement Computing (MC, Norton, MA). The NI FieldPoint (FP) modules and MC USB devices (Table 4) were selected and configured to acquire data for all the on-line measurement variables (Appendix A).

The 16-channel NI FP-DO-401 digital output module was used to control: 1) sequential switching of multiple gas sampling lines, 2) the raceway heating system, and 3) the GSS cooling fan. Serial communication (RS232) was used to acquire data from the multi-gas monitor and calibration variables (calibration time, gas concentration, etc.) from the gas dilutor. Voltage or current analog signals from various analyzers and sensors were connected to FP-AI-112 modules. Type T thermocouples were connected to FP-TC-120 modules. Digital signals from relays were connected to the MC USB DIO96H device. Voltage pulses from proximity sensors used to measure fan rotational speed were detected by the MC USB 4303 Counter.

Table 4. Data acquisition hardware configuration.

Manufacturer and model	I/O type	# units	# channels	Notes
NI FP-AI-112	Analog input	3	16	Single-ended, 16-bit
NI FP-TC-120	Thermocouple	4	8	
NI FP-DO-401	Digital output	1	16	2 A at 10-30 VDC
MC USB 4303 counter	Count input	3	10	
MC USB DIO 96H	Digital input	1	96	

AirDAC averaged the signals (after conversion to engineering units) over 15-s and 60-s intervals and recorded the means into two separate computer files. All real-time data were displayed in tabular and graphic forms for on-site or remote (pcAnywhere, Symantec, Mountain View, CA) viewing (Ni et al., 2009; Ni and Heber, 2010). Measurement alarms, data collection notifications, data files, graphs and statistics of the daily data sets, and modified configuration and fieldnote files were automatically emailed to several recipients after midnight.

3.4. **Monitoring and Recording Farm and Building Operation**

3.4.1. Animal Husbandry and Building Systems

Infrared motion detectors (activity sensors) were mounted to support posts along the center axis of the house to monitor movements of birds and workers. An activity sensor was used to monitor researcher presence in the OFIS.

Data on animal inventory and mortalities were recorded manually and on a daily-basis by the producer, and provided to the site personnel. The average mass of the birds was measured at least weekly between 1 and 47 d of age, during three consecutive cycles of birds. For each measurement period, 25 or 50 birds of each gender (50 or 100 total) were measured in each house and the average mass reported.

Relays that control lights, brooders and feeders were monitored in each house, using auxiliary contacts in 5-VDC circuits in conjunction with the digital inputs of the data acquisition system.

3.4.2. Thermal Environment

Weather data was collected using a solar radiation shielded capacitance-type relative humidity and temperature probe (RH/T) (Model RHT-WM, Novus Automation, Porto Alegre, Brazil), a pyranometer (Model LI-200SL, LI-COR, Lincoln, NE) and a cup anemometer (Wind Sentry, RM Young, Traverse City, MI), which were mounted on a 1-m aluminum tower located on the ridge of house 10 near the OFIS.

For the building environmental conditions, RH/T sensors were located at the center of the west end of each house. Type T thermocouples (TCs) were used to measure temperatures at each sampling point not already monitored with a RH/T probe, and were also distributed with equal spacing along the center of each house. The TC's were attached to the support posts which ran down the center of the house at 3-m intervals. Two TCs were located next to the two brooders closest to the OFIS, and two were located at the center of the evaporative pads. A TC was added on 4/9/09 to monitor the manure temperature in house 12 at floor level.

Thermocouples were also located in the heated raceway between the houses and OFIS. Two TCs were located in the OFIS to measure the temperature of the OFIS and the air-conditioning system. One TC monitored the temperature conditions in the ambient PM monitor enclosure.

3.4.3. Building Airflow

Fan rotational speed and operational status was monitored using a magnetic Hall-effect sensors (speed sensor) installed on each fan except inactive fan #1. The speed sensors were mounted to detect the rotational speed in revolutions per minute (rpm) of either the fan shaft or the fan pulley. The digital signal from the speed sensor was converted into a frequency measurement with a counter module in the data acquisition system.

Static pressure was measured across the north, south, and west walls of each house with differential static pressure sensors (Model 260, Setra Systems, Boxborough, MA). The outside port was located against the outside wall near the ventilation fans of the north, south, and west walls.

Impeller anemometers (Model 27106RS, RM Young, Traverse City, MI) were installed on the outlet of fans 2 and 7 in H12 and fan 7 in H10 (building PREFs).

In-situ airflow measurements were conducted with a 137-cm field-portable fan tester (Fan Assessment Numeration System or FANS, University of Kentucky, Lexington, KY), which was described by Gates et al. (2004). The field data was used to develop equations that would calculate airflow as a function of differential pressure and fan rotational speed, and to assess the uncertainty in airflow predictions.

A total of 237 in-situ fan tests with replication were conducted during April and June, 2008, and April, July and September, 2009. Each fan was tested at least once during three or more of the five testing periods. The belts on the fans had been recently replaced prior to the tests in June 2008.

The airflow curves of the large (Model 48318-235, Chore-Time, Milford, IN) and small (Model AT365Z1CP, Aerotech, Mason, MI) fans were obtained from the Bioenvironmental and Structural Systems (BESS) Lab at the University of Illinois at Urbana-Champaign (BESS, 2003; BESS, 2004). Each performance record consisted of airflow (Q1) measured at several static pressures (P1), and at a relatively constant speeds (N1 = 779 and 550 rpm for small and large fans, respectively).

For each fan type, the BESS fan curve was adjusted to the mean speed (N2) of the fan tests. The mean speeds were 530 and 749 rpm for the large and small fans, respectively. The new, speed-indexed baseline curves were derived using the first ($Q_2 = Q_1(N_2/N_1)$) and second ($\Delta P_2 = \Delta P_1(N_2/N_1)^{0.5}$) fan laws, where Q_2 is the speed-adjusted BESS fan curve at speed N_2. The speed-corrected airflow prediction model is $Q_4 = (a\Delta P_4 + b)\cdot(N_4/N_2)\cdot Q_2$, where ΔP_4 and N_4 are measured fan static pressure and speed. For a given test using the portable tester, the model is $Q_4 = (a\cdot\Delta P_3 + b)\cdot(N_3/N_2)\cdot Q_2$, where ΔP_3 and N_3 are the measured fan static pressure and speed during the fan test, and the fan degradation factor $k = a\cdot\Delta P_3 + b$. The values for the coefficients a and b were those which minimized the sum of square differences between Q_4 and Q_3 for all the valid fan tests within a speed regime. The resulting fan models are shown in Table 5.

Fans were assigned to a sampling stream based on their proximity to the three sampling locations in each house. For each house, fans 2, 3 and 8 constituted Stream 1, fans 4 to 7 made up Stream 2, and Stream 3 was fans 9 to 12. The airflow for each stream was calculated by summing the individual airflows for all fans in the stream.

Table 5. Fan airflow models.

Fan type	Reference speed (N_2)	Polynomial coefficients of $Q_2=f(\Delta P_2)$ at speed N_2				Coefficients of k	
		a3	a2	a1	a0	b1	b0
Large	530	2.943E-06	-2.304E-04	4.368E-02	9.412E+00	8.213E-04	0.887
Small	749	1.474E-05	5.108E-04	3.908E-02	5.617E+00	4.196E-03	0.697

3.4.4. Biomaterials Sampling Methods and Schedule

All analyses of biomaterials were performed by an independent laboratory (Midwest Laboratories, Omaha, NE).

Water was evaluated based on analyses of the water provided to the animals in August 2009.

Feed samples were collected in duplicate from each house and analyzed for nitrogen and solids by Midwest Labs.

Samples of the rice hull bedding material were collected in duplicate from each house and analyzed for nitrogen and solids by Midwest Labs.

The total volume of fresh bedding brought in on 4/18/08 after a complete loadout of old litter was 118 m^3, based on measured litter density.

The estimated volume of litter removed by the decaking procedure was 30 to 45 m^3 based on the volume of manure removed from a house on 12/31/07, and the average volume of litter removed from multiple houses on 1/2/08. A decaked litter density of 474 g/m^{-3} was determined from a 15.3-L sample. On 4/15/08, the manure mass removed during a complete loadout, estimated from the square area and average mass of manure per unit area, was 88 metric tons in H10 and 79 metric tons in H12.

Three types of manure samples were collected. “Surface litter samples” were collected from 16 random locations per house including eight samples from the front of the house with relatively fresh litter, and from the back of the house with the older litter. The two groups together were considered representative of the house litter. At each sampling point, all litter in a 0.6-m radius was brought to the center of the sampling location and mixed thoroughly. Composite samples from the mixtures were analyzed for pH, solids and ammonia. Decaking and loadout samples were collected from 12 random locations in each house during litter decaking and loadout, respectively, and analyzed for ash (after 12/2/08), nitrogen, and solids.

3.5. **Particulate Matter Monitoring**

Real-time PM monitors (TEOM Model 1400a, Thermo Fisher Scientific, Waltham, MA) continuously sampled exhaust PM. A TEOM was placed in each house about 6 m in front of fan 7, which was the PREF (Figure 3). It was approximately at the midpoint of a line connecting fans 7 and 12.

A beta attenuation PM monitor (Beta Gauge Model FH62C-14, Thermo Fisher Scientific, Franklin, MA) continuously measured house inlet PM concentration. The Beta Gauge was enclosed in a protective outdoor enclosure and located at the inlet gas-sampling location of house 10 (Figure 3). The inlet PM monitor was very near the house ventilation inlets and more than 60 m away from the exhaust fans at the west end of the houses. While the driveway around the complex was paved, the space between the houses was barren. Infrequent vehicle traffic in the barren spaces between the houses could have caused “spikes” of measured inlet PM.

At any one time, the sampled PM size class was either PM_{10}, $PM_{2.5}$ or TSP at both TEOMs and the Beta Gauge. The $PM_{2.5}$ size class was measured in February and July, 2008, and January and September, 2009 for 12 to 18 d each time (Table 6). The TSP inlet heads were placed on the TEOMs for six, 7-14 d periods. The PM_{10} concentration was measured at all other times.

3.6. **Continuous Gas Sampling and Monitoring**

Air samples for continuous gas measurements were collected from multiple gas sampling probes with a custom-designed GSS. Each probe was connected to the GSS with Teflon tubing. Tubular raceways between the OFIS and the monitored buildings protected the sampling lines and data signal cables. The sampling lines were wrapped with insulation and heated inside the raceways and at other locations vulnerable to cold air to prevent condensation inside the tubes.

Three gas sampling probes were placed in the west end of each house, near the exhaust fans at a height equal to the fan hubs (Figure 3). One gas sampling probe (A) was located in front of the inlet of fan 2, and between fans 5 and 10. Sampling probes B and C were located 3 m from each sidewall in a cross-sectional plane that was 1 m east of fans 7 and 12. The probe for sampling inlet air was located near one of the two houses at approximately the midpoint (lengthwise) of the house. The occasional 2-3 d stockpiling of litter just outside the far end of the houses was the only on-farm source besides the exhaust from other houses that would contribute to the inlet contaminant concentrations.

Table 6. Sampling schedule for PM_{10}, TSP and $PM_{2.5}$.

Time and day, m/d/y		**Test duration, d**		
Start	**Stop**	**PM_{10}**	**TSP**	**$PM_{2.5}$**
9/28/07	12/10/07	73.6		
12/10/07	12/19/07		8.9	
12/19/07	2/1/08	44.0		
2/1/08	2/19/08			18.1
2/19/08	2/20/08			0.3†
2/19/08	2/20/08	0.3‡		
2/20/08	5/15/08	85.7		
5/15/08	5/28/08		12.8	
5/28/08	7/9/08	42.0		
7/9/08	7/25/08			16.0
7/25/08	11/17/08	115.1		
11/17/08	11/24/08		7.1	
11/24/08	1/5/09	41.9		
1/5/09	1/20/09			15.0
1/20/09	4/9/09	79.0		
4/9/09	4/20/09		11.0	
4/20/09	6/25/09	66.1		
6/25/09	7/8/09		12.9	
7/8/09	9/26/09	80.1		
9/26/09	10/7/09			10.9
10/7/09	10/21/09		14.1	
10/21/09	10/22/09	0.4		
Totals		628.3	66.7	60.3

† All except ambient
‡Only ambient

Each exhaust location was sampled individually for 10 min. The ventilation inlet location was monitored at least twice daily, originally with a 20-min sampling period. After approximately four months of data collection, gas concentration data at each sampling location was studied to determine whether equilibrium occurred within the sampling periods. A statistical analysis confirmed that 10 min was sufficient for the exhaust GSLs, but that 30 min was required for the house inlet. The inlet sampling period was therefore increased from 20 min to 30 min.

Table 7. Analyte sampling locations.

Analyte	House	Sampling Location*	Qty
NH_3 H_2S CO_2	10, 12	GSL-A: Directly in front of the inlet of fan 2, along a line connecting fans 5 and 10	2
	10, 12	GSL-B: 1 m E of fan 12 and 3 m from N wall	2
	10, 12	GSL-C: 1 m E of fan 7 and 3 m from S wall	2
	10, 12	**INLET:** In front of the 5th ventilation inlet from the E end of house 10 on N sidewall	1
$PM_{2.5}$ PM_{10} TSP	10, 12	TEOM located 2 m in front of fan 7	2
	10, 12	**INLET:** Beta-Gauge in front of the 5th ventilation inlet from the E end of house 10 on N sidewall	1
VOC	10, 12	1 m E of fan 7 and 3 m from S wall, at fan hub level (GSL-C)	2

*Gas sampling probes were located at fan hub height, suspended from the ceiling.

One set of gas analyzers in the OFIS was used to sequence through all the GSLs. Hydrogen sulfide was measured with a fluorescence H_2S analyzer (Model 450i, Thermo Fisher Scientific, Waltham, MA). Concentrations of NH_3, methane, ethanol, methane, NMHC and CO_2 were measured with a photoacoustic infrared multi-gas monitor (INNOVA Model 1412, LumaSense Technologies, Ballerup, Denmark).

The INNOVA analyzed NMHC concentrations by measuring THC and subtracting ethanol (manufacturer error) and methane. The THC data was questionable, however, due to irreconcilable interferences by water vapor and other gases. Therefore, the VOC-related gas emissions measured by the INNOVA are not included in this report.

3.7. VOC Sampling

Grab samples of VOC were collected at the PREFs (fan 7 each house) (Table 7), using methodology based on methods TO-15 and TO-16. Sampling was conducted with 6-L stainless-steel canisters (TO-Can, Restek Corp, Bellefonte, PA), equipped with ¼″ bellows valves (Swagelok SS4H) and 207-kPa vacuum gauges. Sampling trains contained flow controllers (Veriflo Model 423XL, Parker-Hannifin Corp., Richmond, CA) with 2- to 4-sccm critical orifices and 7-µm in-line stainless steel filters. Flow controllers were pre-set to a constant flow rate of 3.4 mL/min. Canister sampling was conducted for 24 h, and canister pressures were recorded at the beginning and end of the sampling periods for the calculation of total sample volumes. Sampling was conducted seven times between 7/14/09 and 10/7/09, with duplicate samples typically collected at each location. All canisters were cleaned and passed QC before sample collection.

Canister samples were analyzed at Purdue University’s Trace Contaminant Laboratory. The canisters were pressurized to +207 kPa with ultrapure N2, and transferred to TDS tubes (Carbotrap 300, Supelco, Bellefonte, PA). The pressurized canisters initially yielded sample flows of 50 mL min^{-1} during sample transfer to tubes. Canister heating was introduced when a canister pressure decreased to 13.8 kPa to ensure maximal transfer of nonvolatile components.

Samples were analyzed on a thermodesorption-gas chromatograph-mass spectrometer (TDS-GC-MS), consisting of a gas chromatograph (Model 6890, Agilent Technologies, Palo Alto, CA) coupled with a Model 5795 mass spectrometer detector (Agilent Model 5795) and equipped with a thermal desorption system (Model TDS-G, Gerstel, Baltimore, MD) and a cooled injection system (Gerstel CIS). The GC-MS passed a leak check prior to analyzing each set of samples. Compounds were separated on a 60 m x 0.25 mm x 1µm column. The detector utilized the full scan mode covering masses from 27-270 Daltons in 8 scans/s. The MS quad hold temperature was 150ºC, and the MS source hold temperature was 230ºC. The analytical results were analyzed by ChemStation, and all integrations were manually checked. This method used an external standard compound for instrument monitoring and QA to avoid losses of low-molecular-weight analytes that would occur when purging solvent used with internal standard(s). All TDS tubes were cleaned with a tube conditioning system (Gerstel TC-2 TDS) for 3.5 h at 350ºC prior to each use.

Response curves were generated at both the beginning and the end of the VOC analysis period. The response curves of all chemical standards reach good linearity as 55% of the response curves had $R^2 > 99\%$ and over 98% had $R^2 > 95\%$. Toluene was used as an external standard that was analyzed during each batch of samples to assure quality. The relative bias and standard deviation of 97 toluene checks were -4.3% and 18.8%, respectively. The uncertainty of the mean of duplicate field samples was calculated as 27%, based on the toluene checks.

3.8. **Documentation of Quality Assurance**

3.8.1. Oversight, Maintenance, and Calibration

University of California personnel visited the site a total of 85 person-days and 98 person-days during years 1 and 2 of the monitoring period. An unidentified problem with the site computer or internet provider prevented remote connection to the site computer during the majority of the monitoring period; however, data files and correspondence were emailed from the site computer on a regular basis.

The Science Advisor audited the site on 9/5/07. The Environmental Protection Agency (EPA) conducted site audits on 6/4/08 and 10/5/09.

Various site maintenance and calibration activities were conducted by site personnel (Appendix B). Specific quality assurance tests of the GSS, gas analyzers and other sensors are discussed below.

3.8.2. Gas Sampling System

Two types of GSS leak tests were conducted. The first test examined GSS integrity, by briefly creating a “dead head” against the pump by closing all solenoid valves, while measuring exhaust airflow with a portable rotameter, and recording the leakage flow with the GSS mass flow meter. The second test consisted monitoring GSS flow and pressure after manually setting AirDAC to sample from a particular GSL and plugging the GSL’s gas sampling probe, which created a GSS manifold vacuum of about -70,000 Pa or 0.31 atm. Preliminary tests indicated that GSS flows under dead-head conditions that were 10% or less (<0.45 L/min) of the normal GSS flow rate of 4.5 L/min was indicative of leak-free operation under normal GSS manifold vacuums of -5,000 to -8,000 Pa (0.93-0.96 atm). Leak tests of the GSS were conducted 13 times between 9/26/07 and 9/9/09 (Appendix B). If the dead-head leakage flows were greater than the 0.45 L/min threshold, the cause was investigated and rectified. Systematic checking of individual sampling lines was conducted on 10/17/08 and 9/9/09, while checks of some lines were conducted more frequently. Data was only invalidated when leaks occurred away from the sampling location. If gas sampling probe filter maintenance eliminated a leak, no data was invalidated since leakage air would be the same as sampled air.

3.8.3. Gas Analyzers

Gas measurements were evaluated using multipoint calibrations and zero and span checks (Appendix C). The gas concentration data output by the analyzers was adjusted to correct for bias introduced by the gas sampling and measurement system.

3.8.3.1. Correction of Ammonia Concentrations

A multipoint calibration (MPC) was conducted through the challenge line seven times using purified air (Cat. # AIO.OCE-T, CEM zero-grade, Praxair, Indianapolis, IN) and three (typical) span concentrations of NH_3 (Cat. # NI-AM5MP-AS, Praxair Primary Standard). Except for the MPC on 12/30/07 and 6/26/08, each MPC was conducted with replication (Table 8). The NH_3 was delivered using a 6-port gas dilutor (Model 4040, Environics, Tolland, CT). The R^2 values of each MPC exceeded 0.99, indicating linearity of instrument response to standard gas between 0 and 60 ppm.

Table 8. Multipoint calibration record and results for the NH_3 measurements.

Date	# points	Span concentration, ppm		R^2
		Minimum	Maximum	
12/30/07	4	15	36	0.994
2/25/08	4	12	36	0.999
5/7/08	4	12	36	0.993
6/26/08	4	12	36	0.989
12/3/08	4	20	60	0.999
5/4/09	2	60	60	0.999
8/5/09	4	20	60	0.995

Precision checks were conducted periodically using zero and span gases (Z/S checks), delivered via the dilutor through the challenge line, and responses were recorded to monitor changes in system performance over time. Span checks prior to and after 11/25/08 were conducted with 30 and 60 ppm of NH_3, respectively, except that 20 ppm was used on 8/7/09 and 8/17/09 (Appendix C).

The average response of the analyzer to the zero and span gas applications was assessed, and the results were combined based on changes to the instrument or GSS to create linear correction models (Table 9). The models were used to correct instrument readout data. The measurement accuracy was assessed based on model-corrected zero and span checks (Table 9).

Table 9. Concentration correction and measurement accuracy for ammonia.

Start/end dates	**# of checks**		**Linear model**	**Accuracy, % of span**			
				Bias		**Precision**	
	Zero	**Span**		**z**	**s**	**z**	**s**
1/22/08-4/11/08	5	5	y =1.134(x–0.878)	-0.4	0.4	0.3	2.0
5/2/08-7/29/08	12	12	y =1.213(x-0.358)	-0.3	0.6	0.6	8.5
10/17/08-1/30/09	6	9	y =1.095(x-0.693)	-0.2	0.8	0.6	2.5
1/30/09-7/14/09	9	10	y =1.121(x-0.322)	0.0	-1.1	0.3	2.8
7/14/09-9/27/09	7	7	y =1.201(x-0.174)	-0.1	0.5	0.6	2.4

3.8.3.2. Correction of Hydrogen Sulfide Concentrations

A MPC was conducted through the challenge line seven times using purified air (Cat. # AIO.OCE-T, Praxair CEM zero air) and three or four span concentrations (Cat. # NI-HSR1E-AS, Praxair EPA Protocol Standard). Except for the first three MPCs, each MPC was conducted with replication (Table 10). The H_2S was delivered using a 6-port dilutor (Model 040, Environics, Tolland, CT). The R^2 values of each MPC exceeded 0.999, indicating excellent linearity of instrument response to standard gas between 0 and 1800 ppb.

Table 10. Multipoint calibration record and results for the H_2S measurements.

Date	**# points**	**Span concentration, ppb**		**R^2**
		Minimum	**Maximum**	
11/7/07	5	500	1800	0.999
11/13/07	4	500	1800	0.999
1/2/08	4	500	1800	1.000
6/26/08	4	600	1800	0.999
7/29/08	4	600	1800	1.000
11/24/08	4	150	450	1.000
7/21/09	4	150	450	0.999

Precision checks were conducted periodically using zero gas and span gases (Z/S checks), delivered via the dilutor through the challenge line, and responses were recorded to monitor changes in system performance over time. Span checks were conducted with 150, 450 or 500 ppb of H_2S (Appendix C).

The average response of the analyzer to the zero and span gas applications was assessed, and the results were combined based on changes to the instrument or GSS to create linear correction models (Table 11). The models were used to correct instrument readout data. The measurement accuracy was assessed based on model-corrected zero and span checks (Table 11).

3.8.3.3. Non-Methane Total Hydrocarbons

This measurement was disqualified because interferences severely affected the data quality, and could not be addressed by the manufacturer.

Table 11. Concentration correction and measurement accuracy for hydrogen sulfide.

Start/end dates	# of checks		Linear model	Accuracy, % of span			
	Zero	Span		Bias		Precision	
				z	s	z	s
9/25/07-12/31/07	5	7	y = 0.943(x–5.131)	-0.1	3.1	0.1	5.5
1/2/08-11/24/08	17	17	y = 0.855(x–5.790)	0.0	-1.6	0.2	2.0
11/24/08-9/9/09	20	6	y = 0.998(x–1.985)	0.0	-0.1	0.2	2.3

3.8.3.4. Noise Tests

Analyzer noise tests were conducted to assess the minimum detection limit (MDL) of the gas measurements. The analyzers measured CEM zero air (Praxair Cat. # AIO.OCE-T CEM) continuously for 41 to 52 min after equilibrium of the instrument readout was reached. The MDL was calculated as the t-statistic times the standard deviation of the data collected during the equilibrated period (Table 12).

Table 12. Noise test of gas analyzers with dry air on 9/9/09.

Concentration	Statistical variable				Duration, min	T_{dew},°C
	Min	Max	SD	MDL		
NH_3, ppm	1.02	1.21	0.04	0.10	41	-44.9
H_2S, ppb	2.6	10.8	0.5	1.2	52	-47.0

3.8.4. Particulate Matter Monitors

The quality of the exhaust PM data was assessed through periodic mass verifications and flow and leak checks of the TEOMs (Table 13 and Table 14). The H10 and H12 TEOMs met or exceeded the mass verification criteria (Ko actual within ±2.5% of Ko audit) except on 11/10/07 in H12.

Table 13. Quality assurance tests of house 10 TEOM.

Date	Time since last test, d	Mass error, %	TEOM flows, $L \cdot min^{-1}$		Leak test flows, $L \cdot min^{-1}$	
			Main	Total	Main	Auxiliary
9/21/07	0				0.06	0.06
11/10/07	50	1.10	3.06	16.85	0.04	0.09
12/1/07	21			9.00		
12/1/07	0			16.67		
5/7/08	158	1.68	3.04	16.82	0.05	0.05
12/13/08	220	1.34	3.05	16.32	0.04	0.01
5/11/09	149		2.92	16.30		
6/5/09	25	1.15	3.07	16.95	0.04	0.03
9/26/09	113		2.91	16.14	0.07	0.07
10/20/09	24	1.09	3.04	16.36	0.07	0.08

Table 14. Quality assurance tests of house 12 TEOM.

Date	Time since last test, d	Mass error, %	TEOM flows, L·min^{-1}		Leak test flows, L·min^{-1}	
			Main	Total	Main	Aux.
9/28/07		2.20	3.10	16.95	0.05	0.00
11/10/07	43	2.60	3.09	16.74	0.02	0.03
11/20/07	10	2.40	3.12	16.82	0.01	0.00
5/7/08	169	2.26	3.02	16.84	0.02	0.02
12/13/08	220	2.13	3.06	16.69	0.02	0.02
4/28/09	136	2.10	3.03	16.31	0.04	0.08
5/11/09	13		3.02	16.45		
8/17/09	98	1.89	3.01	16.47	0.03	0.00
9/26/09	40		3.02	16.63	0.03	0.04
10/21/09	25	1.69	3.03	16.68	0.03	0.07

The criteria for total and main flows were 16.67±1.0 and 3.0±0.2 L/min, respectively, and were met on all dates except 12/1/07 in H10.

The leakage criteria were total flow ≤ 0.62 L/min and main flow ≤ 0.15 L/min, respectively. All leak and flow tests of both TEOMs were acceptable on all dates.

Mass verifications and flow calibrations of the ambient PM monitor were conducted periodically (Table 15). The mass verification criteria of <5% was met on all dates except 6/5/09, and total flow check criteria of <4% was met on all dates except 5/26/09.

Table 15. Ambient PM monitoring quality assurance parameters.

Date	Time since last test, d	Mass verification, %	Total flow check, %
9/21/07		0.0	0.0
11/20/07	60		0.0
2/25/08	97	0.0	
5/26/09	456		5.3
6/5/09	10	-8.0	
1/14/10	223	0.0	3.2
1/15/10	1	-0.6	

The TEOM measurements were also evaluated based on collocated measurements of all three PM types (Table 16) after 9/26/09 with both TEOMs situated in H10. The differences in average PM_{10}, TSP and $PM_{2.5}$ concentrations over the collocation periods were 4.2, 7.9 and 13.9%.

Table 16. TEOM collocation test results.

PM type	Average concentration, µg/m^3		Difference, %
	House 10 TEOM	House 12 TEOM	
PM_{10}	649	622	-4.2
TSP	3723	3454	-7.9
$PM_{2.5}$	40	35	-13.9

3.9. **Data Analysis**

3.9.1. Software

All emission data processing was conducted using custom software (CAPECAB, Fibre Recovery Systems, Inc., Calgary, AB). Data was carefully inspected and validated. If a datum was invalid for a known reason, the datum was marked (flagged) invalid and all calculations dependent on that datum were also invalid unless a substitution datum was identified. All periods of invalid data that were longer than one day are listed in Appendix D.

If the QA/QC checks described above indicated a measurement bias, the data was corrected prior to calculating emissions. The CAPECAB program provided a robust method to inspect data, invalidate if necessary, and implement various corrections over specified time periods.

3.9.2. Data Substitution, Validation, Correction and Uncertainty

3.9.2.1. *Pressure*

The static pressure sensor measurements were adjusted based on both multipoint calibrations performed on 9/5/07 and 5/15/08, and time-weighted average zero offsets during the interim periods (Table 17). The average static pressures for each building were determined using data from all properly-operating sensors among the north, west, and south ΔP sensors. For calculating airflow, the average of the functioning sensors in the building was used whenever the sensor on the fan's actual wall failed. The average of the north and south wall ΔP was substituted for the H10 west wall ΔP from 7/1/08 to 7/18/08 and from 11/21/07 to 12/19/07 when the H10 west wall ΔP was invalid.

Table 17. Static pressure sensor zero offsets.

Sensor location	Start/end dates	# of zero checks	Offset
H10 N wall	9/5/07-11/21/07	2	0.03
	11/21/07-5/15/08	2	0.68
	5/15/08-10/21/09	4	0.06
H10 W wall	9/5/07-11/21/07	2	0.29
	11/21/07-5/15/08	2	0.45
	5/15/08-10/21/09	4	0.09
H10 S wall	9/5/07-11/21/07	2	0.28
	11/21/07-5/15/08	2	0.07
	5/15/08-10/21/09	4	-0.14
H12 N wall	9/5/07-11/21/07	2	0.03
	11/21/07-5/15/08	2	0.68
	5/15/08-10/21/09	4	0.33
H12 W wall	9/5/07-11/21/07	2	0.21
	11/21/07-5/15/08	2	-0.53
	5/15/08-10/21/09	4	0.02
H12 S wall	9/5/07-11/21/07	2	-0.17
	11/21/07-5/15/08	2	-0.10
	5/15/08-9/10/09	3	0.51
	9/10/09-10/21/09	1	0.02

Based on the time-weighted averages of the zero checks, calibration offsets ranging from -0.5 to 0.7 Pa were assigned to the different sensors (Table 17).

The atmospheric pressure measurement was not available between cycles, as the TEOMs were offline during house cleaning. Daily mean atmospheric pressure data from the nearest weather station was compared to the measured values from both TEOMs, and found to be representative of the site measurements, and continuous through the time between cycles. Therefore, the weather station measurement was used in all emission calculations.

3.9.2.2. Environmental Sensors

The average exhaust temperature for each house was the mean of the RH/T probe temperature measurement and the TC measurements at fans 7 and 12.The average house temperature was the mean of the four TC measurements down the middle of each house.

The solar sensor signal was collocated with a reference solar sensor on 4/10/09 and yielded a slope of 1.049 and an intercept of 133.6 W/m^2, that was used to correct the raw data. An additional offset of -32 W/m^2 detected between 6/4/09 and 6/25/09 based on nighttime measurements, was used to correct solar radiation data.

3.9.2.3. Fan Operation

Low-level noise was filtered out by setting operational status to “off” (0%) if the average speed was less than 20 to 50 rpm for all fans except the north wall fans of H12. The low-level noise filter level for these fans was 100 rpm.

High-level noise (or spikes) were also filtered out by setting fan speeds greater than the maximum operating speed for each type of fan (assessed through a fan speed frequency analysis) to the maximum operating speed.

3.9.2.4. Gas Concentrations

Times were specified in the data processing software for gas concentration measurements to stabilize based on gas and sampling location (Table 18).

Linear interpolation of corrected gas concentrations was used to fill in concentrations for each minute between two valid concentration measurements at a sampling location, up to a specified maximum interpolation interval (Table 18).

Table 18. Gas concentration data validation and interpolation requirements.

Gas	Exhaust Sampling Locations		Ambient Sampling Location	
	Equilibration period, min	Maximum interpolation interval, min	Equilibration period, min	Maximum interpolation interval, min
NH_3	7	300	17	3000
H_2S	5	300	10	3000

Gas and water vapor concentrations, and sample relative humidity, temperature, pressure, flow rate, and flow direction were invalidated during all gas analyzer MPCs and Z/S checks, and when sample Q < 3.0 L/min. Gas and PM data were invalidated under conditions of positive barn static pressure, because barn airflow measurements require a negative or underpressure in the barn.

Gas concentration data were invalidated due to problems with the INNOVA 1412. The analyzer was brought on-line on 12/28/07. Significant downtime occurred due to factory repair and calibration from 9/2/08 to 10/2/08 and from 6/11/09 to 7/14/09. There was also a chopper motor error in January 2009. Approximately 144 d of NH3 concentration data were lost or invalidated due to INNOVA-related issues.

Gas concentration data was invalidated whenever the GSS failed leak tests. Gas concentrations were invalidated between 9/27/08 and 11/9/08, because of a leak in the GSS and high analyte concentrations detected during zero gas checks (Appendix C).

Standard gas concentrations were calculated on dry and moist bases with Eqns. 3-1 and 3-2, respectively.

$$C'' = \frac{C'}{(1-W)} \tag{3-1}$$

and

$$C' = \frac{P' \cdot c \cdot M}{R \cdot (273 + T')} \tag{3-2}$$

Where:

C''	Standard mass concentration, dry basis (mg $d^{-1}sm^{-3}$ or µg $d^{-1}sm^{-3}$)
C'	Standard mass concentration, moist-air basis (mg sm^{-3} or µg sm^{-3})
P'	Standard pressure (1 atm)
T'	Standard temperature (20°C)
c	Volumetric concentration of gas (ppm or ppb)
M	Molecular weight of gas (g mol^{-1})
R	Universal Gas Constant (0.08206 L atm mol^{-1} $°K^{-1}$)
W	Humidity ratio

3.9.2.5. PM Concentrations

Prior to 2/19/08, the TEOM flow rates were erroneously internally adjusted to 16.7 L·min^{-1} based on standard conditions (20ºC and 1 atm). The PM data was acceptable, however, because the TEOM flow rates corrected for actual air density were still within the required 15.7 to 17.7 L·min^{-1} range. The TEOM settings were changed on 2/19/08 to adjust the flow to 16.7 L·min^{-1} based on actual rather than standard air density.

The TEOMs were configured to output the PM concentration data at the surrounding temperature and atmospheric pressure until 2/19/08, at which time they were reconfigured to output the PM data at standard conditions (20ºC, 1 atm). All PM concentration data prior to 2/19/08 was corrected to standard conditions.

Dry standard PM concentrations were obtained by dividing the standard condition concentrations by one minus the air humidity ratio.

The B10 TEOM data was unavailable between 2/20/09 and 5/11/09 related to an air temperature sensor problem. The B12 PM data was offline between 7/13/09 and 8/16/09, related to sensor hardware problems.

3.9.3. Emission Calculations

3.9.3.1. Particulate Matter

PM emissions were calculated with Eqn. 3-3.

$$E = \left(Q_O \cdot P_O \cdot \left(\frac{273+20}{273+T_O} \right) \right) \cdot \; c'_O - c'_i \tag{3-3}$$

Where:

E	Net PM emission rate (µg s^{-1})
Q_0	Exhaust airflow rate at To (m^3 s^{-1})
P_0	Pressure of exhaust air (atm)
C_0'	PM concentration of exhaust air (µg m^{-3})
C_i'	Ambient PM concentration (µg m^{-3})
T_0	Temperature of exhaust air (°C)

3.9.3.2. Gases

Stream-specific gas emissions were determined as follows:

$$E = Q_O \cdot \frac{P_O \cdot M}{R \cdot (273+T_O)} \cdot (c_O - c_i) \tag{3-4}$$

Where:

E	Stream or house emission rate (mg s^{-1} or µg s^{-1})
Q_O	Stream or house outlet moist airflow rate at To (m^3 s^{-1})
P_O	Exhaust air pressure (atm)
M	Gas molecular weight (g mol^{-1})
R	Universal Gas Constant (0.08206 L atm/mol^{-1} °K^{-1})
T_O	Exhaust air temperature (°C)
c_o	Exhaust air concentration (ppm or ppb)
c_i	Ambient or ventilation air inlet concentration (ppm or ppb)

Building emissions were the summation of the stream emissions. If the interpolated stream concentration was invalid for one stream in a house, the average of the other two stream concentrations was substituted in the emission calculation. Building emission was divided by variables (house inventory, feed consumption) or constants (floor area) to normalize emissions to site-specific characteristics.

3.9.3.3. Volatile Organic Compounds

The total VOC concentration was multiplied by building airflow for the 24-h canister sampling period to yield an average emission rate. If two samples were successfully collected for a building at one sampling event, the average concentration was used in the calculation.

4. RESULTS

4.1. Farm Production Information

The farm production information, including inventory, bird mass and density are presented in Table E2. The bird mass estimates are based on a regression curve fit through the bird mass versus age data collected over three cycles of birds.

The monitoring period extended across 14 growth cycles, which ranged from 43 to 48 d long. The time between flocks averaged 11 d and ranged from 6 to 25 d. The average flock size was 20,636 birds in each house. Litter was decaked eight times and loaded out five times. The manure loadout periods started on 11/2/07, 4/14/08, 9/25/08, 3/26/09 and 9/13/09.

4.2. Characteristics of Biomaterials

The summarized results of lab analyses of the various biomaterials are available in Appendix F**Error! Reference source not found.**. The nitrogen content of the ricehull bedding material ranged from 0.4 to 0.7% nitrogen (wet-basis). The nitrogen content of the feed ranged from 2.3 to 4.3% nitrogen (wet-basis), and reflects the change in diet formulation with bird age.

4.3. Environmental Conditions

4.3.1. Ambient Conditions

According to historical climatic information daytime average high temperatures ranges from 12°C in the winter to 35°C in the summer. Average overnight lows range from 3°C in winter to 16°C in summer. Typical prevailing winds for the region are from the southeast in the winter and west-northwest during the rest of the year.

Table E1 shows the daily average outdoor temperature, relative humidity, wind speed, wind direction, solar radiation and barometric pressure. The average temperature on site was 16.7°C, similar to the average temperature condition for the area (Table 19).

4.3.2. House Conditions

The environmental conditions in H10 and H12 are shown in Table E3. The average exhaust temperatures reflect the management practice to concentrate the birds in the east ends of the houses where the brooders are located (opposite end from the exhaust fans and temperature measurements), for the first 10 d of each cycle (Figure 4). After this initial period, when the birds occupy the entire house, the exhaust temperature reflects the decreasing setpoint temperature of the ventilation system (Table 1). The sharp decreases in average exhaust temperature, especially during winter months, correspond to the production preparation period between cycles when the heating and ventilation system was shut off.

Table 19. Monthly averages for weather conditions in the area*.

Month	Temperature (°C)			Wind speed (km/h)	Wind direction
	High	Low	Mean		
January	12	3	8	13	SE
February	16	5	12	13	SE
March	19	6	14	15	WNW
April	23	8	17	15	WNW
May	28	11	20	17	W
June	32	14	23	18	W
July	35	16	26	16	WNW
August	34	16	25	15	WNW
September	31	14	23	14	WNW
October	26	10	18	12	WNW
November	17	6	12	12	SE
December	12	3	8	13	SE
Annual Average	24	9	17		

*** http://www.weather.com/weather/wxclimatology/monthly/USCA0714**

4.3.3. Ventilation Rates

The median static pressure differential was -15±5 Pa in all cases. The fraction of time that the pressure was positive ranged from 18.4 to 25.8%. Most of the positive pressures were likely wind-induced during times when duty cycled fans were off, and no other fans were running in the house. Static pressure was greater than -40 Pa over 90% of the time.

The ventilation control system set point was based on both ambient temperature and age of bird (Table 1). Figure 4 demonstrates an increasing airflow rate with time during each cycle, and a higher maximum airflow rate during warmer weather. The maximum daily mean airflow measurements for both houses occurred on 3/29/09, at which time the houses were in production preparation phase and empty of birds.

4.4. **Particulate Matter Concentration and Emission**

4.4.1. PM$_{10}$

The DM inlet PM$_{10}$ concentration ranged from 4 to 262 µg dsm^{-3}, whereas the DM H10 and H12 PM$_{10}$ exhaust concentrations ranged from 20 to 5030 µg·dsm^{-3}and from 27 to 4550 µg·dsm^{-3}, respectively (Table E4).

The ADM (±SD) inlet, H10 and H12 PM$_{10}$ concentrations were 59±42, 896±670 and 1016±679 µg·dsm^{-3}, respectively (Table E4).

The overall mean PM$_{10}$ emission rates were 873±831g·d^{-1} (45.1±40.1 mg·d^{-1}bird^{-1}) for H10 and 879±781 g·d^{-1} (44.2±37.1 mg·d^{-1}bird^{-1}) for H12 (Figure 5).

The ADM PM$_{10}$ emissions increased with bird age during each of the 13 broiler growth cycles (Figure 5).

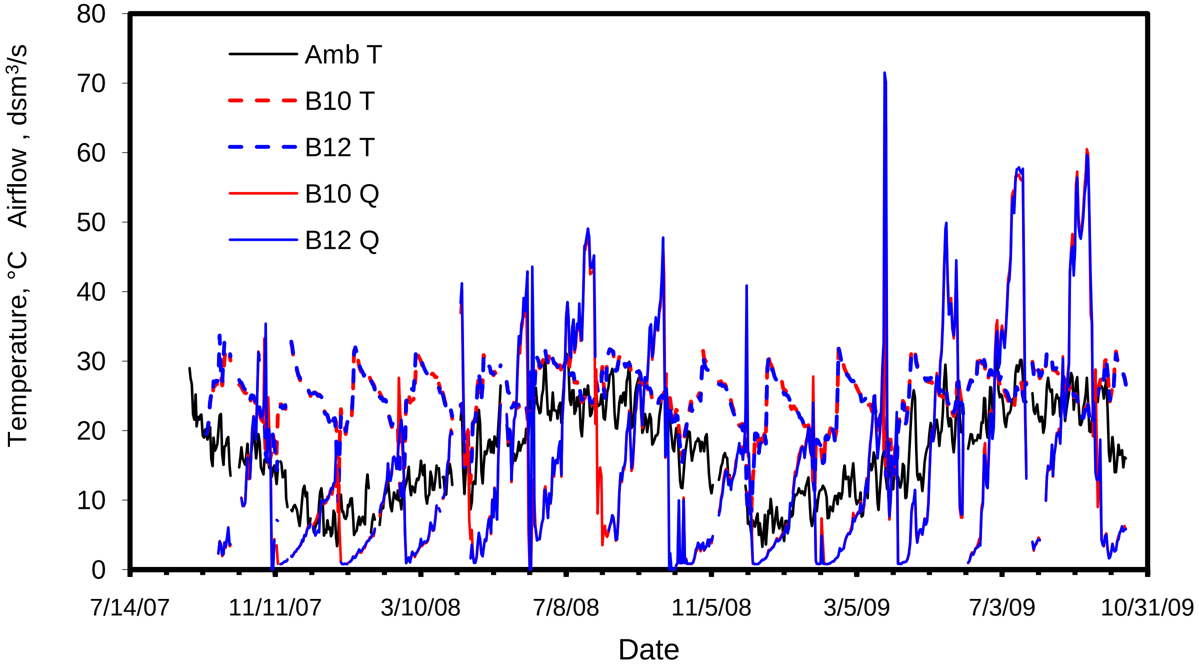

Figure 4. Ambient and exhaust temperatures (T) and dry standard airflow rates (Q) of house s 10 and 12.

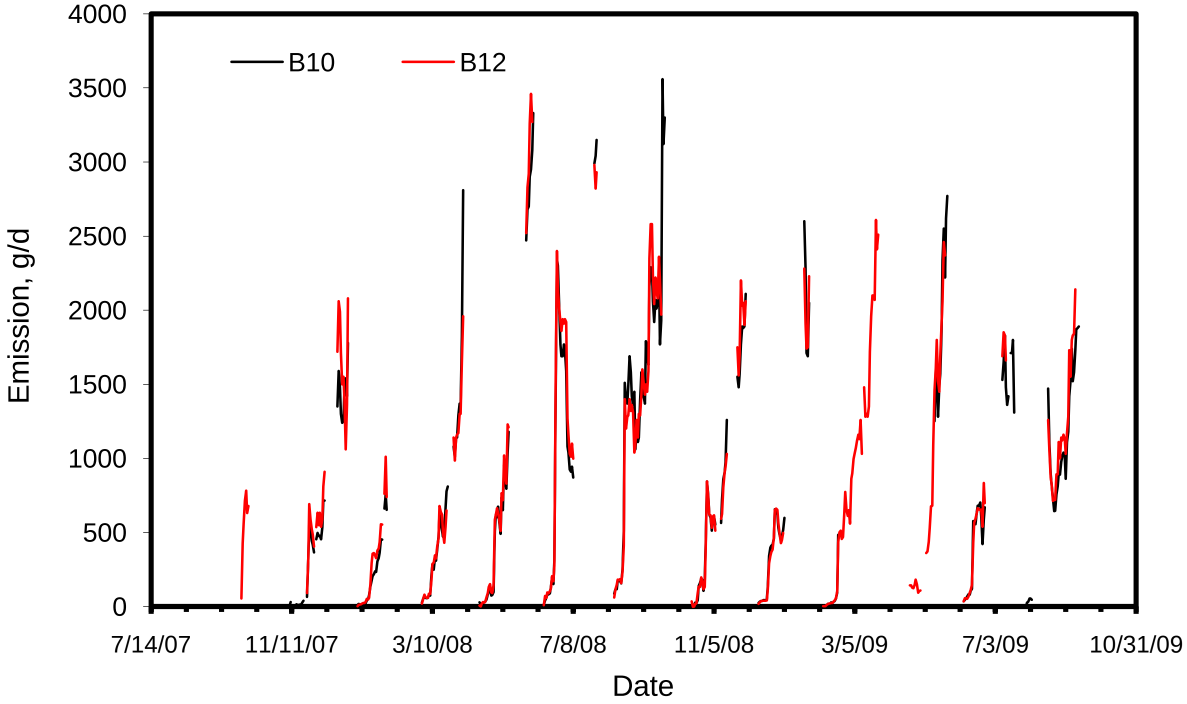

Figure 5. Daily mean PM_{10} emissions.

4.4.2. $PM_{2.5}$

Daily mean concentrations of $PM_{2.5}$ ranged from 6 to 86 µg dsm^{-3} in the inlet air (n=53 d), 36 to 169 µg dsm^{-3} in H10 exhaust air (n= 51 d) and from 63 to 158 µg dsm^{-3} in H12 exhaust air (n= 43 d) (Table E4).

The ADM inlet, and H10 and H12 exhaust concentrations were 22±12, 98±37 and 110±24 µg dsm^{-3}, respectively (Table E4).

The overall mean $PM_{2.5}$ emission rates were 99±63 g d^{-1} (4.8±3.0 mg d^{-1}bird^{-1}) from H10, and 124±48 g d^{-1} (6.0±2.3 mg d^{-1}bird^{-1}) from H12 (Table E5) (Figure 6).

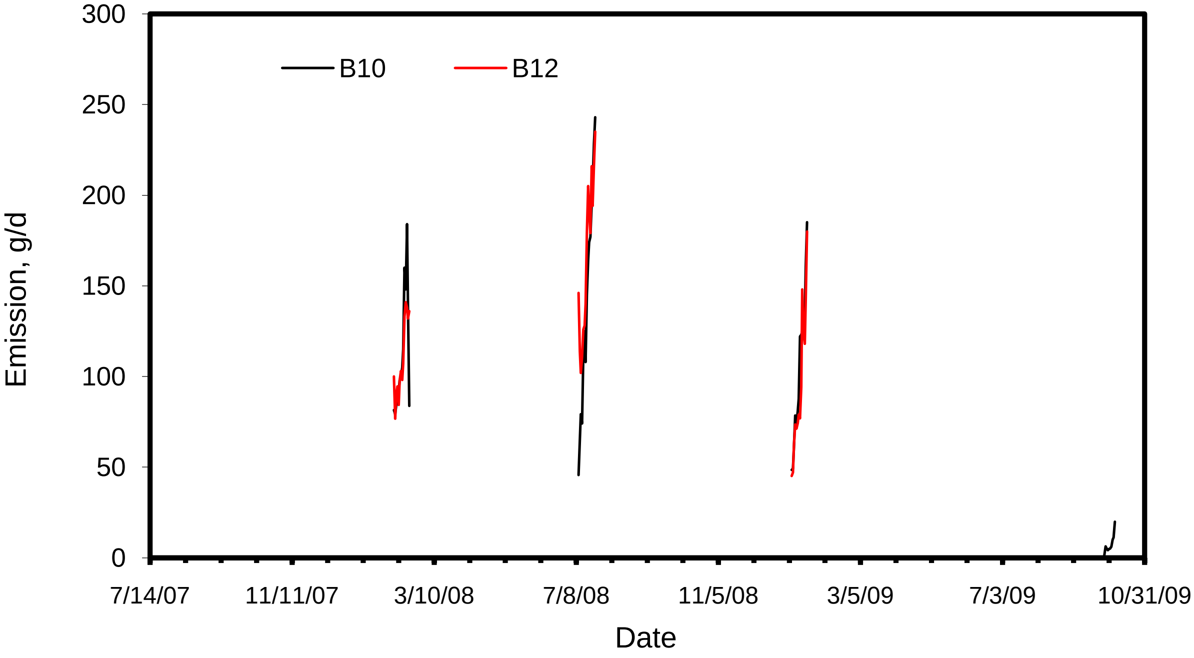

Figure 6. Daily mean $PM_{2.5}$ emissions.

4.4.3. TSP

Data from the six TSP measurement periods are shown in Table E4. Daily mean TSP concentrations ranged from 13 to 232 µg dsm^{-3} in the inlet air (n=46 d), 782 to 4530 µg dsm^{-3} in H10 exhaust air (n=37 d) and from 55 to 4270 µg dsm^{-3} in H12 exhaust air (n=40 d) (Table E4).

The ADM inlet, and H10 and H12 exhaust concentrations were 71±43, 2548±1046 and 1927±1462 µg dsm^{-3}, respectively (Table E4).

The ADM TSP emissions ranged from 3 to 6150 g d^{-1} (Figure 7). Emission rates are shown in Figure 7. The overall mean TSP emission rates were 2652±891 g d^{-1} (129±41 mg d^{-1-1}bird^{-1}) for H10 (n= 37 d), and 2270±1595 g d^{-1} for H12 (n=39 d) (Table E5).

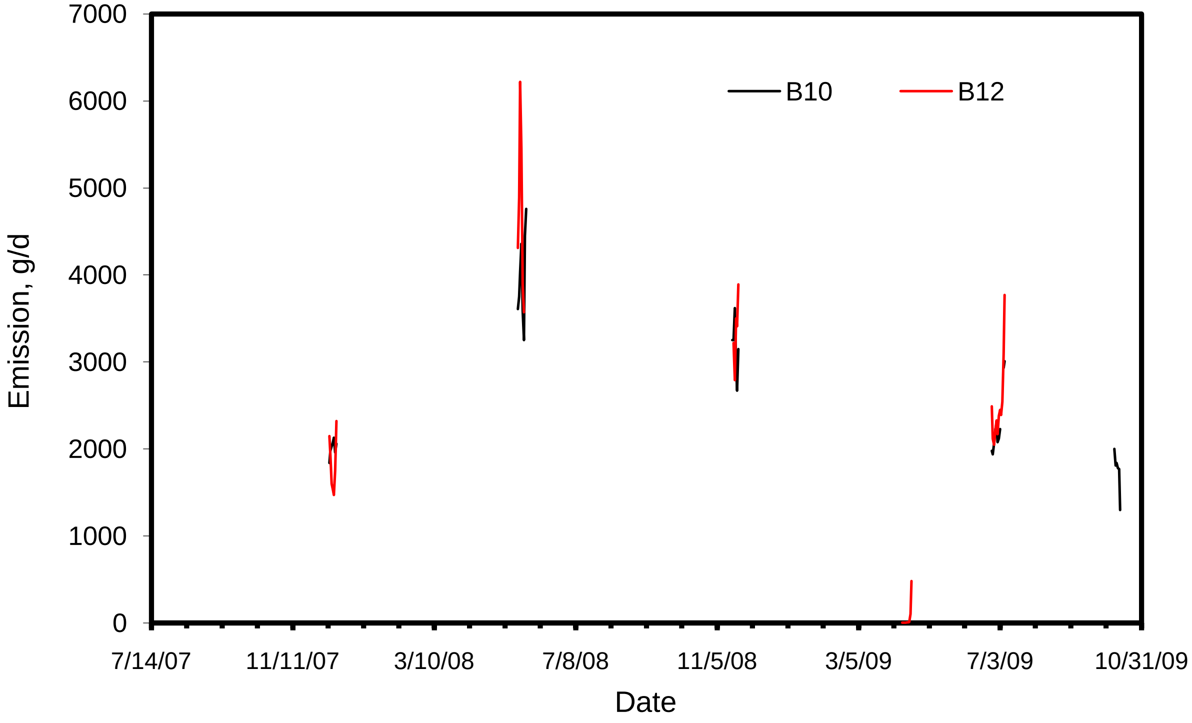

Figure 7. Daily mean TSP emissions.

4.5. VOC Concentrations and Emissions

The 20 most prevalent VOCs detected in the canister samples accounted for 89.1% of the total quantified mass (Table 20). The most prevalent compound was pentane, which accounted for 55.3% of the total mass.

Concentrations of total VOC in exhaust air ranged from 0.39 to 1.44 mg m^{-3} in H10 and from 0.43 to 14.1 mg m^{-3} in H12 (Table 21). The mean total VOC concentrations were 8.74 and 11.3 mg m^{-3} in H10 and H12, respectively.

Total VOC emissions (ng s^{-1}) during each sampling period were determined by multiplying the mean building airflow rate (m^3 s^{-1}) by the total mass (ng m^{-3}) and converting to kg d^{-1}. The VOC emission rate from H10 and H12 ranged from 0.56 to 3.94 kg d^{-1}, and from 0.50 to 5.76 kg d^{-1}, respectively. The mean VOC emission rates from H10 and H12 were 1.78±1.18 kg d^{-1} (n=7 d), and 3.12±3.12kg d^{-1} (n=6 d), respectively (Table 21).

4.6. Hydrogen Sulfide Concentrations and Emissions

Daily mean inlet and exhaust H_2S concentrations for the entire test are provided in Table E6.

The average daily mean H_2S concentrations were approximately 2.1±2.6 (n=614) ppb in the inlet air, and 41±37 (n=602) and 38±34 (n=600) ppb in the exhausts of H10 and H12, respectively.

Daily mean H_2S emissions from H10 and H12 are tabulated in Table E7 and plotted in Figure 8.

Table 20. Average concentration of 20 most prevalent VOCs.

Compound	Concentration., ng·m^{-3}	% of total	Cumulative %
2,3-Butanedione	3.11E+05	34.33%	34.3
Dimethyl disulfide	9.43E+04	10.41%	44.7
Acetaldehyde	6.77E+04	7.47%	52.2
2-Butanone	6.32E+04	6.98%	59.2
iso-Propanol	4.11E+04	4.54%	63.7
Pentane	3.96E+04	4.37%	68.1
Dimethyl sulfide	3.03E+04	3.35%	71.4
Acetic acid	2.71E+04	2.99%	74.4
Hexanal	1.69E+04	1.86%	76.3
Ethyl acetate	1.65E+04	1.82%	78.1
Hexane	1.44E+04	1.59%	79.7
Propanoic acid	1.36E+04	1.51%	81.2
Pentanal	1.31E+04	1.45%	82.7
Phenol	1.22E+04	1.35%	84.0
1-Butanol	9.38E+03	1.04%	85.0
2-Pentanone	8.86E+03	0.98%	86.0
4-Methyl-phenol	8.61E+03	0.95%	87.0
Heptanal	8.50E+03	0.94%	87.9
Butanal	8.39E+03	0.93%	88.8
Octanal	8.20E+03	0.91%	89.7

Table 21. Emission of total VOC for each sampling day.

Date	# canisters		Concentration, mg m^{-3}		Airflow, m^3 s^{-1}		Emission, kg d^{-1}	
	H10	H12	H10	H12	H10	H12	H10	H12
07/14/10	2	2	0.78	1.10	58.8	59.7	3.94	5.70
08/03/10	2	2	0.91	0.75	4.50	4.41	0.35	0.29
08/16/10	2	2	0.74	0.76	18.9	18.8	1.21	1.24
08/26/10	2	2	0.96	1.36	30.4	29.4	2.53	3.45
09/03/10	2	2	0.39	0.43	56.3	55.4	1.89	2.06
09/12/10	2	0	0.39	N/A	51.2	N/A	1.72	N/A
10/07/10	2	2	1.42	1.8	5.12	4.73	0.63	0.73
Mean	2.0	1.7	0.80	1.03	32.2	28.8	1.75	2.24

The ADM H_2S (SD) emission rates from H10 and H12 were 52.9±50.4 (n=592) and 50.3±50.6 (n=590) mg d^{-1}, respectively.

The ADM (SD) bird-specific H_2S emission rates from H10 and H12 were 2.94±2.49 (n=491) and 2.83±2.53 (n=488) mg d^{-1} bird^{-1}, respectively.

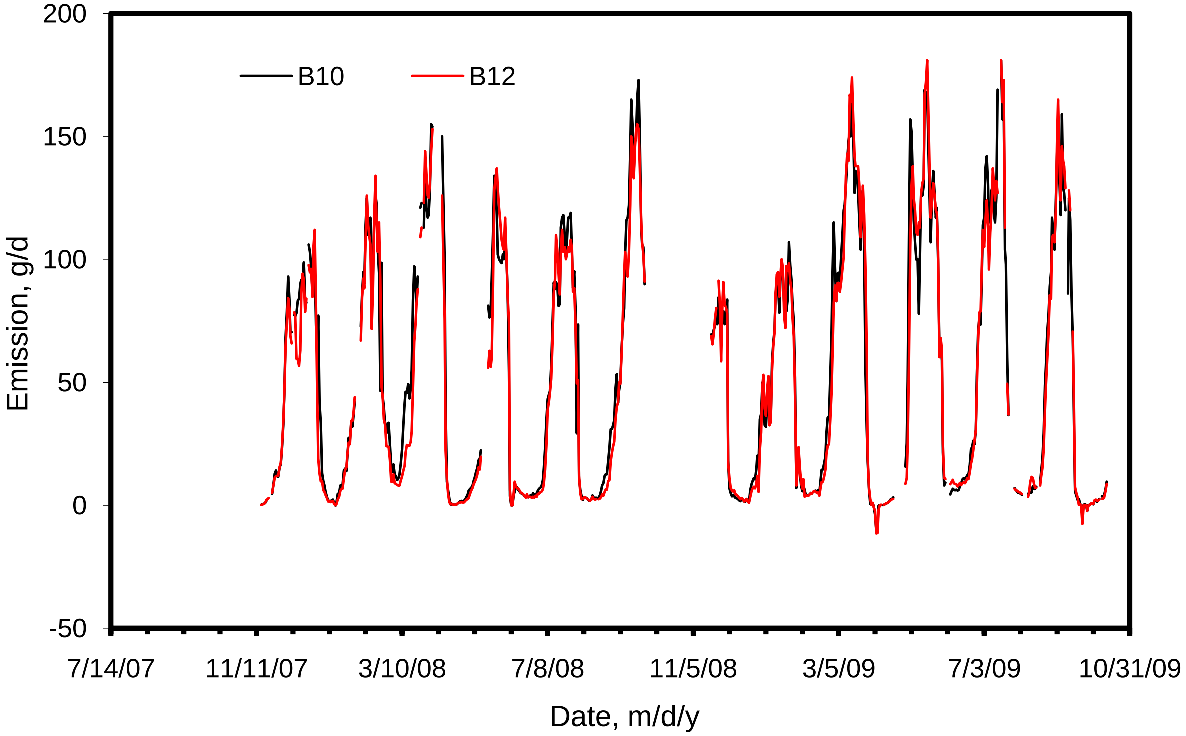

Figure 8. Daily mean H_2S emissions.

4.7. Ammonia Concentrations and Emissions

Daily mean inlet and exhaust NH_3 concentrations for the entire test are provided in Table E8.

The average daily mean NH_3 concentrations were approximately 0.3±0.6 (n=485) ppm in the inlet air, and 23.0±29.4 (n=478) and 20.5±26.6 (n=476) ppm in the exhausts of H10 and H12, respectively.

Daily mean NH_3 emissions from H10 and H12 are tabulated in Table E9 and plotted in Figure 9 for the entire test period. The NH_3 emission rates exhibited an increasing trend corresponding to bird age, and the lowest emission rates occurred between cycles when the litter was completely removed from the house, versus decaked. The “spike” in the emission rate on 8/2/08 occurred when the house was empty, during the decaking procedure.

The ADM NH_3 (SD) emission rates from H10 and H12 were 10.2±9.2 (n=467) and 9.0±8.4 (n=466) g d^{-1}, respectively.

The ADM bird-specific NH_3 (SD) emission rates from H10 and H12 were 539±450 (n=373) and 472±420 (n=370) g d^{-1} $bird^{-1}$, respectively.

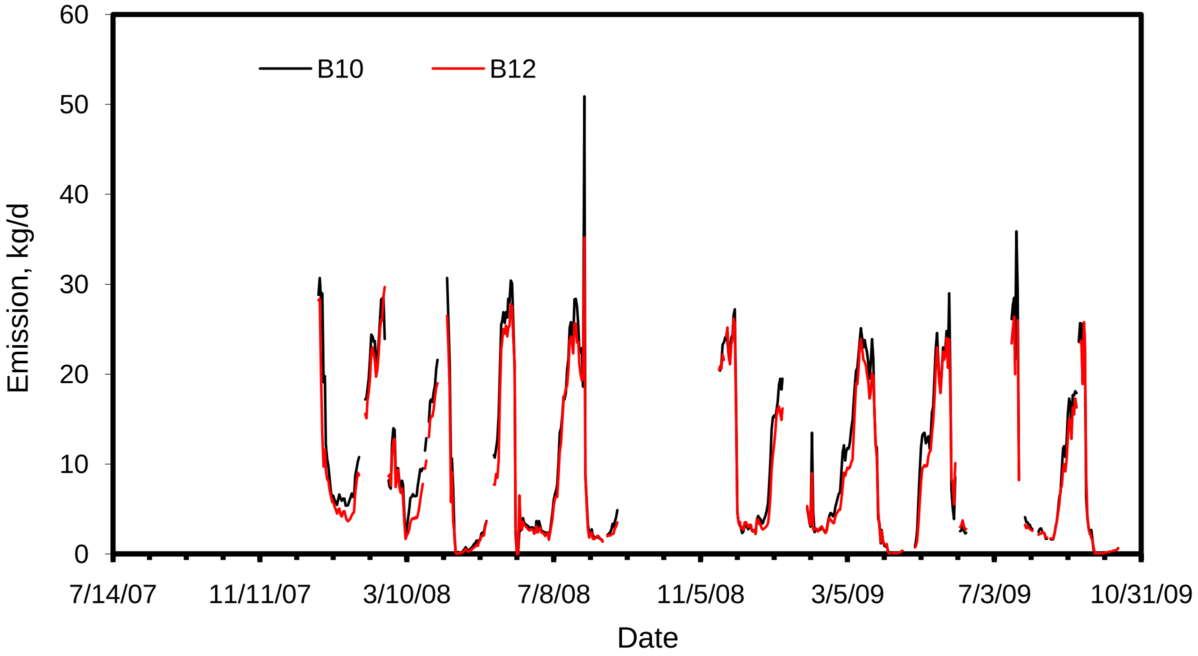

Figure 9. Daily mean NH_3 emissions.

4.8. Emission Data Completeness

Daily completeness data is given in Table E10. The number of complete data days (>75% valid required for reporting a daily mean) were calculated for emission measurements conducted from 9/27/07 to 10/21/09 (Table 22). The number of daily means of NH_3 emissions was reduced by delays in receiving the INNOVA 1412 at the beginning of the study, and by calibration and maintenance issues with the INNOVA 1412. The quantity of PM emissions data was reduced by TEOM failures.

Table 22. Emissions data completeness (days with >75% valid emission data collection).

Location	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
H10	467	592	352	53	37
H12	466	590	376	43	39

4.9. Reconciliation with Data Quality Objectives

The data quality objectives prior to the study were to measure gas and PM emissions from mechanically-ventilated buildings with total relative uncertainties of 27% and 32%, respectively.

4.9.1. Airflow

The overall average airflows for H10 and H12 were 14.7 ± 14.1 $dsm^3\ s^{-1}$ (n=658), and 15.0 ± 14.6 $dsm^3\ s^{-1}$ (n=648), respectively**.** The average airflows were approximately equivalent to one 91-cm fan and 1.6, 122-cm fans operating in each house. The airflow measurement uncertainty at these conditions was 13.4%, based on the fan models.

4.9.2. Gas Emissions

The bias and precision of NH_3 concentration measurements were derived from the NH_3 zero/span checks as compared with the NH_3 correction models (Table 9). The time-weighted relative bias and precision of NH_3 measurements were -0.2% and 0.7% and 1.7% and 4.3% for zero and span, respectively.

The bias and precision of H_2S concentration measurements were derived from the H_2S zero and span checks as compared with the H_2S correction models (Table 11). The time-weighted relative bias and precision of H_2S measurements were -0.0% and 0.2% and 0.3% and 5.4% for zero and span, respectively.

Based on these measurement errors calculated for concentrations and airflows, the uncertainties of NH_3 and H_2S emissions from H10 and H12 was 17.1 and 17.7%, respectively.

4.9.3. PM Emissions

The precisions of the PM_{10}, TSP and $PM_{2.5}$ concentration measurements were 3.0, 5.3 and 9.4%, respectively, based on collocation tests of TEOMs (Table 16). The time-weighted relative biases of the TEOMs were 0.74 and 1.54% for H10 and H12 based on mass flow checks (Table 13 and Table 14). The uncertainties of PM_{10}, TSP and $PM_{2.5}$ emissions from H10 were 15.0%, 17.4 and 23.3%, respectively. The uncertainties of PM_{10}, TSP and $PM_{2.5}$ emissions from H12 were 15.1, 17.4 and 23.4, respectively.

5. SUMMARY

The emissions of NH_3, H_2S, PM_{10}, TSP, $PM_{2.5}$ and VOCs from two 21,000-bird broiler houses (houses 10 and 12) at a 16-house ranch in California were measured during a two-year monitoring study. Rice hulls were used as litter. The buildings were tunnel-ventilated with single-speed fans.

The overall average emission rates from house 10 were 10.2 kg d^{-1} of NH_3, 52.9 g d^{-1} of H_2S, 873 g d^{-1} of PM_{10}, 98.8 g d^{-1} of $PM_{2.5}$, 2650 g d^{-1} of TSP, and 1.96 kg d^{-1} of total VOC. The overall average emission rates from house 12 were 9.0 kg d^{-1} of NH_3, 50.3 g d^{-1} of H_2S, 879 g d^{-1} of PM_{10}, 124 g d^{-1} of $PM_{2.5}$, 2270 g d^{-1} of TSP, and 2.52 kg d^{-1} of total VOC.

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7. DEFINITIONS AND ACRONYMS

AirDAC	Air Data Acquisition and Control – computer program
ADM	Average daily mean
BESS	Bioenvironmental and Structural Systems lab at University of Illinois
CAPECAB	Calculations of Air Pollutant Emissions from Confined Animal Buildings
CO_2	Carbon dioxide
CH_4	Methane
DAC	Data acquisition
DM	Daily mean
ΔP	Differential pressure
FANS	Fan Airflow Numeration System
GC-MS	Gas chromatograph mass spectrometer
GSL	Gas sampling location(s)
GSS	Gas sampling system
H10, H12	House 10, House 12
H_2S	Hydrogen sulfide
MDL	Minimum detection limit
MPC	Multipoint calibration
MS	Mass spectrometer
n	Number or count
NAEMS	National Air Emissions Monitoring Study
NH_3	Ammonia
NMHC	Non-methane hydrocarbons
Q	Airflow
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
OFIS	On farm instrument shelter
PM	Particulate matter
PREF	Primary representative exhaust fan
RH/T	Relative humidity/temperature
RH	Relative humidity
SD	Standard deviation
TC	Thermocouple
T_{dew}	Dew point temperature
TDS	Thermal desorption system
TEOM	Tapered element oscillating microbalance
TSP	Total suspended particulate
VOC	Volatile organic compounds
Z/S	Zero/span

APPENDIX A. MEASUREMENT VARIABLES

Table A1. Site measurement variables, instruments and sensors, and digital controls.

Data Col#	Data file heading	Instrument, sensor, controller	Sensor location	Monitoring/control location	Range / target	DAC hardware
1	Date & time	---				---
2	Smpl loc#	---				---
3	Cal gas #	Environics	Rack		0-7 gas #	---
4	Cal gas, ppm	Environics	Rack		From 0 ppm	---
5	NH3, ppm	Innova 1412	Rack	7 gas sampling lines	From 0.2 ppm	---
6	CO2, ppm	Innova 1412	Rack	7 gas sampling lines	From 3.4 ppm	---
7	N2O/C2H6O, ppm	Innova 1412	Rack	7 gas sampling lines	Varies	---
8	CH4/N2O, ppm	Innova 1412	Rack	7 gas sampling lines	Varies	---
9	THC/N2O/CH4, ppm	Innova 1412	Rack	7 gas sampling lines	Varies	---
10	WV, Tdew	Innova 1412	Rack	7 gas sampling lines	Not available	---
11	H2S, ppb	H2S analyzer	Rack	7 gas sampling lines	Varies	FP-AI-112-1
12	SO2, ppb	H2S analyzer	Rack	7 gas sampling lines	Varies	FP-AI-112-1
13	Smpl P, Pa	Setra 209 P sensor	GSS	7 gas sampling lines	0-14.7 psiv	FP-AI-112-1
14	Smpl Q, L/m	Mass flow	GSS	7 gas sampling lines	0-10 L/min	FP-AI-112-1
15	Smpl RH, %	Humitter 50Y	GSS	7 gas sampling lines	0-100 %	FP-AI-112-1
16	Smpl T, C	Humitter 50Y	GSS	7 gas sampling lines	-40 to 60 deg C	FP-AI-112-1
17	Smpl dir, %t	Flow direction sensor	GSS	7 gas sampling lines	0.065 - 0.065 V	FP-AI-112-1
18	GSS T, C	AD 592D T sensor	GSS	GSS	0-70 deg C	FP-AI-112-1
19	12 PM, ug/m3	TEOM #1	H12	H12, room center between F 7&12	-1000-9000 ug/m3	FP-AI-112-1
20	12 Filter, %	TEOM #1	H12	H12, room center between F 7&12	0-140%	FP-AI-112-1
21	12 Atm P, atm	TEOM #1	H12	H12, room center between F 7&12	0.8-1.3 atm	FP-AI-112-1
22	10 PM, ug/m3	TEOM #2	H10	H10, room center between F 7&12	-1000-9000 ug/m3	FP-AI-112-1
23	10 Filter, %	TEOM #2	H10	H10, room center between F 7&12	0-140%	FP-AI-112-1
24	Amb PM, ug/m3	Beta Gauge	Amb	Outside S side of B3, W end of Inlet	0-5000 ug/m3	FP-AI-112-1
25	CS, ppb	H2S analyzer	Rack	7 gas sampling lines	Varies	FP-AI-112-1
26	12N ΔP, Pa	Setra 260 P sensor #1	OFIS	H12N, beside fan 12	-100 to 100 Pa	FP-AI-112-1
27	12W ΔP, Pa	Setra 260 P sensor #2	OFIS	H12W, beside fan 2	-100 to 100 Pa	FP-AI-112-2
28	12S ΔP, Pa	Setra 260 P sensor #3	OFIS	H12S, beside fan 7	-100 to 100 Pa	FP-AI-112-2
29	10N ΔP, Pa	Setra 260 P sensor #4	OFIS	H10N beside fan 12	-100 to 100 Pa	FP-AI-112-2
30	10W ΔP, Pa	Setra 260 P sensor #5	OFIS	H10W, beside fan 2	-100 to 100 Pa	FP-AI-112-2
31	10S ΔP, Pa	Setra 260 P sensor #6	OFIS	H10S, beside fan 7	-100 to 100 Pa	FP-AI-112-2

Data Col#	Data file heading	Instrument, sensor, controller	Sensor location	Monitoring/control location	Range / target	DAC hardware
32	OFIS ΔP/H12 E, Pa	Setra 260 P sensor #7	OFIS	Inside and outside of OFIS/H12E	-100 to 100 Pa	FP-AI-112-2
33	Wind D, deg	03002VM Wind Sentry	Roof	Roof top tower	0-360 degree	FP-AI-112-2
34	Wind V, m/s	03002VM Wind Sentry	Roof	Roof top tower	0-50 m/s	FP-AI-112-2
35	Solar, W/m2	LI-200SL Pyranometer	Roof	Roof top tower	0-1500 W/m2	FP-AI-112-2
36	Amb RH, %	NOVUS RHT-WM #1	Roof	Roof top tower	0-100 %	FP-AI-112-2
37	Amb T, C	NOVUS RHT-WM #1	Roof	Roof top tower	-20-80 deg C	FP-AI-112-2
38	12 RH, %	NOVUS RHT-WM #2	H12	H12, room center between F 7&12	0-100 %	FP-AI-112-2
39	12 T, C	NOVUS RHT-WM #2	H12	H12, room center between F 7&12	0 - 100 deg C	FP-AI-112-2
40	10 RH, %	NOVUS RHT-WM #3	H10	H10, room center between F 7&12	0-100 %	FP-AI-112-2
41	10 T, C	NOVUS RHT-WM #3	H10	H10, room center between F 7&12	0 - 100 deg C	FP-AI-112-2
42	12Act1 , V	Activity sensor #1	H12Ac1	H12, west end of brooders	0 to 2 VDC	FP-AI-112-2
43	12Act2 , V	Activity sensor #2	H12Ac2	H12, middle of W end of brooders	0 to 2 VDC	FP-AI-112-3
44	12Act3 , V	Activity sensor #3	H12Ac3	H12, between E edge of cool cell	0 to 2 VDC	FP-AI-112-3
45	12Act4 , V	Activity sensor #4	H12Ac4	H12, E end wall	0 to 2 VDC	FP-AI-112-3
46	10Act1 , V	Activity sensor #5	H10Ac1	H10, W end of brooders	0 to 2 VDC	FP-AI-112-3
47	10Act2 , V	Activity sensor #6	H10Ac2	H10, middle of W end of brooders	0 to 2 VDC	FP-AI-112-3
48	10Act3 , V	Activity sensor #7	H10Ac3	H10, between E edge of cool cell	0 to 2 VDC	FP-AI-112-3
49	10Act4 , V	Activity sensor #8	H10Ac4	H10, Eend wall	0 to 2 VDC	FP-AI-112-3
50	OFIS Act , V	Activity sensor #9	OFIS	OFIS	0 to 2 VDC	FP-AI-112-3
51	10F7Ane, V	Anemometer 1	H10	H10 fan 7	-0.5 to 0.5 VDC	FP-AI-112-3
52	10F12Ane, V	Anemometer 2	H10	H10 fan 12	-0.5 to 0.5 VDC	FP-AI-112-3
53	12F7Ane, V	Anemometer 3	H12	H12 fan 7	-0.5 to 0.5 VDC	FP-AI-112-3
59	12F7 T, C	TC T type	H12F7	H12 in front of fan 7	-270 to 390 C	FP-TC-120-1
60	12F12 T, C	TC T type	H12F12	H12 in front of fan 12	-270 to 390 C	FP-TC-120-1
61	12 Mid1 T, C	TC T type	H12 Mid1	H12 room center	-270 to 390 C	FP-TC-120-1
62	12 Mid2 T, C	TC T type	H12 Mid2	H12 room center	-270 to 390 C	FP-TC-120-1
63	12 Mid3 T, C	TC T type	H12 Mid3	H12 room center	-270 to 390 C	FP-TC-120-1
64	12 Mid4 T, C	TC T type	H12 Mid4	H12 room center	-270 to 390 C	FP-TC-120-1
65	12 SBr T, C	TC T type	H12 SBrooder	H12 SW Brooder	-270 to 390 C	FP-TC-120-1
66	12 NBr T, C	TC T type	H12 NBrooder	H12 NW Brooder	-270 to 390 C	FP-TC-120-1
67	12 SIn T, C	TC T type	H12 SInlet	H12 S Inlet	-270 to 390 C	FP-TC-120-2
68	12 NIn T, C	TC T type	H12 NInlet	H12 N Inlet	-270 to 390 C	FP-TC-120-2
69	10F7 T, C	TC T type	H10F7	H10 in front of fan 7	-270 to 390 C	FP-TC-120-2
70	10F12 T, C	TC T type	H10F12	H10 in front of fan 12	-270 to 390 C	FP-TC-120-2
71	10 Mid1 T, C	TC T type	H10 Mid1	H10 room center	-270 to 390 C	FP-TC-120-2
72	10 Mid2 T, C	TC T type	H10 Mid2	H10 room center	-270 to 390 C	FP-TC-120-2
73	10 Mid3 T, C	TC T type	H10 Mid3	H10 room center	-270 to 390 C	FP-TC-120-2

Data Col#	Data file heading	Instrument, sensor, controller	Sensor location	Monitoring/control location	Range / target	DAC hardware
74	10 Mid4 T, C	TC T type	H10 Mid4	H10 room center	-270 to 390 C	FP-TC-120-2
75	10 SBr T, C	TC T type	H10 SBrooder	H10 SW Brooder	-270 to 390 C	FP-TC-120-3
76	10 NBr T, C	TC T type	H10 NBrooder	H10 NW Brooder	-270 to 390 C	FP-TC-120-3
77	10 SIn T, C	TC T type	H10 SInlet	H10 S Inlet	-270 to 390 C	FP-TC-120-3
78	10 NIn T, C	TC T type	H10 NInlet	H10 N Inlet	-270 to 390 C	FP-TC-120-3
79	Rwy10 T, C	TC T type	RwyH10	Between OFIS and H10	-270 to 390 C	FP-TC-120-3
80	Rwy10 HT, C	TC T type	RwyH10 HT	Between OFIS and H10	-270 to 390 C	FP-TC-120-3
81	Rwy12 T, C	TC T type	RwyH12	Between OFIS and H12	-270 to 390 C	FP-TC-120-3
82	Rwy12 HT, C	TC T type	RwyH12 HT	Between OFIS and H12	-270 to 390 C	FP-TC-120-3
83	OFIS T, C	TC T type	OFIS	DAC Panel	-270 to 390 C	FP-TC-120-4
84	OFIS AC T, C	TC T type	OFIS AC	Wall A/C Exhaust	-270 to 390 C	FP-TC-120-4
85	Beta box T, C	TC T type	Beta Enclosure	Beta Gauge Enclosure	-270 to 390 C	FP-TC-120-4
86	H12 Floor T, C	TC T type	H12 Floor	Manure Pile	-270 to 390 C	FP-TC-120-4
91	10F2, rpm	Fan speed sensor #1	H10F2	House 10 fan 2	0 to 5000 rpm	USB-4303-1
92	10F3, rpm	Fan speed sensor #2	H10F3	House 10 fan 3	0 to 5000 rpm	USB-4303-1
93	10F4, rpm	Fan speed sensor #3	H10F4	House 10 fan 4	0 to 5000 rpm	USB-4303-1
94	10F5, rpm	Fan speed sensor #4	H10F5	House 10 fan 5	0 to 5000 rpm	USB-4303-1
95	10F6, rpm	Fan speed sensor #5	H10F6	House 10 fan 6	0 to 5000 rpm	USB-4303-1
96	10F7, rpm	Fan speed sensor #6	H10F7	House 10 fan 7	0 to 5000 rpm	USB-4303-1
97	10F8, rpm	Fan speed sensor #7	H10F8	House 10 fan 8	0 to 5000 rpm	USB-4303-1
98	10F9, rpm	Fan speed sensor #8	H10F9	House 10 fan 9	0 to 5000 rpm	USB-4303-1
99	10F10, rpm	Fan speed sensor #9	H10F10	House 10 fan 10	0 to 5000 rpm	USB-4303-1
100	10F11, rpm	Fan speed sensor #10	H10F11	House 10 fan 11	0 to 5000 rpm	USB-4303-1
101	10F12, rpm	Fan speed sensor #11	H10F12	House 10 fan 12	0 to 5000 rpm	USB-4303-2
102	12F2, rpm	Fan speed sensor #12	H12F2	House 12 fan 2	0 to 5000 rpm	USB-4303-2
103	12F3, rpm	Fan speed sensor #13	H12F3	House 12 fan 3	0 to 5000 rpm	USB-4303-2
104	12F4, rpm	Fan speed sensor #14	H12F4	House 12 fan 4	0 to 5000 rpm	USB-4303-2
105	12F5, rpm	Fan speed sensor #15	H12F5	House 12 fan 5	0 to 5000 rpm	USB-4303-2
106	12F6, rpm	Fan speed sensor #16	H12F6	House 12 fan 6	0 to 5000 rpm	USB-4303-2
107	12F7, rpm	Fan speed sensor #17	H12F7	House 12 fan 7	0 to 5000 rpm	USB-4303-2
108	12F8, rpm	Fan speed sensor #18	H12F8	House 12 fan 8	0 to 5000 rpm	USB-4303-2
109	12F9, rpm	Fan speed sensor #19	H12F9	House 12 fan 9	0 to 5000 rpm	USB-4303-2
110	12F10, rpm	Fan speed sensor #20	H12F10	House 12 fan 10	0 to 5000 rpm	USB-4303-2
111	12F11, rpm	Fan speed sensor #21	H12F11	House 12 fan 11	0 to 5000 rpm	USB-4303-3
112	12F12, rpm	Fan speed sensor #22	H12F12	House 12 fan 12	0 to 5000 rpm	USB-4303-3
113	Reserved					USB-4303-3
114	Reserved					USB-4303-3

Data Col#	Data file heading	Instrument, sensor, controller	Sensor location	Monitoring/control location	Range / target	DAC hardware
115	Reserved					USB-4303-3
116	Reserved					USB-4303-3
117	Reserved					USB-4303-3
118	Reserved					USB-4303-3
119	Reserved					USB-4303-3
120	Reserved					USB-4303-3
121	10 Feed, %t	House controller	H10	H10 Feed	0-100%t	DIO 96H/50
122	10 Light 1, %t	House controller	H10	H10 Light 1	0-100%t	DIO 96H/50
123	10 Light 2, %t	House controller	H10	H10 Light 2	0-100%t	DIO 96H/50
124	10 Crtn on, %t	House controller	H10	H10 Tunnel curtain open	0-100%t	DIO 96H/50
125	10 Crtn off, %t	House controller	H10	H10 Tunnel curtain close	0-100%t	DIO 96H/50
126	10 Vn on, %t	House controller	H10	H10 Vent open	0-100%t	DIO 96H/50
127	10 Vn off, %t	House controller	H10	H10 Vent close	0-100%t	DIO 96H/50
128	10 Ht 1, %t	House controller	H10	H10 Heater 1	0-100%t	DIO 96H/50
129	10 Ht 2, %t	House controller	H10	H10 Heater 2	0-100%t	DIO 96H/50
130	10 Ht 3, %t	House controller	H10	H10 Heater 3	0-100%t	DIO 96H/50
131	10 Ht 4, %t	House controller	H10	H10 Heater 4	0-100%t	DIO 96H/50
132	10 Ht 5, %t	House controller	H10	H10 Heater 5	0-100%t	DIO 96H/50
133	10 Cool S, %t	House controller	H10	H10 CoolPad South	0-100%t	DIO 96H/50
134	10 Cool N, %t	House controller	H10	H10 CoolPad North	0-100%t	DIO 96H/50
135	12 Feed, %t	House controller	H12	H12 Feed	0-100%t	DIO 96H/50
136	12 Light 1, %t	House controller	H12	H12 Light 1	0-100%t	DIO 96H/50
137	12 Light 2, %t	House controller	H12	H12 Light 2	0-100%t	DIO 96H/50
138	12 Crtn on, %t	House controller	H12	H12 Tunnel curtain open	0-100%t	DIO 96H/50
139	12 Crtn off, %t	House controller	H12	H12 Tunnel curtain close	0-100%t	DIO 96H/50
140	12 Vn on, %t	House controller	H12	H12 Vent open	0-100%t	DIO 96H/50
141	12 Vn off, %t	House controller	H12	H12 Vent close	0-100%t	DIO 96H/50
142	12 Ht 1, %t	House controller	H12	H12 Heater 1	0-100%t	DIO 96H/50
143	12 Ht 2, %t	House controller	H12	H12 Heater 2	0-100%t	DIO 96H/50
144	12 Ht 3, %t	House controller	H12	H12 Heater 3	0-100%t	DIO 96H/50
145	12 Ht 4, %t	House controller	H12	H12 Heater 4	0-100%t	DIO 96H/50
146	12 Ht 5, %t	House controller	H12	H12 Heater 5	0-100%t	DIO 96H/50
147	12 Cool S, %t	House controller	H12	H12 CoolPad South	0-100%t	DIO 96H/50
148	12 Cool N, %t	House controller	H12	H12 CoolPad North	0-100%t	DIO 96H/50

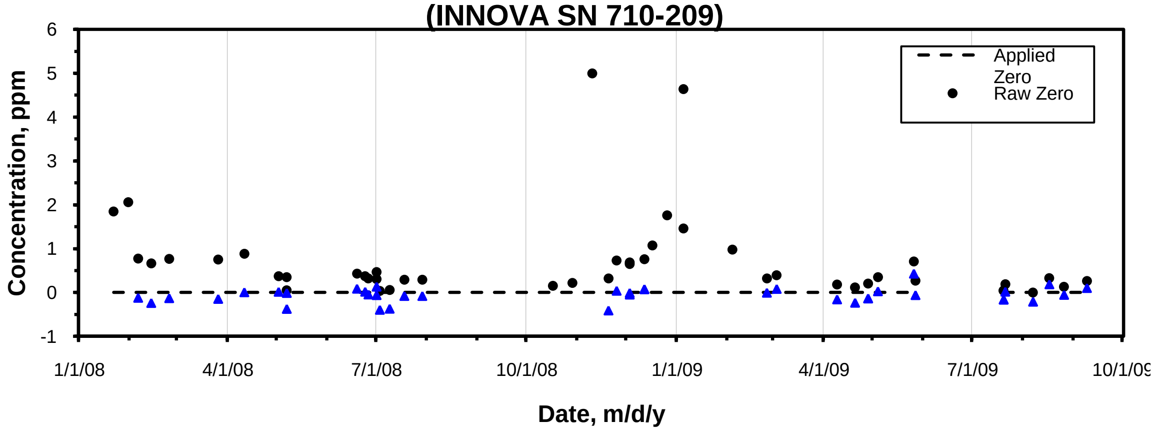
APPENDIX B. RECORD OF MAINTENANCE AND CALIBRATION.

Maintenance and Calibration Tasks	
Category	**Times Completed**
Environment Sensing and Other	
Clean RH/T probe	99
Calibration check of RH/T probe	3
Calibration check of thermocouples	7
Performance check of weather station	88
Direction verification of wind indicator	3
Clean solar sensor	96
Check solar sensor with collocated sensor	2
Clean motion sensors	95
Air Flow Measurement System	
Fan test events	6
Zero check of pressure sensors (ΔP)	97
Multipoint calibration of pressures sensors (ΔP)	1
Drift & accuracy check of anemometer(s)	3
Particulate Matter Measurement System	
Clean TOEM screens	85
Check/clean TEOM inlet head(s)	100
Replace TEOM filters	76
Verify TEOM mass transducer calibration	8
Leak test of TEOM	8
Verify TEOM flow rate & MFC accuracy	8
Change TEOM in-line filters	9
Check/clean Beta Gauge inlet head	101
Check Beta Gauge airflow	5
Validate Beta Gauge mass w/foil set	4
Calibrate Beta Gauge mass & airflow	5
Gas Measurement System	
Clean/replace GSS membrane filters	59
Leak check of GSS	13
Calibration check of all lines	7
Replace GSS filters	30
Calibrate GSS pressure and flow sensors	7
Flow calibration/check MFC flow of Environics Dilutor	2
Precision check of Multigas Analyzer	54
Multipoint calibration of Multigas Analyzer	17
Precision check of TEC 450I	54
Multipoint calibration of TEC 450I	12

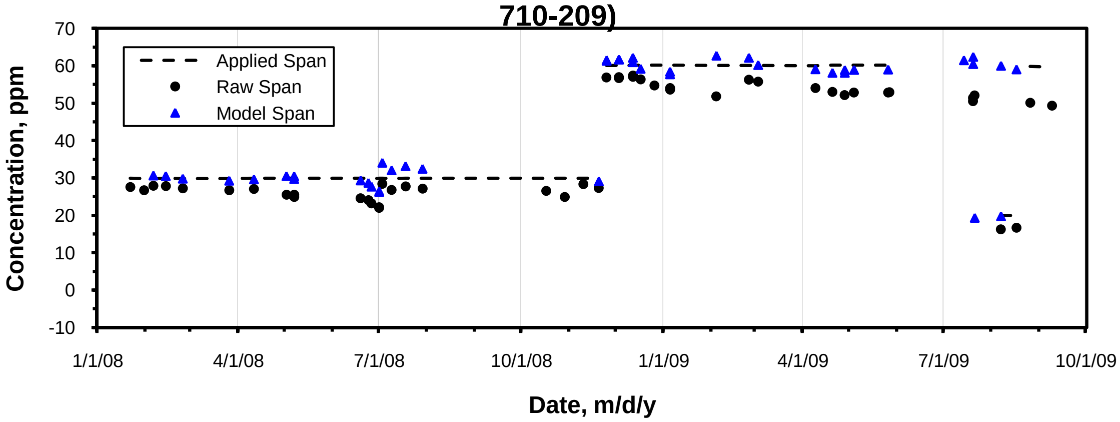
APPENDIX C. GAS ANALYZER CALIBRATIONS.

AMMONIA

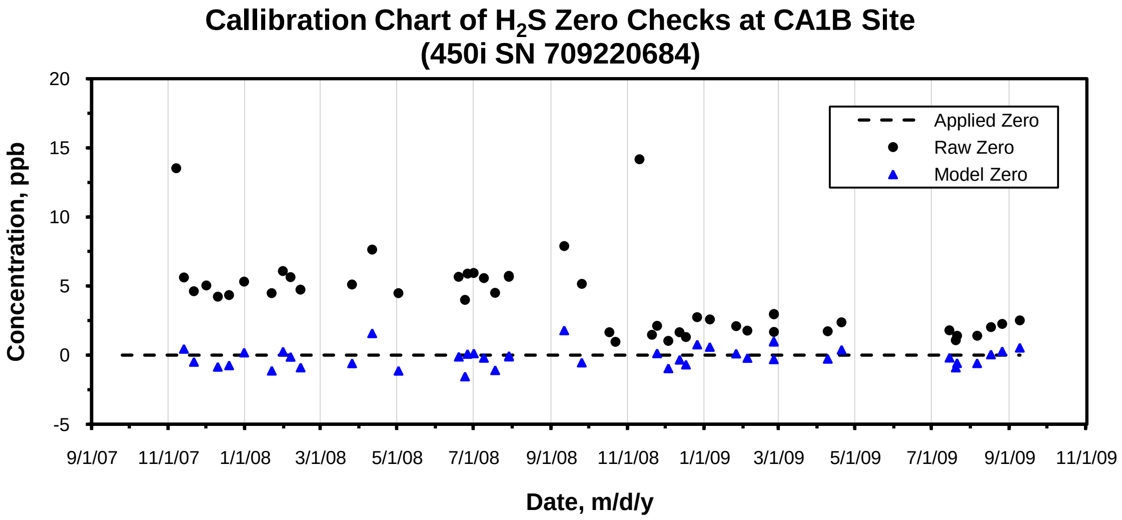
Callibration Chart of NH_3 Zero Checks at CA1B Site (INNOVA SN 710-209)

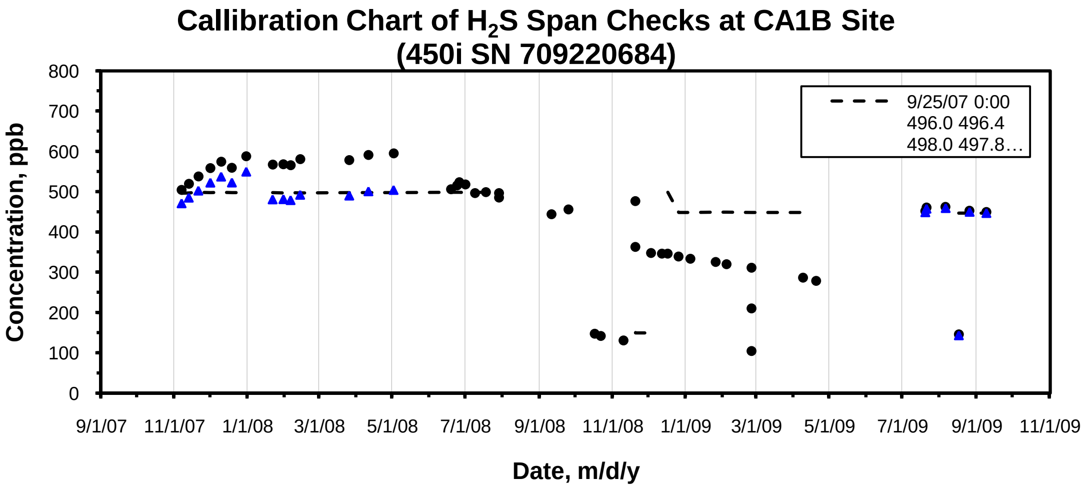


Callibration Chart of NH_3 Span Checks at CA1B Site (INNOVA SN 710-209)



HYDROGEN SULFIDE





APPENDIX D. MAJOR DATA INVALIDATIONS.

Variable Description	Start Date and Time	End Date and Time	Minutes	Comment
B12 N B T	11/3/07 1:28	11/7/07 16:32	6665	Systematic Error-TC signal temporarily offline
B12 S B T	11/3/07 1:56	11/7/07 17:42	6707	Systematic Error-signal temporarily offline
B10 N In T	11/5/07 10:31	11/10/07 14:32	7442	Systematic Error-signal temporarily offline
B12 PM	11/10/2007 19:52	11/20/2007 14:33	14081	Out of Range-Instrument did not pass mass transducer calibration on 11/10
B10 PM and filter	2/19/08 12:27	2/25/08 13:18	8692	Sampling Elsewhere
B12 PM and filter and atm P	2/19/08 14:22	2/25/08 13:18	8577	Sampling Elsewhere-FN indicate TEOMs moved into trailer during bird removal
B10 Mid3 T	2/21/08 6:38	2/22/08 12:34	1797	Systematic Error-signal temporarily offline
All INNOVA signals	2/22/08 12:27	2/23/08 14:29	1563	Off-FN indicate INNOVA offline to install EtOH filter
Amb PM	2/25/08 17:06	2/29/08 12:11	5466	Systematic Error
B12 PM and filter	3/23/08 16:30	3/25/08 12:44	2655	Systematic Error-Measurement likely affected by dust overload
B10 PM and filter	3/23/08 19:02	3/25/08 12:31	2490	Systematic Error-Measurement likely affected by dust overload
B12 PM and filter and atm P	4/13/08 11:39	4/18/08 14:59	7401	Off-FN indicate TEOM turned off and moved to OFIS while barn was cleaned
B10 PM and filter	4/13/08 11:39	4/18/08 14:59	7401	Off-FN indicate TEOMs turned off and moved into OFIS while barn was cleaned
Raw SO2	4/13/08 23:28	4/15/08 0:22	1495	Sampling Elsewhere
B12 RH and T	4/16/08 9:11	4/18/08 16:19	3309	Systematic Error-RH signal affected by cleaning process
B12 RH and T	4/18/08 15:51	4/20/08 2:24	2074	Systematic Error
All B12 Activity signals	5/6/08 11:22	6/5/08 14:36	43395	Systematic Error-FN indicate signals were in error because of a poor cable connection
B12 PM	5/26/08 1:43	5/28/08 11:50	3488	Pegged
B10 PM	5/27/08 7:58	5/28/08 11:13	1636	Pegged
B12 PM and filter	6/5/08 11:22	6/12/08 11:48	10107	Off-TEOM turned off and moved into OFIS during barn cleaning
B12 PM and filter and atm P	6/5/08 11:42	6/12/08 11:48	10087	Off-TEOM offline and moved into OFIS during barn cleaning
B10 PM and filter	6/5/08 11:42	6/12/08 11:48	10087	Off-TEOM turned off and moved into OFIS during barn cleaning
B10W dP	7/1/08 10:01	7/18/08 10:27	24507	Systematic Error-FN indicate one of the tubes became disconnected
B12 PM and filter	7/29/08 11:12	8/11/08 12:34	18803	Off-FN indicate TEOM turned off and moved into OFIS between cycles
B10 PM and filter	7/29/08 11:12	8/11/08 12:46	18815	Off-FN indicate TEOM turned off and moved into OFIS between cycles
B12 Atm P	7/29/08 11:21	8/11/08 10:28	18668	Off-FN indicate TEOM turned off between cycles
B12 RH and T	8/2/08 6:13	8/11/08 17:45	13653	Failure-FN indicate sensor failure and tip replaced
All INNOVA signals	8/18/08 15:39	8/20/08 3:07	2129	Systematic Error-FN indicate SIT settings were not correct

Variable Description	Start Date and Time	End Date and Time	Minutes	Comment
All INNOVA signals	8/30/08 11:58	9/2/08 11:15	4278	Failure-FN indicate chopper failure
All INNOVA signals	9/2/08 11:01	10/2/08 15:32	43472	Off-FN indicate INNOVA sent to manufacturer, California Analytical Inst.
B10F12 T	9/14/08 6:19	9/22/08 13:52	11974	Systematic Error-FN indicate sensor problem
B12 PM	9/20/08 15:06	9/22/08 12:19	2714	Pegged-signal exceeds range of analyzer
B12 PM	9/22/08 12:54	9/24/08 13:53	2940	Low Flow-FN indicate flow error with TEOM
B12 PM and filter, atm P	9/25/08 13:58	10/16/08 13:41	30224	Off-FN indicate TEOM turned off between cycles
B10 PM and filter	9/25/08 13:59	10/16/08 14:06	30248	Off-FN indicate TEOMs turned off and moved into OFIS between cycles
All GSS signals	9/27/08 0:01	11/19/08 18:07	77407	Low Flow-FN and calibration data indicate a leak at the GSS
B10 RH and T	9/30/08 12:02	10/2/08 17:33	3212	Systematic Error-systems temporarily showing a lot of noise which may be related to cleaning activities in barn
AirDAC N2O	9/30/08 23:57	10/2/08 15:12	2356	Off-filter offline
B10 PM	11/5/08 11:49	11/7/08 14:05	3017	Pegged-signal exceeds range of analyzer-likely caused by plugged filter
B12 PM	11/5/08 18:55	11/7/08 12:12	2478	Pegged-signal exceeds range of sensor-likely caused by plugged filter
12 Crtn off	11/12/08 9:11	10/22/09 18:24	495914	Failure-FN indicate relay was not working
Amb RH and T	11/22/08 5:40	12/2/08 12:56	14837	Failure-FN indicate the sensor tip failed
B12 PM and filter	11/30/08 3:42	12/2/08 12:06	3385	Low Flow-low flow caused by plugged filter
B10 PM and filter	11/30/08 16:10	12/2/08 11:43	2614	Low Flow-low flow caused by plugged filter
B12 S B T	12/3/08 14:01	12/12/08 14:34	12994	Failure-FN indicate TC failed and was repaired
B12 PM and filter and atm P	12/3/08 14:09	12/12/08 14:12	12964	Off-FN indicate TEOMs offline and moved into OFIS during barn cleaning
B10 PM and filter	12/3/08 14:09	12/12/08 13:38	12930	Off-FN indicate TEOMs offline and moved into OFIS during barn cleaning
B12 N B T	12/10/08 14:03	12/12/08 14:29	2907	Valid-Flagged NOI in error
B12 N B T	12/10/08 14:49	12/12/08 14:29	2861	Noise-signal appears affected by B12 S B T
B12 PM and filter	12/25/08 14:06	12/26/08 16:28	1583	Low Flow-flow error caused by full filter
B12 PM and filter	1/4/09 1:13	1/5/09 12:23	2111	Low Flow-FN indicate filter required changing
B10 RH and T	1/9/09 8:10	1/10/09 22:15	2286	Systematic Error-sensor unstable - tip later changed
All INNOVA signals	1/12/09 17:43	1/15/09 12:48	4026	Failure-FN indicate chopper failure
All INNOVA signals	1/15/09 12:34	1/30/09 12:51	21618	Off-FN indicate INNOVA offline while under repair
B12 PM and filter	1/26/09 11:43	2/5/09 16:25	14683	Off-FN indicate TEOMs off and moved to OFIS between cycles
B10 PM and filter	1/26/09 11:57	2/5/09 16:25	14669	Off-FN indicate TEOM turned off and moved to OFIS between cycles
B12 Atm P	1/26/09 12:14	2/5/09 16:11	14638	Off-FN indicate TEOM offline
B10 Mid1 T	1/29/09 17:03	2/4/09 8:19	8117	Systematic Error-high temperature signal cannot be linked to a heater so it is assumed an error
B10 PM	2/20/09 12:31	2/24/09 20:39	6249	Failure-FN indicate air temperature problem
B10 Filter	2/20/09 12:31	2/24/09 20:39	6249	Failure-FN indicate air temperature problem
B10 PM and filter	2/24/09 20:04	5/11/09 12:46	109003	Off-FN indicate TEOM offline while awaiting pump parts

Variable Description	Start Date and Time	End Date and Time	Minutes	Comment
B10F12 T	3/26/09 10:58	4/9/09 9:57	20100	Systematic Error-signal temporarily unstable
B12 PM and filter and atm P	3/26/09 11:26	4/9/09 13:10	20265	Off-FN indicate TEOM turned off and moved into trailer between cycles
B10 Mid1 T	3/29/09 20:17	4/9/09 9:35	15199	Systematic Error-signal temporarily unstable
All GSS signals	4/20/09 15:28	4/28/09 11:39	11292	Systematic Error-FN indicate nafion tubing left in system
B12 PM and filter	4/30/09 20:29	5/4/09 12:30	5282	Low Flow-FN indicate filter change alleviated problem
B12 PM	5/22/09 12:25	5/26/09 12:09	5745	Systematic Error-noisy signal may be related to filter
B12 PM and filter	5/26/09 11:49	6/4/09 11:26	12938	Off-FN indicate TEOMs moved to OFIS during barn cleaning
B12 Atm P	5/26/09 11:49	6/4/09 14:41	13133	Off-TEOM offline during barn cleaning
B10 PM and filter	5/26/09 11:49	6/4/09 11:26	12938	Off-FN indicate TEOMs moved to OFIS during barn cleaning
OFIS T	5/26/09 14:34	6/4/09 11:22	12769	Systematic Error-signal temporarily out of range
B10Act4	6/4/09 8:06	7/14/09 17:53	58188	Failure-FN indicate sensor failure
All DIO96H signals	6/4/09 12:17	6/25/09 16:32	30496	DAC-DIO96H module not working properly
All INNOVA signals	6/11/09 13:55	7/14/09 14:41	47567	Off-FN indicate INNOVA offline
B12 Mid4 T	6/26/09 15:22	10/22/09 18:01	170080	Failure-FN indicate TC is not operating properly
B12 PM and filter	7/13/09 0:12	8/3/09 14:43	31112	Low Flow-FN indicate TEOM pump failure
B12 Atm P	7/14/09 12:50	8/16/09 13:39	47570	Off-TEOM offline
AirDAC N2O	7/14/09 13:09	7/21/09 9:32	9864	Off-FN indicate TOC measurement in place of N2O
B10 PM and filter	7/20/09 15:22	7/27/09 13:51	9990	Off-FN indicate TEOM offline during barn cleaning
B12 PM and filter	8/3/09 14:02	8/16/09 15:47	18826	Failure-FN indicate TEOM battery and software problem
B10 PM	8/4/09 11:24	8/16/09 14:59	17496	Systematic Error-noisy signal suggests filter was not seated properly
USB-4303 signals	8/4/09 12:12	8/7/09 12:18	4327	DAC-FN indicate USB module problem
All DIO96H signals	8/26/09 16:23	9/9/09 13:20	19978	DAC-FN indicate problem with DIO module
OFIS dP	9/10/09 7:39	10/21/09 9:10	59132	Off-sensor uninstalled and used as replacement elsewhere
B12Act4	9/10/09 9:38	10/21/09 11:11	59134	Off-FN indicate sensor uninstalled
B12 PM and filter	9/10/09 18:40	9/13/09 13:53	4034	Sampling Elsewhere-FN indicate TEOM collocated in B10
B12 PM and filter	9/13/09 13:19	9/26/09 14:16	18778	Off-FN indicate TEOMs moved into OFIS during barn cleaning
B10 PM and filter	9/13/09 13:19	9/26/09 14:16	18778	Off-FN indicate TEOMs moved to OFIS during barn cleaning
B12 Atm P	9/13/09 13:37	9/26/09 12:49	18673	Off-FN indicate TEOM offline during barn cleaning
B12 PM and filter	9/26/09 13:12	10/22/09 13:06	37435	Sampling Elsewhere-FN indicate TEOM in B10 for collocation

APPENDIX E. DAILY MEANS.

Table E1. Daily means (SD) of weather parameters.

Table E1. Daily means (SD) of weather parameters at Site CA1B for September, 2007.

Day	Temp, °C		RH, %	WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	29.0	(5.0)		3.52	(1.61)	332	(124)				
2	27.6	(5.5)		3.27	(1.38)	331	(112)				
3	26.7	(5.2)		3.50	(1.61)	336	(134)				
4	22.3	(4.3)		4.74	(1.23)	324	(59)				
5	21.6	(4.9)		3.59	(2.03)	308	(71)				
6	25.2	(6.3)		2.02	(1.26)	356	(112)				
7	20.6	(4.0)		4.58	(1.30)	324	(36)				
8	22.0	(5.6)		3.77	(1.03)	324	(50)				
9	21.6	(4.6)		4.49	(0.98)	329	(39)				
10	22.2	(4.7)		3.62	(1.19)	332	(65)				
11	22.3	(4.6)		4.35	(1.23)	323	(19)				
12	19.3	(3.8)		5.85	(1.73)	319	(20)				
13	19.0	(4.1)		3.62	(1.40)	336	(104)				
14	20.2	(4.3)		2.91	(1.21)	337	(129)				
15	19.2	(4.3)		3.58	(1.50)	321	(52)			101.1	(0.0)
16	18.7	(4.1)		4.14	(1.53)	327	(74)			101.0	(0.0)
17	19.5	(4.6)		3.06	(1.97)	330	(121)			100.9	(0.0)
18	20.5	(6.1)		2.87	(1.93)	45	(109)			100.7	(0.1)
19	15.9	(3.7)		3.47	(2.06)	31	(100)			100.7	(0.0)
20	14.9	(4.8)		1.57	(1.08)	325	(113)			100.7	(0.0)
21	19.0	(5.1)		1.85	(0.96)	347	(104)			100.7	(0.1)
22	17.1	(2.2)		2.33	(1.31)	210	(94)			101.0	(0.1)
23	17.5	(3.4)		2.30	(1.76)	319	(114)			101.2	(0.1)
24	18.1	(5.1)		2.34	(1.31)	321	(114)			101.3	(0.0)
25	19.9	(5.9)		2.06	(1.18)	328	(131)			101.2	(0.0)
26	22.2	(6.1)		1.64	(0.85)	351	(143)			100.9	(0.1)
27	22.4	(5.7)		1.83	(1.27)	354	(125)			100.7	(0.0)
28	16.6	(3.0)		3.71	(1.39)	321	(106)	153	(257)	100.9	(0.1)
29	15.1	(4.5)		4.60	(2.66)	308	(60)	216	(296)	101.2	(0.0)
30	17.7	(7.3)		2.14	(1.61)	117	(98)	208	(289)	101.3	(0.1)
Avg	20.5			3.24		333		193		101.0	
n	30		0	30		30		3		16	
SD	3.4			1.06		83		28		0.2	
Min	14.9			1.57		31		153		100.7	
Max	29.0			5.85		356		216		101.3	

Table E1. Daily means (SD) of weather parameters at Site CA1B for October, 2007.

Day	Temp, ºC		RH, %	WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	17.8	(3.4)		4.27	(2.06)	324	(105)	187	(284)	101.4	(0.0)
2	18.8	(5.9)		1.68	(1.23)	336	(127)	205	(285)	101.1	(0.1)
3	19.1	(5.7)		2.54	(1.62)	357	(124)	202	(284)	100.8	(0.1)
4	15.0	(3.5)		5.30	(2.16)	321	(106)	195	(275)	100.9	(0.1)
5	13.5	(2.9)		2.99	(1.94)	327	(114)	175	(262)	101.4	(0.2)
6										101.6	(0.0)
7										101.2	(0.2)
8										100.8	(0.0)
9										101.1	(0.2)
10										101.1	(0.1)
11										100.8	(0.1)
12	14.7	(1.8)		2.20	(1.47)	282	(97)	69	(153)	100.8	(0.1)
13	16.2	(3.0)		2.19	(1.29)	315	(95)	169	(262)	101.0	(0.0)
14	17.6	(4.9)		1.47	(0.91)	84	(100)	179	(261)	100.9	(0.0)
15	16.0	(2.8)		3.72	(1.30)	328	(107)	139	(233)	100.9	(0.0)
16	15.5	(2.3)		3.18	(1.21)	15	(109)	125	(218)	101.1	(0.1)
17	15.1	(2.5)		2.21	(1.29)	319	(111)	140	(228)	101.5	(0.1)
18	16.7	(3.9)		2.30	(1.28)	333	(122)	171	(257)	101.4	(0.1)
19	18.1	(4.4)		1.90	(1.38)	11	(123)	172	(253)	101.4	(0.1)
20	14.9	(2.5)		6.14	(2.87)	324	(80)	160	(249)	101.7	(0.1)
21	13.4	(4.7)		3.01	(2.24)	325	(101)	176	(257)	102.1	(0.1)
22	16.9	(6.7)		1.23	(0.76)	114	(71)	170	(256)	102.0	(0.1)
23	18.1	(6.2)		1.42	(1.06)	341	(119)	168	(251)	101.7	(0.1)
24	19.9	(6.7)		1.19	(0.70)	23	(115)	167	(248)	101.1	(0.2)
25	18.5	(5.6)		1.28	(1.04)	330	(108)	150	(224)	100.8	(0.0)
26	16.0	(4.4)		2.02	(0.78)	310	(37)	162	(237)	101.1	(0.2)
27	17.7	(5.3)		1.44	(0.79)	313	(89)	132	(217)	101.6	(0.1)
28	19.5	(4.4)		2.14	(0.88)	304	(76)	143	(228)	101.6	(0.1)
29	18.4	(4.3)		1.87	(1.60)	11	(118)	125	(219)	101.6	(0.1)
30	14.7	(2.8)		3.03	(1.34)	340	(102)	135	(217)	101.7	(0.0)
31	14.2	(3.5)		1.39	(0.85)	308	(108)	118	(194)	101.6	(0.1)
Avg	16.7			2.48		336		157		101.3	
n	25		0	25		25		25		31	
SD	1.9			1.24		122		30		0.4	
Min	13.4			1.19		11		69		100.8	
Max	19.9			6.14		357		205		102.1	

Table E1. Daily means (SD) of weather parameters at Site CA1B for November, 2007.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	13.7	(4.3)			1.92	(1.30)	317	(100)	120	(208)	101.5	(0.0)
2	15.8	(4.6)			1.40	(0.90)	42	(105)	145	(221)	101.6	(0.0)
3	16.0	(5.8)			0.96	(0.60)	69	(101)	146	(228)	101.5	(0.0)
4	15.4	(5.5)			0.79	(0.67)	32	(111)	143	(224)	101.3	(0.1)
5	15.7	(5.7)			1.07	(0.84)	322	(111)	140	(218)	101.2	(0.0)
6	14.6	(4.7)			1.71	(0.95)	321	(95)	122	(211)	101.2	(0.0)
7	15.3	(6.1)			0.84	(0.60)	20	(122)	127	(209)	101.2	(0.0)
8	13.4	(3.2)			2.98	(1.44)	334	(86)	96	(183)	101.2	(0.0)
9	14.5	(3.5)			1.68	(0.94)	315	(115)	116	(200)	101.3	(0.0)
10	15.0	(5.1)			0.81	(0.78)	60	(107)	99	(181)	101.2	(0.0)
11	13.9	(2.0)	78.8	(10.4)	4.14	(2.58)	335	(109)	70	(145)	101.5	(0.2)
12	12.3	(4.8)	74.2	(10.1)	1.24	(1.02)	83	(101)	137	(220)	101.8	(0.0)
13	14.5	(4.1)	77.8	(8.7)	2.05	(1.66)	322	(109)	131	(207)	101.6	(0.1)
14											101.4	(0.0)
15	15.6	(4.7)	78.2	(12.0)	1.29	(0.89)	27	(121)	126	(207)	101.4	(0.0)
16	15.3	(2.7)	77.6	(10.0)	2.32	(1.19)	335	(100)	120	(209)	101.5	(0.0)
17	13.3	(4.0)	81.1	(11.0)	1.57	(1.16)	342	(137)	131	(213)	101.5	(0.0)
18	13.6	(4.8)	80.5	(12.1)	0.85	(0.77)	355	(139)	132	(213)	101.5	(0.0)
19	14.3	(3.4)	79.4	(10.8)	2.03	(1.03)	338	(133)	117	(196)	101.5	(0.0)
20	10.2	(3.0)	67.6	(15.3)	3.39	(1.30)	301	(42)	135	(217)	101.5	(0.0)
21	9.0	(4.9)	58.8	(16.3)	1.34	(1.04)	349	(130)	130	(210)	101.5	(0.0)
22											101.4	(0.0)
23											101.4	(0.0)
24	8.6	(5.5)	59.8	(19.3)	1.22	(0.89)	140	(81)	111	(193)	101.4	(0.0)
25	8.4	(3.3)	69.3	(9.0)	1.24	(0.89)	320	(112)	55	(108)	101.6	(0.1)
26	9.1	(5.6)	68.1	(15.7)	0.83	(0.53)	87	(86)	112	(186)	101.8	(0.0)
27	9.3	(3.9)	66.9	(10.8)	2.62	(1.58)	295	(95)	82	(147)	101.9	(0.1)
28	8.9	(4.4)	58.5	(12.0)	1.24	(1.14)	50	(112)	118	(191)	101.8	(0.2)
29	8.5	(4.2)	70.8	(12.0)	1.41	(1.21)	46	(107)	106	(183)	101.1	(0.2)
30	7.3	(3.4)	59.4	(17.1)	3.02	(2.50)	337	(120)	119	(203)	100.8	(0.1)
Avg	12.6		71.0		1.70		359		118		101.4	
n	27		17		27		27		27		30	
SD	2.9		8.0		0.86		134		22		0.2	
Min	7.3		58.5		0.79		20		55		100.8	
Max	16.0		81.1		4.14		355		146		101.9	

Table E1. Daily means (SD) of weather parameters at Site CA1B for December, 2007.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	6.3	(4.3)	64.7	(13.6)	2.15	(0.85)	114	(21)	111	(190)	101.7	(0.4)
2	8.1	(5.1)	53.4	(13.4)	2.84	(1.48)	126	(24)	136	(199)	102.5	(0.1)
3	10.2	(5.0)	48.0	(11.4)	1.52	(0.96)	111	(59)	150	(200)	102.5	(0.1)
4	11.6	(1.8)	76.4	(13.5)	2.76	(1.51)	307	(95)	60	(79)	101.9	(0.3)
5	12.1	(2.3)	85.2	(8.3)	1.91	(1.13)	332	(113)	105	(147)	101.1	(0.2)
6	10.5	(1.6)	90.3	(2.0)	3.07	(2.26)	123	(22)	31	(36)	100.7	(0.0)
7	11.1	(1.9)	78.5	(10.2)	3.60	(1.56)	269	(56)	57	(90)	101.0	(0.1)
8	6.3	(2.6)	78.3	(11.1)	2.30	(1.61)	327	(108)	133	(191)	101.4	(0.1)
9	6.2	(3.7)	72.5	(12.7)	1.37	(1.09)	11	(113)	138	(199)	101.4	(0.1)
10	7.4	(3.3)	78.0	(10.8)	1.61	(0.92)					101.5	(0.2)
11											102.1	(0.2)
12	6.0	(3.8)	69.5	(8.0)	1.31	(0.77)	78	(96)	111	(175)	102.2	(0.1)
13	5.3	(4.0)	72.4	(11.9)	1.35	(0.93)	32	(113)	126	(180)	102.0	(0.0)
14	6.1	(4.6)	71.6	(13.6)	1.29	(0.68)	107	(49)	121	(173)	102.1	(0.0)
15	6.8	(3.8)	78.1	(10.7)	1.03	(0.95)	20	(123)	126	(178)	101.8	(0.2)
16	6.7	(4.2)	82.2	(10.2)	1.52	(0.87)	105	(69)	109	(164)	101.4	(0.0)
17	9.6	(1.5)	80.7	(3.9)	2.51	(0.88)	134	(16)	66	(85)	101.4	(0.0)
18	11.1	(1.0)	88.5	(2.2)	3.14	(1.32)	134	(49)	34	(34)	101.6	(0.2)
19	11.7	(1.8)	81.5	(7.0)	1.77	(0.75)	103	(101)	112	(159)	101.8	(0.0)
20	10.0	(2.1)	79.3	(11.8)	4.72	(1.33)	260	(75)	119	(190)	102.0	(0.2)
21	4.9	(2.6)	73.2	(10.4)	2.90	(1.78)	333	(107)	111	(174)	102.5	(0.2)
22	5.7	(4.0)	76.1	(12.3)	1.17	(0.68)	182	(94)	117	(183)	102.8	(0.0)
23	5.3	(3.6)	83.5	(10.9)	1.33	(0.68)	83	(101)	103	(159)	102.6	(0.1)
24	7.1	(2.9)	77.2	(13.8)	4.10	(2.63)	317	(94)	88	(146)	102.4	(0.0)
25	5.8	(2.8)	72.0	(8.8)	2.01	(1.34)	128	(80)	124	(183)	102.2	(0.1)
26	6.1	(2.6)	68.3	(18.4)	5.24	(3.18)	328	(93)	121	(185)	102.1	(0.0)
27	4.8	(2.3)	63.2	(9.4)	3.01	(1.65)	18	(111)	94	(140)	102.1	(0.1)
28	5.2	(1.3)	80.4	(6.4)	2.46	(1.48)	113	(62)	25	(43)	102.0	(0.0)
29	8.5	(2.7)	78.8	(7.5)	1.45	(0.85)	119	(41)	49	(98)	102.1	(0.1)
30	8.1	(2.2)	87.0	(2.3)	3.20	(1.87)	315	(78)	38	(80)	102.3	(0.0)
31	4.6	(2.8)	79.6	(8.1)	1.87	(0.99)	22	(111)	81	(151)	102.2	(0.1)
Avg	7.6		75.6		2.35		65		96		101.9	
n	30		30		30		29		29		31	
SD	2.3		9.2		1.06		108		35		0.5	
Min	4.6		48.0		1.03		11		25		100.7	
Max	12.1		90.3		5.24		333		150		102.8	

Table E1. Daily means (SD) of weather parameters at Site CA1B for January, 2008.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	3.4	(2.8)	89.1	(3.3)	1.05	(0.84)	339	(112)	74	(142)	101.8	(0.2)
2	4.8	(5.1)	79.8	(12.5)	1.19	(0.82)	132	(63)	94	(180)	101.3	(0.1)
3	10.0	(3.7)	66.5	(14.4)	1.79	(1.24)	133	(41)	24	(91)	100.6	(0.3)
4	10.8	(1.1)	80.0	(9.7)	6.74	(3.69)	123	(58)	-8	(17)	100.3	(0.1)
5	8.3	(1.6)	85.7	(3.9)	3.64	(1.82)	134	(50)	18	(68)	100.7	(0.1)
6	8.4	(2.0)	80.3	(9.3)	1.69	(0.93)	116	(56)	75	(166)	101.2	(0.2)
7	7.5	(2.5)	76.9	(11.0)	2.06	(1.54)	332	(119)	110	(184)	101.7	(0.1)
8	7.3	(1.7)	83.0	(3.1)	3.12	(1.59)	130	(31)	8	(55)	101.9	(0.1)
9	7.8	(1.4)	88.4	(1.6)	1.61	(1.41)	320	(105)			102.0	(0.0)
10	9.3	(1.3)	88.2	(3.8)	1.53	(0.86)	121	(55)	23	(60)	102.0	(0.0)
11	9.1	(0.9)	90.1	(1.9)	1.32	(1.08)	303	(99)	12	(43)	102.1	(0.0)
12	10.2	(1.6)	82.9	(6.5)	1.76	(1.21)	305	(84)	95	(177)	102.2	(0.0)
13	10.3	(2.4)	80.3	(9.7)	0.78	(0.61)	99	(83)	77	(139)	102.3	(0.0)
14	7.7	(3.8)	85.2	(8.5)	1.27	(0.96)	48	(105)	112	(190)	102.1	(0.1)
15	5.0	(1.5)	92.3	(1.9)	1.31	(1.32)	313	(104)	39	(78)	101.8	(0.1)
16	5.4	(3.0)	76.1	(10.7)	1.72	(1.11)	331	(104)	117	(187)	101.8	(0.1)
17	5.6	(4.4)	69.5	(17.9)	0.98	(0.72)	117	(76)	131	(209)	101.9	(0.0)
18	6.8	(4.9)	74.1	(14.0)	0.89	(0.59)	94	(71)	127	(205)	102.0	(0.0)
19	7.6	(5.1)	74.7	(12.5)	0.92	(0.55)	101	(83)	128	(202)	101.6	(0.3)
20	6.4	(3.3)	76.7	(10.8)	2.42	(2.01)	16	(112)	103	(182)	101.2	(0.0)
21	7.1	(2.2)	77.3	(8.1)	2.35	(1.32)	132	(31)	62	(126)	101.3	(0.1)
22	7.6	(0.9)	83.9	(3.1)	2.78	(1.54)	114	(72)	36	(92)	101.2	(0.1)
23	6.8	(1.1)	86.0	(1.9)	1.81	(1.20)	194	(88)	17	(50)	100.8	(0.1)
24	6.5	(1.9)	78.9	(5.6)	5.13	(1.35)	129	(7)	39	(81)	100.7	(0.1)
25	12.0	(1.8)	64.2	(6.9)	5.84	(1.33)	127	(4)	24	(64)	100.9	(0.0)
26	13.7	(1.9)	56.4	(8.0)	4.31	(1.92)	122	(29)	90	(164)	100.5	(0.3)
27	11.7	(1.1)	77.3	(4.4)	5.11	(2.10)	138	(38)	41	(114)	100.7	(0.4)
28					2.32	(1.66)	303	(105)	133	(228)	101.7	(0.2)
29	5.3	(2.3)	75.6	(4.4)	2.23	(1.18)	106	(44)	47	(87)	102.2	(0.1)
30	7.0	(2.0)	71.0	(8.5)	2.00	(1.53)	345	(112)	139	(226)	102.2	(0.0)
31	8.0	(1.7)	73.4	(5.2)	2.98	(1.50)	130	(50)	50	(104)	102.1	(0.1)
Avg	7.9		78.8		2.41		101		68		101.5	
n	30		30		31		31		30		31	
SD	2.3		8.0		1.52		98		44		0.6	
Min	3.4		56.4		0.78		16		-8		100.3	
Max	13.7		92.3		6.74		345		139		102.3	

Table E1. Daily means (SD) of weather parameters at Site CA1B for February, 2008.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	7.2	(1.9)	74.8	(3.7)	2.48	(1.41)	328	(104)	114	(186)	101.7	(0.1)
2											101.1	(0.3)
3											101.1	(0.3)
4											102.0	(0.2)
5	6.4	(4.4)	68.4	(10.8)	1.17	(0.72)	142	(83)	161	(237)	102.3	(0.0)
6	8.2	(3.9)	73.7	(3.2)	2.48	(1.84)	352	(125)	160	(231)	102.3	(0.0)
7	9.0	(4.4)	70.9	(6.1)	1.51	(1.12)	339	(119)	166	(231)	102.1	(0.1)
8	8.8	(3.6)	70.5	(6.3)	1.95	(1.02)	1	(133)	152	(226)	101.9	(0.1)
9	10.7	(5.0)	71.4	(6.0)	0.99	(0.63)	86	(100)	180	(234)	101.8	(0.0)
10	11.0	(4.8)	69.7	(5.3)	1.49	(1.05)	34	(111)	180	(238)	101.8	(0.0)
11	11.6	(4.4)	69.9	(5.7)	1.37	(1.02)	55	(111)	186	(239)	101.7	(0.1)
12	12.9	(5.0)	68.4	(7.5)	1.23	(0.67)	87	(84)	186	(241)	101.2	(0.2)
13	10.9	(2.9)	54.8	(17.1)	5.59	(4.03)	341	(110)	165	(215)	101.0	(0.1)
14	9.1	(3.0)	43.9	(9.1)	7.43	(2.84)	323	(29)	191	(262)	101.5	(0.1)
15	8.4	(5.1)	60.4	(14.1)	2.03	(0.84)	117	(46)	201	(253)	101.8	(0.0)
16	10.0	(5.0)	60.9	(14.5)	1.62	(0.88)	359	(123)	198	(262)	101.7	(0.1)
17	11.1	(5.2)	63.2	(13.2)	0.85	(0.54)	58	(97)	200	(253)	101.5	(0.1)
18	10.4	(4.1)	68.7	(4.9)	2.40	(0.97)	328	(85)	184	(246)	101.4	(0.0)
19	10.1	(2.3)	69.6	(2.7)	2.23	(1.18)	335	(118)	77	(126)	101.4	(0.0)
20	11.4	(2.3)	66.9	(5.0)	1.77	(1.06)	6	(107)	151	(250)	101.1	(0.1)
21	9.9	(2.5)	70.3	(3.2)	3.98	(1.98)	126	(28)	40	(108)	100.9	(0.0)
22	10.0	(1.0)	68.4	(2.8)	1.90	(1.04)	72	(106)			100.9	(0.0)
23	8.7	(2.8)	67.2	(4.1)	4.18	(2.29)	123	(13)	31	(78)	101.1	(0.1)
24	11.5	(1.6)	66.5	(4.7)	4.31	(2.06)	126	(32)	49	(103)	101.8	(0.3)
25	10.8	(3.1)	64.4	(5.7)	2.47	(1.83)	326	(105)	177	(268)	102.2	(0.1)
26	11.9	(5.1)	63.7	(5.3)	0.61	(0.52)	57	(107)	163	(251)	101.9	(0.1)
27	12.4	(4.3)	62.4	(4.9)	1.72	(1.27)	333	(122)	176	(260)	101.4	(0.1)
28	13.4	(5.4)	60.5	(6.2)	0.91	(0.63)	84	(91)	198	(288)	101.3	(0.1)
29	14.8	(5.7)	58.8	(8.1)	1.74	(1.27)	79	(106)	176	(275)	101.6	(0.1)
Avg	10.4		65.7		2.32		36		155		101.6	
n	26		26		26		26		25		29	
SD	1.9		6.4		1.55		130		50		0.4	
Min	6.4		43.9		0.61		1		31		100.9	
Max	14.8		74.8		7.43		359		201		102.3	

Table E1. Daily means (SD) of weather parameters at Site CA1B for March, 2008.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	11.7	(2.3)	61.1	(7.4)	5.35	(2.20)	321	(24)	157	(259)	101.9	(0.0)
2	10.7	(4.2)	58.4	(12.7)	3.14	(2.04)	330	(107)	210	(303)	102.0	(0.1)
3	12.0	(5.8)	57.8	(10.5)	1.37	(0.83)	117	(66)	211	(295)	101.9	(0.2)
4	11.7	(4.9)	61.3	(8.3)	2.33	(1.66)	331	(120)	217	(301)	101.5	(0.0)
5	11.1	(4.3)	59.2	(12.6)	2.43	(1.54)	335	(129)	220	(308)	101.8	(0.1)
6	12.3	(4.2)	66.7	(4.7)	1.50	(0.91)	3	(113)	138	(221)	102.1	(0.0)
7	13.1	(4.9)	62.6	(5.6)	1.53	(0.83)	326	(118)	184	(267)	101.9	(0.1)
8	12.9	(3.8)	62.6	(10.4)	3.77	(2.09)	331	(125)	210	(295)	101.7	(0.0)
9	13.7	(6.1)	60.0	(13.9)	0.95	(0.77)	79	(97)	234	(313)	101.8	(0.1)
10	15.7	(5.7)	57.6	(11.7)	1.46	(1.01)	67	(107)	199	(289)	102.0	(0.0)
11	14.6	(3.5)	67.4	(4.3)	3.19	(1.51)	330	(94)	172	(260)	101.8	(0.1)
12	13.6	(3.8)	64.7	(7.5)	2.98	(1.95)	338	(122)	190	(289)	101.6	(0.0)
13	15.1	(3.1)	62.2	(8.8)	2.75	(2.19)	327	(109)	181	(278)	101.6	(0.0)
14	10.6	(3.6)	60.7	(7.7)	2.92	(2.08)	315	(119)	206	(315)	101.4	(0.2)
15	9.5	(2.4)	64.1	(7.9)	3.23	(2.29)	332	(112)	185	(291)	101.2	(0.0)
16	10.5	(4.6)	52.8	(17.0)	7.83	(2.64)	318	(15)	246	(326)	101.5	(0.2)
17	10.8	(5.6)	54.6	(15.1)	1.93	(1.30)	346	(119)	245	(325)	101.9	(0.0)
18	14.1	(6.0)	61.7	(10.9)	1.55	(0.87)	61	(104)	232	(319)	101.8	(0.1)
19	13.3	(4.1)	61.7	(6.0)	2.67	(1.45)	334	(136)	245	(326)	101.9	(0.1)
20	11.5	(3.7)	56.8	(10.7)	3.66	(1.31)	327	(85)	250	(330)	102.1	(0.1)
21	11.5	(5.1)	58.6	(11.8)	4.12	(1.91)	318	(40)	249	(326)	102.1	(0.1)
22	12.9	(6.8)	57.8	(14.3)	1.22	(0.68)	7	(119)	255	(333)	101.9	(0.1)
23	15.0	(6.2)	54.9	(14.5)	1.85	(1.24)	356	(133)	265	(339)	101.6	(0.1)
24											101.6	(0.1)
25	14.6	(4.0)	61.0	(8.5)	3.60	(1.17)	331	(72)	155	(254)	101.9	(0.1)
26	11.8	(3.8)	59.9	(10.1)	4.50	(1.89)	325	(51)	262	(333)	102.0	(0.0)
27											101.6	(0.2)
28	13.3	(4.1)	58.1	(13.6)	2.05	(0.99)	342	(133)	238	(331)	101.1	(0.1)
29	13.4	(2.3)	63.2	(6.6)	2.88	(1.21)	318	(75)	139	(182)	101.2	(0.1)
30	11.0	(4.0)	59.8	(12.6)	2.57	(1.24)	313	(84)	210	(323)	101.4	(0.1)
31	10.8	(4.9)	59.3	(12.7)	1.84	(1.32)	330	(119)	271	(341)	101.4	(0.1)
Avg	12.5		60.2		2.80		341		213		101.7	
n	29		29		29		29		29		31	
SD	1.6		3.3		1.41		113		37		0.3	
Min	9.5		52.8		0.95		3		138		101.1	
Max	15.7		67.4		7.83		356		271		102.1	

Table E1. Daily means (SD) of weather parameters at Site CA1B for April, 2008.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	13.7	(5.1)	53.6	(15.8)	1.54	(0.80)	352	(134)	268	(348)	101.3	(0.0)
2	13.9	(4.1)	60.6	(11.3)	1.81	(0.93)	307	(94)	165	(236)	101.5	(0.1)
3	15.2	(4.7)	57.5	(13.1)	2.46	(1.21)	335	(133)	275	(347)	101.6	(0.0)
4	14.2	(5.1)	55.3	(16.0)	3.21	(1.73)	340	(122)	251	(329)	101.4	(0.1)
5	12.2	(4.4)	60.3	(10.0)	4.19	(1.36)	327	(82)	295	(346)	101.3	(0.1)
6											101.5	(0.0)
7											101.4	(0.1)
8											101.2	(0.0)
9											101.4	(0.1)
10											101.6	(0.0)
11											101.6	(0.0)
12	21.6	(7.3)	50.0	(16.1)	1.19	(0.63)	22	(115)	298	(365)	101.3	(0.1)
13	23.4	(7.5)	43.8	(15.1)	1.44	(0.85)	79	(105)	298	(359)	101.2	(0.0)
14	14.4	(3.6)	56.0	(12.0)	5.28	(2.47)	322	(76)	274	(340)	101.4	(0.1)
15	10.9	(4.3)	54.4	(17.0)	4.66	(2.27)	320	(76)	268	(355)	101.5	(0.0)
16	14.0	(6.1)	49.8	(17.1)	3.53	(1.97)	321	(98)	276	(364)	101.4	(0.0)
17	17.9	(7.5)	47.5	(19.2)	1.34	(0.78)	111	(73)	286	(358)	101.1	(0.2)
18	17.9	(6.2)	53.3	(15.3)	2.20	(1.33)	351	(123)	252	(339)	100.9	(0.0)
19	11.3	(4.2)	55.7	(14.0)	4.00	(2.41)	329	(130)	282	(351)	101.3	(0.2)
20	8.7	(4.2)	55.0	(16.1)	3.51	(1.98)	323	(115)	289	(358)	101.7	(0.0)
21	9.7	(5.0)	56.8	(15.3)	2.72	(1.38)	338	(134)	284	(353)	101.5	(0.1)
22	12.3	(3.7)	62.1	(11.4)	1.91	(1.08)	320	(98)	153	(257)	101.4	(0.0)
23	12.7	(3.3)	58.1	(8.7)	3.55	(2.05)	319	(105)	195	(296)	101.7	(0.1)
24	12.3	(5.7)	54.3	(15.9)	4.65	(2.22)	320	(67)	291	(363)	101.9	(0.0)
25	16.2	(6.3)	50.8	(15.9)	3.21	(1.86)	333	(125)	292	(356)	101.7	(0.1)
26	19.9	(6.4)	51.9	(14.4)	2.83	(1.58)	333	(125)	296	(358)	101.4	(0.0)
27	23.0	(6.6)	47.8	(14.6)	1.89	(1.06)	353	(137)	300	(362)	101.2	(0.1)
28	21.0	(5.3)	50.3	(13.3)	3.34	(1.39)	335	(136)	259	(322)	101.2	(0.0)
29	14.1	(3.4)	58.7	(10.1)	5.84	(1.83)	310	(59)	307	(365)	101.3	(0.0)
30	12.4	(4.4)	51.5	(19.6)	6.29	(2.73)	316	(52)	309	(370)	101.3	(0.0)
Avg	15.1		54.0		3.19		335		269		101.4	
n	24		24		24		24		24		30	
SD	4.1		4.4		1.41		87		41		0.2	
Min	8.7		43.8		1.19		22		153		100.9	
Max	23.4		62.1		6.29		353		309		101.9	

Table E1. Daily means (SD) of weather parameters at Site CA1B for May, 2008.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	15.0	(5.8)	47.6	(19.0)	3.92	(1.68)	318	(90)	311	(373)	101.2	(0.0)
2	17.0	(5.7)	47.1	(13.5)	2.23	(1.40)	355	(133)	244	(319)	101.1	(0.1)
3	16.6	(5.7)	57.6	(13.8)	3.69	(1.05)	324	(91)	298	(364)	100.7	(0.1)
4	17.3	(5.5)	59.3	(13.4)	3.12	(2.05)	324	(121)	294	(367)	100.5	(0.1)
5	18.6	(6.3)	57.4	(14.3)	2.08	(0.92)	339	(133)	303	(363)	100.7	(0.1)
6	18.7	(5.5)	59.9	(10.3)	3.27	(1.08)	322	(79)	302	(360)	100.9	(0.0)
7	16.9	(3.6)	59.4	(10.4)	3.97	(1.97)	334	(129)	307	(367)	100.9	(0.0)
8	18.4	(5.3)	54.0	(13.9)	2.32	(1.34)	332	(137)	308	(365)	100.9	(0.0)
9	16.8	(5.2)	55.7	(13.1)	4.31	(1.50)	326	(102)	306	(361)	100.9	(0.0)
10	19.2	(6.0)	52.1	(14.7)	2.75	(0.90)	330	(121)	307	(364)	100.9	(0.1)
11	18.6	(4.5)	56.1	(12.5)	3.61	(1.21)	327	(113)	298	(348)	100.8	(0.0)
12	17.7	(4.6)	46.1	(17.3)	5.81	(2.49)	313	(32)	315	(374)	100.9	(0.1)
13	20.7	(6.7)	42.5	(18.5)	3.93	(1.39)	312	(75)	323	(379)	101.1	(0.0)
14	23.7	(5.4)	47.3	(9.2)	2.15	(1.23)	312	(97)	276	(353)	100.9	(0.1)
15	26.5	(6.6)	52.3	(15.8)	1.51	(0.97)	309	(104)	301	(359)	100.9	(0.1)
16											101.1	(0.0)
17											101.0	(0.1)
18											100.8	(0.1)
19											100.8	(0.0)
20	20.9	(4.7)	52.3	(13.3)	4.72	(2.41)	307	(65)	317	(366)	100.7	(0.1)
21	17.8	(4.9)	47.6	(15.5)	7.88	(2.93)	311	(44)	336	(376)	100.0	(0.3)
22	18.9	(3.6)	35.7	(7.3)	9.18	(3.58)	315	(38)	332	(375)	99.5	(0.0)
23	18.0	(3.9)	51.4	(10.3)	2.57	(1.28)	304	(73)	276	(362)	100.2	(0.4)
24	14.2	(0.7)	70.1	(4.4)	1.91	(0.95)	13	(114)	80	(91)	100.8	(0.0)
25	15.3	(2.7)	64.5	(8.1)	3.31	(1.27)	310	(86)	185	(243)	100.9	(0.0)
26	16.7	(4.2)	60.7	(12.5)	2.80	(1.53)	325	(98)	320	(379)	101.0	(0.0)
27	15.7	(3.7)	62.4	(9.8)	4.02	(0.88)	317	(71)	237	(282)	101.2	(0.1)
28	16.3	(4.4)	60.1	(11.6)	3.72	(1.22)	318	(61)	320	(362)	101.3	(0.0)
29	17.0	(4.7)	59.2	(14.2)	3.68	(1.44)	318	(92)	337	(374)	101.3	(0.0)
30	18.4	(5.7)	57.9	(15.6)	3.44	(1.20)	322	(66)	331	(379)	101.3	(0.0)
31	17.1	(4.6)	61.9	(12.0)	4.37	(1.01)	318	(59)	335	(373)	101.3	(0.0)
Avg	18.1		54.7		3.71		323		293		100.9	
n	27		27		27		27		27		31	
SD	2.5		7.3		1.67		59		53		0.4	
Min	14.2		35.7		1.51		13		80		99.5	
Max	26.5		70.1		9.18		355		337		101.3	

Table E1. Daily means (SD) of weather parameters at Site CA1B for June, 2008.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	17.9	(5.4)	57.5	(14.1)	4.02	(1.10)	318	(59)	345	(377)	101.2	(0.0)
2	18.1	(6.0)	56.0	(13.6)	4.41	(1.33)	316	(48)	339	(376)	101.0	(0.1)
3	18.8	(4.5)	59.8	(7.0)	4.70	(1.66)	322	(96)	324	(355)	100.7	(0.1)
4	18.2	(4.3)	50.0	(17.8)	5.99	(2.58)	320	(79)	343	(379)	100.7	(0.1)
5	20.3	(5.8)	52.0	(17.4)	3.88	(1.38)	320	(102)	344	(378)	100.8	(0.0)
6	18.8	(4.8)	52.1	(17.0)	5.22	(2.33)	320	(95)	329	(377)	100.8	(0.0)
7	19.3	(6.2)	48.2	(18.5)	5.23	(2.21)	311	(33)	343	(383)	100.8	(0.0)
8	22.6	(6.6)	43.5	(15.5)	2.67	(1.10)	316	(107)	343	(386)	100.7	(0.0)
9	25.2	(6.6)	42.5	(11.8)	2.68	(1.34)	327	(123)	342	(385)	100.7	(0.0)
10	23.1	(4.2)	37.8	(18.2)	6.27	(3.12)	314	(64)	350	(390)	100.7	(0.0)
11	22.2	(5.3)	33.6	(8.9)	5.52	(2.58)	303	(44)	344	(383)	100.7	(0.0)
12	23.8	(6.4)	38.8	(10.7)	2.22	(1.06)	314	(98)	321	(376)	100.7	(0.0)
13	26.2	(6.8)	38.1	(11.2)	2.58	(1.22)	335	(129)	318	(374)	100.8	(0.0)
14	24.0	(5.6)	46.3	(9.3)	3.54	(0.90)	333	(111)	300	(365)	100.8	(0.0)
15	23.3	(6.5)	48.5	(14.0)	3.21	(1.04)	317	(65)	319	(381)	100.8	(0.0)
16	22.5	(6.4)	47.4	(12.8)	3.73	(0.85)	324	(59)	336	(391)	101.0	(0.1)
17	22.7	(6.7)	50.2	(15.4)	4.09	(1.15)	321	(61)	329	(386)	101.2	(0.0)
18	25.0	(5.8)	34.4	(10.6)	4.19	(1.95)	330	(112)	343	(390)	101.1	(0.1)
19	25.9	(6.5)	36.6	(10.6)	2.87	(1.14)	331	(130)	333	(380)	100.9	(0.0)
20	29.6	(7.3)	32.7	(11.8)	1.81	(0.84)	344	(141)	323	(372)	100.9	(0.0)
21	30.0	(5.9)	33.2	(8.8)	2.08	(1.42)	343	(138)	217	(329)	101.0	(0.1)
22	25.8	(5.1)	33.3	(6.8)	3.56	(1.13)	336	(130)	313	(376)	101.0	(0.1)
23	22.3	(5.4)	44.7	(8.2)	3.70	(1.14)	323	(96)	307	(368)	100.8	(0.0)
24	22.8	(5.9)	50.0	(11.5)	3.17	(0.82)	329	(102)	259	(321)	100.8	(0.0)
25	21.5	(5.3)	55.8	(10.2)	3.77	(0.86)	320	(44)	301	(359)	100.7	(0.0)
26	22.6	(5.8)	59.3	(11.4)	2.78	(1.08)	322	(102)	267	(332)	100.6	(0.0)
27	25.5	(5.1)	53.7	(11.6)	2.93	(1.45)	322	(109)	254	(322)	100.7	(0.1)
28	22.9	(5.0)	54.8	(12.4)	4.34	(0.95)	322	(30)	285	(342)	101.0	(0.0)
29	22.9	(6.3)	53.2	(16.5)	3.43	(0.79)	321	(64)	308	(362)	101.0	(0.0)
30	22.8	(5.2)	57.2	(11.6)	4.15	(0.90)	327	(59)	319	(366)	101.0	(0.0)
Avg	22.9		46.7		3.76		323		317		100.9	
n	30		30		30		30		30		30	
SD	3.0		8.6		1.11		9		31		0.2	
Min	17.9		32.7		1.81		303		217		100.6	
Max	30.0		59.8		6.27		344		350		101.2	

Table E1. Daily means (SD) of weather parameters at Site CA1B for July, 2008.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	21.7	(5.5)	60.2	(14.6)	4.42	(0.88)	323	(51)	307	(354)	100.8	(0.1)
2	23.5	(5.7)	49.1	(12.5)	3.80	(1.55)	334	(119)	323	(379)	100.7	(0.0)
3	24.0	(5.1)	52.4	(8.4)	4.09	(1.64)	328	(111)	315	(368)	100.9	(0.1)
4	21.1	(4.2)	61.2	(12.6)	3.77	(0.92)	325	(68)	273	(329)	100.8	(0.1)
5	23.8	(6.1)	58.3	(15.4)	3.60	(1.48)	326	(95)	326	(374)	100.5	(0.1)
6	26.3	(5.4)	56.0	(11.7)	3.08	(1.37)	329	(125)	313	(365)	100.2	(0.0)
7	29.8	(6.0)	46.9	(12.2)	1.66	(0.90)	322	(122)	293	(352)	100.1	(0.0)
8	31.1	(5.6)	47.0	(10.3)	2.00	(1.00)	323	(114)	286	(352)	100.1	(0.0)
9	30.7	(4.7)	41.2	(5.1)	3.84	(1.29)	331	(116)	273	(339)	100.1	(0.0)
10	29.7	(4.9)	45.5	(8.2)	2.83	(1.31)	340	(134)	269	(326)	100.3	(0.1)
11	24.5	(4.5)	57.6	(9.8)	3.27	(0.89)	317	(56)	244	(305)	100.8	(0.1)
12	23.7	(5.1)	60.1	(12.4)	4.21	(0.88)	324	(50)	286	(341)	100.9	(0.0)
13	25.8	(5.3)	54.8	(9.4)	3.69	(0.70)	325	(63)	277	(337)	100.8	(0.0)
14	25.8	(4.4)	53.7	(8.4)	4.28	(1.11)	325	(56)	277	(338)	100.9	(0.1)
15	22.4	(4.8)	63.6	(10.8)	4.81	(0.91)	324	(34)	291	(347)	101.1	(0.0)
16	22.9	(5.9)	60.2	(13.0)	3.90	(1.12)	328	(79)	300	(353)	101.0	(0.1)
17	24.8	(5.4)	49.6	(12.0)	3.55	(1.23)	331	(117)	315	(371)	100.8	(0.1)
18	23.5	(6.4)	56.1	(13.9)	3.40	(1.27)	323	(92)	314	(369)	100.4	(0.1)
19	25.1	(5.7)	48.4	(11.0)	2.90	(0.99)	322	(89)	301	(362)	100.5	(0.1)
20	20.4	(5.2)	60.8	(11.9)	4.42	(1.01)	320	(43)	267	(335)	100.8	(0.1)
21	19.2	(4.9)	64.2	(12.1)	4.86	(0.97)	326	(53)	292	(361)	100.9	(0.0)
22	22.0	(6.8)	56.7	(16.7)	3.60	(1.33)	320	(78)	314	(369)	100.7	(0.0)
23	26.0	(5.8)	46.4	(12.8)	1.98	(1.15)	333	(124)	293	(349)	100.7	(0.0)
24	24.9	(5.8)	48.2	(11.6)	2.82	(1.11)	320	(85)	306	(368)	100.7	(0.0)
25	25.3	(5.6)	51.2	(11.4)	2.88	(1.43)	323	(99)	282	(348)	100.7	(0.0)
26	26.5	(5.7)	44.3	(11.4)	3.10	(1.52)	335	(135)	293	(352)	100.8	(0.0)
27	24.4	(4.9)	49.5	(12.7)	3.92	(1.47)	327	(89)	306	(364)	100.9	(0.0)
28	22.1	(5.6)	55.1	(13.6)	3.90	(1.14)	325	(75)	306	(364)	101.0	(0.0)
29	22.4	(5.6)	52.7	(13.0)	3.42	(1.46)	324	(95)	289	(354)	100.9	(0.1)
30	23.5	(6.0)	51.0	(11.9)	3.06	(1.05)	324	(89)	303	(359)	100.8	(0.0)
31	24.6	(5.6)	42.1	(12.8)	2.97	(1.50)	317	(97)	298	(352)	100.7	(0.0)
Avg	24.6		53.0		3.48		326		295		100.7	
n	31		31		31		31		31		31	
SD	2.8		6.2		0.76		5		18		0.3	
Min	19.2		41.2		1.66		317		244		100.1	
Max	31.1		64.2		4.86		340		326		101.1	

Table E1. Daily means (SD) of weather parameters at Site CA1B for August, 2008.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	23.8	(6.0)	45.5	(10.9)	3.70	(1.29)	328	(96)	302	(354)	100.6	(0.0)
2	25.3	(5.7)	49.3	(13.9)	3.59	(1.60)	332	(121)	295	(350)	100.6	(0.0)
3	23.5	(5.8)	43.8	(10.3)	3.56	(1.25)	326	(83)	307	(358)	100.7	(0.0)
4	23.6	(6.3)	50.0	(14.5)	3.52	(1.01)	320	(48)	299	(354)	100.8	(0.0)
5	23.8	(5.2)	46.1	(8.8)	3.86	(0.90)	321	(32)	256	(342)	100.8	(0.0)
6	25.2	(5.2)	44.8	(8.1)	3.32	(0.82)	322	(61)	267	(330)	100.8	(0.0)
7	24.8	(5.1)	43.1	(6.9)	3.55	(1.10)	323	(78)	278	(337)	100.7	(0.0)
8	21.8	(5.4)	58.2	(12.4)	4.15	(0.91)	323	(45)	286	(343)	100.9	(0.1)
9	21.6	(5.7)	55.9	(15.3)	3.74	(0.93)	327	(79)	291	(349)	101.0	(0.0)
10	23.7	(6.1)	51.7	(16.4)	2.61	(1.51)	324	(123)	290	(348)	100.8	(0.1)
11	25.5	(6.5)	48.6	(15.2)	1.81	(1.12)	332	(132)	263	(349)	100.5	(0.1)
12	26.3	(5.8)	48.8	(10.5)	2.38	(1.35)	320	(115)	286	(346)	100.4	(0.0)
13	28.0	(6.4)	50.9	(13.2)	1.96	(0.93)	326	(123)	276	(339)	100.4	(0.0)
14	28.2	(5.7)	48.7	(11.2)	2.42	(1.28)	323	(126)	252	(324)	100.5	(0.0)
15	28.9	(5.5)	39.2	(8.6)	2.82	(0.86)	338	(135)	273	(336)	100.4	(0.0)
16	27.7	(4.8)	44.2	(10.4)	3.37	(1.01)	325	(100)	271	(332)	100.5	(0.0)
17	22.6	(5.5)	62.5	(14.5)	3.76	(0.81)	322	(36)	257	(326)	100.7	(0.1)
18	20.4	(4.6)	65.9	(11.1)	4.56	(1.12)	326	(56)	244	(316)	100.9	(0.0)
19	20.3	(4.6)	65.0	(12.6)	4.18	(1.07)	328	(61)	249	(315)	100.8	(0.1)
20	22.3	(5.5)	65.9	(12.4)	3.29	(1.22)	325	(94)	273	(333)	100.6	(0.1)
21	24.0	(4.1)	62.3	(12.8)	3.28	(1.27)	328	(123)	269	(330)	100.5	(0.0)
22	25.0	(6.0)	56.3	(14.5)	2.20	(0.92)	318	(82)	277	(341)	100.6	(0.0)
23	24.0	(5.6)	60.0	(13.2)	3.27	(0.89)	320	(76)	269	(331)	100.6	(0.0)
24	25.4	(6.0)	55.8	(14.6)	2.94	(1.14)	321	(96)	271	(333)	100.5	(0.0)
25	25.5	(5.1)	44.2	(10.9)	3.96	(1.33)	330	(110)	271	(332)	100.4	(0.0)
26	23.6	(5.4)	48.4	(10.0)	2.97	(1.09)	323	(92)	270	(330)	100.4	(0.0)
27	27.0	(6.4)	45.4	(12.2)	2.24	(1.16)	328	(126)	265	(329)	100.4	(0.0)
28	27.9	(6.1)	47.4	(12.8)	1.80	(1.11)	322	(118)	262	(326)	100.2	(0.1)
29	29.9	(6.5)	42.0	(11.7)	1.59	(0.87)	330	(124)	255	(321)	100.0	(0.1)
30	26.5	(5.7)	40.2	(9.3)	2.70	(1.26)	323	(97)	267	(332)	100.1	(0.1)
31	20.4	(4.9)	47.0	(13.6)	3.79	(1.32)	335	(115)	271	(329)	100.5	(0.1)
Avg	24.7		50.9		3.13		325		273		100.6	
n	31		31		31		31		31		31	
SD	2.5		7.7		0.77		5		15		0.2	
Min	20.3		39.2		1.59		318		244		100.0	
Max	29.9		65.9		4.56		338		307		101.0	

Table E1. Daily means (SD) of weather parameters at Site CA1B for September, 2008.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	20.8	(5.2)	42.0	(13.0)	4.16	(2.04)	302	(71)	267	(329)	100.7	(0.0)
2	22.7	(7.0)	44.9	(16.3)	1.68	(0.95)	330	(107)	243	(313)	100.7	(0.0)
3	25.3	(6.6)	42.4	(14.1)	1.56	(0.84)	332	(134)	248	(320)	100.6	(0.0)
4	26.3	(6.3)	39.8	(11.5)	1.49	(0.93)	346	(135)	246	(317)	100.5	(0.0)
5	27.0	(6.1)	40.4	(8.9)	1.79	(0.99)	336	(126)	233	(306)	100.4	(0.0)
6	27.6	(6.3)	41.7	(11.3)	1.78	(0.94)	342	(137)	229	(302)	100.3	(0.1)
7	27.7	(6.7)	38.3	(10.6)	1.84	(0.95)	333	(118)	238	(313)	100.2	(0.0)
8	22.8	(6.4)	54.4	(15.4)	3.23	(0.74)	316	(29)	238	(311)	100.2	(0.0)
9	19.7	(5.0)	65.9	(14.4)	4.00	(1.07)	327	(70)	226	(299)	100.4	(0.1)
10	20.3	(5.7)	63.9	(13.8)	3.04	(1.21)	326	(95)	216	(290)	100.5	(0.0)
11	22.4	(5.7)	59.4	(13.9)	2.24	(1.11)	326	(111)	224	(297)	100.6	(0.0)
12	21.6	(5.7)	58.7	(15.3)	2.66	(1.19)	327	(93)	231	(304)	100.7	(0.0)
13	19.8	(5.9)	61.8	(14.4)	3.46	(1.06)	319	(49)	222	(299)	100.8	(0.1)
14	21.0	(5.8)	61.2	(14.2)	3.17	(0.94)	321	(79)	220	(294)	100.9	(0.0)
15	22.4	(5.8)	58.2	(13.9)	2.77	(1.06)	319	(86)	215	(289)	100.9	(0.0)
16	21.7	(5.3)	57.7	(12.8)	3.32	(0.70)	319	(55)	199	(280)	101.0	(0.1)
17	18.0	(4.4)	64.6	(12.5)	4.80	(0.71)	330	(47)	213	(286)	101.1	(0.0)
18	18.2	(5.3)	62.7	(14.2)	3.46	(1.13)	330	(77)	211	(283)	101.1	(0.0)
19	18.7	(4.2)	63.6	(13.8)	3.69	(1.10)	334	(102)	207	(281)	101.2	(0.0)
20	19.3	(3.6)	66.8	(10.1)	3.31	(1.13)	334	(118)	204	(276)	101.1	(0.1)
21	19.3	(4.5)	63.8	(11.8)	2.70	(0.93)	324	(92)	188	(259)	101.0	(0.0)
22	19.7	(5.6)	56.6	(18.7)	3.36	(1.50)	318	(86)	207	(277)	101.1	(0.0)
23	22.1	(6.2)	46.9	(13.9)	1.53	(0.82)	344	(128)	202	(273)	101.0	(0.0)
24	23.3	(6.2)	44.8	(12.2)	1.81	(0.85)	351	(125)	189	(268)	100.9	(0.0)
25	24.8	(5.4)	38.1	(11.2)	1.98	(1.02)	326	(111)	190	(262)	100.9	(0.0)
26	24.9	(5.9)	48.1	(11.7)	1.94	(0.85)	322	(90)	187	(267)	100.9	(0.0)
27	25.3	(5.6)	46.4	(12.9)	2.69	(1.07)	316	(76)	175	(265)	100.8	(0.0)
28	25.0	(5.8)	46.5	(13.4)	2.04	(1.05)	329	(124)	180	(257)	100.9	(0.0)
29	22.7	(5.1)	57.9	(12.8)	2.92	(0.73)	325	(76)	166	(256)	101.0	(0.1)
30	22.9	(5.9)	58.5	(15.4)	2.41	(0.80)	318	(66)	159	(254)	101.1	(0.0)
Avg	22.4		53.2		2.69		327		212		100.8	
n	30		30		30		30		30		30	
SD	2.8		9.4		0.87		10		25		0.3	
Min	18.0		38.1		1.49		302		159		100.2	
Max	27.7		66.8		4.80		351		267		101.2	

Table E1. Daily means (SD) of weather parameters at Site CA1B for October, 2008.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	24.6	(5.9)	43.5	(9.3)	2.58	(0.72)	320	(87)	149	(249)	101.0	(0.0)
2	21.2	(2.9)	64.2	(8.2)	4.12	(1.28)	330	(79)	148	(221)	100.8	(0.1)
3	19.3	(3.7)	65.7	(13.7)	1.39	(0.88)	345	(133)	94	(174)	100.7	(0.0)
4	17.5	(2.4)	72.7	(5.8)	2.39	(1.33)	141	(93)	92	(166)	101.0	(0.1)
5	17.0	(3.7)	66.1	(13.6)	2.48	(1.12)	342	(144)	193	(273)	101.3	(0.1)
6	18.7	(4.7)	63.7	(12.6)	2.16	(1.17)	334	(123)	198	(279)	101.5	(0.0)
7	20.4	(5.4)	61.3	(15.5)	2.40	(1.58)	331	(128)	196	(278)	101.2	(0.1)
8	20.3	(5.1)	58.5	(15.5)	2.36	(1.47)	333	(131)	193	(275)	100.9	(0.0)
9	16.3	(3.9)	46.5	(21.5)	5.63	(2.85)	323	(76)	193	(276)	100.9	(0.0)
10	12.8	(3.2)	39.7	(9.6)	5.72	(2.19)	310	(30)	188	(270)	100.9	(0.0)
11	11.8	(4.5)	40.0	(11.5)	6.02	(2.54)	312	(47)	187	(268)	101.3	(0.2)
12	11.7	(5.5)	39.4	(12.7)	2.79	(1.24)	309	(90)	186	(268)	101.8	(0.1)
13	13.9	(6.5)	39.9	(13.6)	1.50	(0.88)	134	(69)	182	(260)	101.8	(0.1)
14	16.4	(6.5)	39.6	(14.2)	1.12	(0.77)	110	(88)	180	(261)	101.5	(0.1)
15	17.8	(6.8)	41.1	(11.5)	1.33	(1.17)	348	(117)	175	(257)	101.4	(0.0)
16	18.8	(7.0)	45.3	(13.4)	0.73	(0.59)	28	(115)	174	(251)	101.4	(0.0)
17	19.9	(7.2)	45.6	(13.0)	1.04	(0.65)	86	(100)	156	(237)	101.3	(0.0)
18	19.8	(4.4)	46.8	(10.8)	2.52	(1.28)	334	(123)	118	(202)	101.2	(0.0)
19	17.0	(4.8)	53.5	(12.4)	2.83	(0.95)	325	(73)	167	(246)	101.5	(0.1)
20	15.7	(4.4)	61.4	(14.7)	3.21	(1.54)	332	(116)	170	(249)	101.6	(0.0)
21	16.8	(5.0)	58.0	(17.0)	2.88	(1.71)	315	(85)	170	(247)	101.6	(0.0)
22	17.5	(7.0)	51.2	(15.5)	0.83	(0.59)	77	(94)	166	(242)	101.4	(0.1)
23	18.4	(6.6)	47.3	(13.1)	1.17	(0.80)	2	(116)	170	(240)	101.3	(0.0)
24	18.5	(6.8)	44.8	(11.5)	0.90	(0.65)	65	(102)	172	(235)	101.3	(0.0)
25	18.9	(6.9)	46.7	(12.5)	1.11	(0.73)	49	(106)	171	(234)	101.4	(0.0)
26	18.6	(7.0)	48.0	(14.1)	1.25	(0.67)	26	(109)	172	(238)	101.6	(0.1)
27	17.0	(5.1)	56.8	(9.8)	1.58	(0.92)	327	(125)	136	(210)	101.7	(0.0)
28	18.4	(5.7)	55.4	(15.6)	1.29	(0.78)	330	(130)	163	(230)	101.5	(0.1)
29	17.9	(6.5)	51.8	(11.8)	0.94	(0.77)	107	(59)	144	(213)	101.1	(0.1)
30	17.0	(3.2)	63.2	(12.8)	2.28	(1.87)	143	(80)	58	(112)	101.3	(0.2)
31	19.1	(1.9)	66.5	(8.7)	3.34	(1.74)	132	(18)	79	(157)	101.4	(0.1)
Avg	17.7		52.4		2.32		359		159		101.3	
n	31		31		31		31		31		31	
SD	2.6		9.7		1.41		124		36		0.3	
Min	11.7		39.4		0.73		2		58		100.7	
Max	24.6		72.7		6.02		348		198		101.8	

Table E1. Daily means (SD) of weather parameters at Site CA1B for November, 2008.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	19.5	(1.6)	61.1	(9.5)	3.89	(1.11)	131	(34)	16	(50)	101.3	(0.1)
2	16.5	(2.5)	73.8	(8.7)	2.06	(0.90)	60	(111)	109	(182)	101.2	(0.1)
3	13.9	(2.3)	74.5	(6.3)	2.00	(1.45)	160	(89)	68	(130)	101.3	(0.1)
4	11.9	(2.3)	71.5	(10.4)	2.88	(1.38)	315	(84)	137	(212)	101.8	(0.1)
5	11.0	(3.4)	69.9	(10.2)	3.11	(1.08)	318	(64)	140	(202)	102.2	(0.1)
6	12.2	(3.7)	70.9	(9.4)	1.67	(0.98)	312	(103)	157	(218)	102.1	(0.1)
7											101.5	(0.2)
8											100.9	(0.1)
9											101.1	(0.2)
10											101.7	(0.1)
11	12.9	(3.5)	71.4	(2.5)	2.25	(1.55)	344	(127)	122	(189)	102.0	(0.0)
12	13.8	(3.7)	66.3	(5.6)	1.50	(0.97)	342	(130)	141	(206)	101.9	(0.1)
13	14.8	(4.7)	64.9	(5.9)	1.78	(1.44)	3	(125)	145	(207)	101.7	(0.0)
14	15.3	(4.4)	64.1	(3.8)	1.12	(0.66)	95	(97)	141	(199)	101.7	(0.0)
15	16.4	(5.6)	60.3	(7.2)	0.69	(0.49)	79	(93)	142	(199)	101.6	(0.0)
16	16.8	(6.0)	60.3	(9.8)	0.43	(0.36)	56	(104)	145	(200)	101.7	(0.0)
17	16.2	(5.9)	61.7	(10.2)	0.44	(0.41)	34	(107)	141	(204)	101.7	(0.0)
18	16.1	(6.0)	61.0	(9.4)	0.49	(0.48)	51	(113)	130	(196)	101.6	(0.0)
19	12.9	(4.1)	59.5	(5.2)	2.01	(1.15)	333	(111)	112	(184)	101.7	(0.1)
20	13.6	(3.6)	60.8	(5.6)	3.46	(1.87)	327	(107)	112	(189)	101.8	(0.0)
21	11.5	(3.9)	62.1	(4.8)	1.40	(1.00)	10	(119)	103	(155)	101.6	(0.0)
22					0.96	(0.69)	342	(108)	110	(166)	101.5	(0.0)
23					0.87	(0.56)	99	(92)	115	(173)	101.4	(0.0)
24					1.11	(0.77)	344	(123)	95	(160)	101.3	(0.0)
25					1.44	(0.72)	182	(91)	67	(109)	101.1	(0.1)
26					1.28	(0.73)	321	(110)	33	(39)	101.2	(0.2)
27					2.19	(1.43)	325	(113)	49	(61)	101.8	(0.1)
28					1.64	(1.48)	346	(133)	66	(90)	102.0	(0.0)
29					1.00	(0.74)	114	(86)	108	(146)	101.9	(0.0)
30					0.91	(0.68)	144	(77)	119	(162)	101.8	(0.0)
Avg	14.4		65.5		1.64		16		109		101.6	
n	17		17		26		26		26		30	
SD	2.2		5.2		0.90		128		37		0.3	
Min	11.0		59.5		0.43		3		16		100.9	
Max	19.5		74.5		3.89		346		157		102.2	

Table E1. Daily means (SD) of weather parameters at Site CA1B for December, 2008.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1					0.99	(0.59)	171	(80)	50	(56)	101.8	(0.0)
2					2.54	(1.68)	325	(100)	61	(98)	101.8	(0.0)
3	12.1	(0.8)	83.5	(5.7)	1.17	(0.60)	126	(57)	26	(40)	101.7	(0.1)
4	10.8	(2.6)	76.9	(6.7)	0.96	(0.69)	130	(76)	45	(93)	101.8	(0.1)
5	6.6	(2.8)	88.8	(3.9)	1.02	(0.84)	109	(79)	51	(97)	102.1	(0.0)
6	6.9	(0.7)	90.1	(3.2)	1.13	(0.76)	147	(76)	11	(48)	101.9	(0.1)
7	6.3	(1.0)	89.7	(2.9)	1.05	(0.81)	4	(117)	33	(83)	101.6	(0.0)
8	5.0	(1.5)	95.0	(1.3)	1.78	(1.53)	282	(95)	4	(31)	101.9	(0.2)
9	7.1	(3.4)	85.8	(10.5)	0.92	(0.76)	140	(73)	90	(163)	102.3	(0.0)
10	6.6	(4.6)	81.6	(11.8)	0.95	(0.69)	90	(97)	78	(149)	102.0	(0.2)
11	6.2	(2.8)	88.5	(4.2)	1.56	(0.76)	128	(61)	49	(113)	101.3	(0.2)
12	7.4	(3.8)	88.9	(6.7)	1.77	(1.08)	46	(107)	65	(135)	100.8	(0.0)
13	8.1	(2.5)	67.0	(14.3)	3.55	(1.73)	291	(85)	76	(155)	100.9	(0.1)
14	5.0	(3.4)	77.0	(10.5)	3.70	(1.81)	122	(18)	41	(94)	100.8	(0.1)
15	6.7	(2.2)	80.4	(8.7)	2.71	(1.48)	142	(73)	64	(147)	100.9	(0.2)
16	5.3	(2.5)	85.6	(6.5)	2.37	(1.22)	102	(94)	41	(96)	101.2	(0.0)
17	3.3	(2.6)	75.8	(12.1)	3.83	(2.13)	314	(76)	106	(183)	101.4	(0.2)
18	5.3	(4.6)	71.1	(13.8)	2.81	(0.91)	124	(15)	91	(174)	102.0	(0.2)
19	7.9	(1.7)	75.1	(7.5)	2.08	(1.06)	106	(96)	36	(88)	102.3	(0.0)
20	3.6	(1.7)	92.5	(1.9)	1.64	(1.11)	337	(129)	36	(84)	102.0	(0.2)
21	6.0	(2.5)	92.2	(2.0)	2.57	(1.58)	130	(29)	11	(49)	101.2	(0.2)
22	8.5	(2.1)	80.8	(12.0)	1.98	(1.30)	64	(106)	87	(170)	100.9	(0.0)
23	8.1	(2.0)	79.7	(9.4)	1.82	(0.56)	121	(17)	63	(120)	100.9	(0.1)
24	10.2	(1.1)	72.4	(5.4)	4.20	(0.92)	127	(9)	13	(48)	100.6	(0.1)
25	8.6	(1.9)	73.9	(10.2)	5.88	(2.97)	255	(78)	67	(149)	101.2	(0.4)
26	5.3	(2.6)	72.6	(9.4)	2.44	(1.84)	334	(125)	111	(190)	102.3	(0.2)
27	6.5	(3.8)	71.9	(11.3)	1.28	(1.04)	109	(59)	105	(182)	102.5	(0.0)
28	8.0	(4.1)	72.9	(12.1)	1.07	(0.68)	110	(67)	117	(187)	102.3	(0.1)
29	9.0	(3.8)	78.4	(8.8)	1.49	(1.11)	39	(107)	107	(176)	102.0	(0.0)
30	6.6	(1.0)	92.9	(2.3)	0.78	(0.72)	212	(90)	46	(89)	102.0	(0.0)
31	5.9	(0.7)	94.9	(0.4)	1.05	(0.68)	111	(94)	16	(44)	101.9	(0.1)
Avg	7.0		81.9		2.04		110		58		101.6	
n	29		29		31		31		31		31	
SD	2.0		8.1		1.18		90		32		0.5	
Min	3.3		67.0		0.78		4		4		100.6	
Max	12.1		95.0		5.88		337		117		102.5	

Table E1. Daily means (SD) of weather parameters at Site CA1B for January, 2009.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	6.8	(0.8)	89.7	(4.9)	1.61	(0.73)	118	(51)	22	(53)	101.5	(0.2)
2	7.5	(0.6)	89.3	(2.1)	2.44	(1.32)	134	(57)	17	(47)	101.3	(0.1)
3	5.5	(1.9)	87.8	(6.5)	3.21	(1.99)	330	(118)	63	(132)	101.6	(0.1)
4	4.1	(3.9)	78.1	(13.7)	1.34	(0.92)	61	(99)	124	(196)	101.9	(0.1)
5	7.0	(1.2)	86.4	(2.4)	2.26	(0.90)	128	(89)	26	(55)	102.1	(0.1)
6	7.0	(1.5)	87.8	(4.6)	2.06	(1.20)	320	(111)	40	(96)	102.2	(0.0)
7	5.2	(2.7)	89.9	(3.3)	1.09	(0.67)	116	(87)	24	(56)	102.0	(0.1)
8	6.0	(1.8)	91.5	(1.9)	3.80	(2.06)	334	(106)	24	(58)	102.1	(0.1)
9	8.6	(2.7)	78.0	(11.1)	1.62	(0.86)	113	(87)	132	(199)	102.6	(0.2)
10	7.6	(4.7)	79.5	(11.3)	1.20	(0.65)	65	(98)	135	(195)	102.9	(0.0)
11	7.9	(4.7)	80.7	(10.2)	1.25	(0.67)	99	(71)	127	(187)	102.6	(0.1)
12	9.7	(4.7)	76.4	(13.4)	1.37	(0.73)	107	(49)	131	(183)	102.4	(0.0)
13	10.8	(5.6)	73.1	(15.0)	1.05	(0.59)	86	(86)	143	(198)	102.2	(0.1)
14	10.7	(5.3)	76.1	(13.2)	1.04	(0.58)	70	(89)	139	(191)	101.9	(0.0)
15	11.0	(5.6)	74.7	(13.7)	1.04	(0.67)	73	(97)	136	(198)	102.0	(0.1)
16	11.7	(5.6)	72.3	(14.9)	0.92	(0.54)	75	(99)	136	(198)	102.1	(0.0)
17	11.3	(5.3)	70.3	(14.1)	1.14	(0.74)	55	(104)	141	(198)	102.1	(0.0)
18	11.0	(5.1)	69.0	(14.3)	1.51	(0.75)	343	(118)	147	(202)	102.1	(0.0)
19	11.3	(6.0)	70.1	(15.8)	1.00	(0.51)	74	(98)	147	(203)	101.9	(0.1)
20	10.9	(5.5)	69.2	(14.4)	1.23	(0.62)	355	(111)	138	(202)	101.5	(0.1)
21	10.7	(2.4)	82.3	(6.5)	1.69	(1.00)	349	(108)	27	(61)	101.3	(0.0)
22	12.0	(1.6)	90.9	(3.1)	1.85	(1.36)	333	(111)	31	(62)	101.4	(0.0)
23	12.6	(0.9)	93.6	(1.2)	1.24	(0.68)	328	(106)	22	(41)	101.5	(0.1)
24	13.3	(1.5)	86.9	(6.6)	2.30	(1.17)	335	(108)	65	(120)	101.5	(0.1)
25	9.7	(1.6)	76.8	(7.7)	2.05	(1.17)	312	(109)	84	(174)	101.5	(0.1)
26	7.3	(2.5)	81.4	(10.2)	2.63	(1.34)	322	(96)	124	(215)	102.2	(0.3)
27	6.3	(4.2)	72.0	(12.4)	1.95	(1.16)	318	(103)	142	(227)	102.7	(0.1)
28	7.2	(3.9)	76.0	(13.8)	2.51	(1.41)	344	(114)	137	(224)	102.5	(0.1)
29	8.9	(4.8)	76.0	(13.3)	1.61	(0.73)	113	(40)	136	(219)	102.3	(0.1)
30	10.0	(5.3)	77.3	(12.8)	0.77	(0.59)	42	(103)	134	(218)	102.0	(0.1)
31	8.4	(4.8)	82.4	(11.1)	1.27	(0.79)	34	(124)			101.8	(0.1)
Avg	9.0		80.2		1.68		39		96		102.0	
n	31		31		31		31		30		31	
SD	2.4		7.3		0.70		124		51		0.4	
Min	4.1		69.0		0.77		34		17		101.3	
Max	13.3		93.6		3.80		355		147		102.9	

Table E1. Daily means (SD) of weather parameters at Site CA1B for February, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	10.1	(4.8)	78.6	(11.4)	0.86	(0.58)	50	(104)	145	(222)	102.0	(0.0)
2	11.2	(5.5)	78.1	(12.7)	0.90	(0.55)	68	(91)	151	(221)	101.8	(0.2)
3	11.5	(6.1)	77.0	(14.4)	0.89	(0.61)	76	(94)	160	(226)	101.3	(0.1)
4	11.5	(5.0)	78.3	(12.6)	1.00	(0.75)	45	(104)	112	(187)	101.1	(0.0)
5	12.1	(1.6)	78.0	(7.0)	2.55	(1.41)	125	(76)	77	(155)	100.9	(0.1)
6	11.8	(1.9)	82.5	(6.7)	1.74	(1.08)	116	(69)	78	(125)	100.7	(0.0)
7	11.3	(2.8)	82.8	(8.8)	2.00	(1.62)	320	(119)	169	(236)	100.7	(0.0)
8	10.4	(3.0)	79.6	(9.5)	3.64	(2.05)	155	(47)	123	(193)	100.9	(0.1)
9	7.4	(2.2)	72.7	(8.4)	2.62	(1.84)	298	(92)	128	(230)	101.4	(0.2)
10	7.5	(4.4)	66.7	(15.4)	1.80	(0.83)	74	(106)	163	(245)	101.8	(0.0)
11	9.1	(2.1)	75.6	(9.7)	3.12	(1.39)	135	(57)	140	(233)	101.7	(0.0)
12	8.8	(2.2)	78.0	(9.3)	1.43	(0.77)	140	(69)	99	(163)	101.5	(0.2)
13	8.4	(1.5)	78.6	(7.4)	3.34	(1.11)	131	(35)	130	(237)	101.3	(0.0)
14	9.7	(2.3)	72.5	(11.8)	4.16	(1.05)	137	(8)	158	(250)	100.9	(0.2)
15	10.6	(1.2)	66.7	(5.8)	6.39	(2.15)	122	(11)	35	(59)	100.3	(0.1)
16	10.6	(1.1)	74.4	(9.7)	5.14	(1.94)	133	(17)	72	(114)	100.7	(0.3)
17	9.4	(0.9)	80.4	(4.5)	5.70	(1.81)	133	(6)	61	(144)	101.6	(0.2)
18	11.0	(3.4)	74.5	(11.0)	1.11	(0.78)	113	(62)	179	(250)	102.0	(0.0)
19	11.0	(5.5)	71.3	(16.9)	1.05	(0.81)	47	(113)	201	(270)	101.8	(0.1)
20	10.2	(4.3)	75.7	(12.0)	1.74	(1.17)	335	(126)	167	(244)	101.6	(0.1)
21	11.1	(3.9)	78.8	(8.0)	2.20	(1.00)	123	(36)	114	(166)	101.4	(0.0)
22	14.1	(1.3)	80.4	(3.4)	4.95	(1.36)	135	(12)	25	(45)	101.5	(0.0)
23	15.0	(1.6)	84.1	(3.6)	3.04	(1.49)	130	(30)	65	(106)	101.6	(0.0)
24	13.0	(2.9)	76.8	(10.1)	2.57	(1.19)	344	(122)	200	(284)	101.7	(0.0)
25	13.3	(3.0)	72.6	(12.1)	1.58	(0.83)	25	(132)	183	(286)	101.8	(0.0)
26	13.4	(3.3)	77.1	(10.3)	2.52	(0.92)	37	(105)	188	(262)	101.8	(0.0)
27	10.5	(3.6)	74.8	(12.1)	2.48	(1.43)	350	(139)	222	(288)	101.6	(0.1)
28	12.4	(4.1)	78.8	(8.0)	1.38	(0.80)	110	(50)	119	(166)	101.4	(0.0)
Avg	10.9		76.6		2.57		92		131		101.4	
n	28		28		28		28		28		28	
SD	1.8		4.2		1.50		94		51		0.4	
Min	7.4		66.7		0.86		25		25		100.3	
Max	15.0		84.1		6.39		350		222		102.0	

Table E1. Daily means (SD) of weather parameters at Site CA1B for March, 2009.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	13.8	(1.2)	83.7	(5.9)	3.16	(2.04)	90	(95)	10	(15)	101.2	(0.1)
2	15.3	(1.5)	78.3	(6.1)	4.18	(2.32)	153	(37)	103	(174)	101.1	(0.0)
3	12.7	(1.3)	78.4	(6.6)	3.67	(1.41)	155	(29)	80	(140)	101.2	(0.1)
4	10.4	(2.4)	75.5	(13.6)	1.91	(1.33)	127	(87)	186	(280)	101.5	(0.1)
5	9.4	(4.1)	73.7	(13.2)	1.60	(0.86)	358	(124)	229	(298)	101.7	(0.0)
6	9.9	(2.7)	74.1	(11.9)	2.12	(1.02)	346	(132)	180	(268)	101.6	(0.0)
7	9.7	(4.4)	73.0	(15.9)	1.46	(0.91)	4	(136)	241	(302)	101.4	(0.1)
8	11.1	(5.3)	67.5	(16.4)	1.47	(0.77)	69	(110)	244	(305)	101.3	(0.1)
9	7.6	(2.7)	60.3	(14.5)	3.90	(1.91)	317	(78)	255	(312)	101.6	(0.0)
10	7.8	(4.2)	63.5	(16.9)	1.94	(1.34)	339	(129)	254	(314)	101.5	(0.1)
11	9.5	(5.2)	63.9	(16.1)	1.60	(0.76)	336	(126)	226	(287)	101.4	(0.0)
12	11.8	(4.5)	66.3	(13.0)	2.73	(1.18)	332	(94)	248	(307)	101.5	(0.0)
13	12.2	(5.2)	70.3	(13.7)	1.74	(0.98)	355	(133)	255	(313)	101.4	(0.1)
14	10.3	(2.7)	74.5	(11.1)	4.07	(1.34)	329	(95)	229	(301)	101.4	(0.1)
15	14.3	(4.2)	71.4	(13.1)	1.87	(1.15)	359	(119)	241	(308)	101.8	(0.1)
16	15.2	(3.8)	75.1	(12.7)	2.37	(1.38)	336	(109)	237	(307)	102.1	(0.0)
17	14.3	(3.3)	76.1	(12.7)	3.46	(1.61)	323	(38)	233	(288)	101.9	(0.1)
18	14.8	(4.4)	73.2	(15.3)	2.82	(1.63)	332	(118)	246	(307)	101.4	(0.2)
19	16.9	(5.1)	68.5	(14.8)	1.88	(1.07)	354	(134)	256	(321)	101.0	(0.1)
20	16.2	(4.5)	72.1	(12.3)	2.45	(1.15)	343	(147)	259	(315)	100.9	(0.0)
21	13.6	(2.5)	76.6	(9.3)	2.94	(1.29)	350	(128)	209	(289)	101.3	(0.2)
22	9.6	(2.0)	70.6	(12.7)	4.18	(2.43)	287	(88)	202	(288)	101.9	(0.1)
23	8.6	(4.4)	60.4	(17.6)	4.42	(2.68)	321	(84)	275	(328)	102.0	(0.1)
24	11.3	(5.3)	67.1	(14.5)	2.17	(1.80)	29	(123)	271	(327)	101.7	(0.1)
25	13.8	(5.3)	67.7	(16.6)	2.56	(1.77)	353	(120)	255	(307)	101.3	(0.1)
26	16.2	(5.2)	63.3	(20.0)	6.09	(2.57)	323	(47)	274	(324)	101.1	(0.0)
27	16.9	(5.5)	60.4	(16.1)	1.60	(0.86)	327	(126)	270	(325)	101.1	(0.1)
28	18.5	(5.8)	62.1	(18.7)	1.71	(0.87)	60	(107)	273	(326)	100.9	(0.0)
29	13.2	(3.3)	49.9	(22.8)	6.26	(3.01)	327	(74)	284	(334)	101.1	(0.2)
30	11.6	(4.7)	48.0	(13.6)	2.59	(1.91)	332	(124)	276	(325)	101.3	(0.0)
31	14.3	(5.6)	57.2	(16.9)	2.31	(1.76)	1	(124)	263	(324)	101.1	(0.1)
Avg	12.6		68.5		2.81		350		228		101.4	
n	31		31		31		31		31		31	
SD	2.9		8.1		1.25		122		60		0.3	
Min	7.6		48.0		1.46		1		10		100.9	
Max	18.5		83.7		6.26		359		284		102.1	

Table E1. Daily means (SD) of weather parameters at Site CA1B for April, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	16.0	(5.3)	59.2	(18.0)	5.32	(3.02)	324	(97)	272	(327)	100.9	(0.0)
2	13.6	(4.1)	64.7	(13.2)	3.48	(2.14)	326	(124)	283	(336)	100.9	(0.0)
3	11.6	(4.3)	53.7	(23.2)	5.94	(3.51)	317	(80)	292	(343)	101.1	(0.1)
4	11.6	(6.1)	47.8	(20.0)	2.02	(1.16)	339	(123)	301	(349)	101.4	(0.0)
5	15.3	(7.7)	44.9	(23.4)	1.75	(1.10)	101	(43)	301	(349)	101.3	(0.1)
6	17.9	(7.7)	42.0	(18.9)	1.23	(0.88)	27	(115)	295	(348)	101.1	(0.0)
7	13.0	(2.6)	70.6	(15.7)	2.62	(1.36)	36	(123)	128	(229)	101.2	(0.1)
8	13.4	(2.7)	72.6	(13.3)	1.66	(0.91)	93	(97)	195	(292)	101.3	(0.1)
9	12.3	(1.8)	82.1	(6.8)	1.32	(0.88)	32	(106)	90	(126)	100.9	(0.1)
10	11.8	(2.2)	82.0	(9.6)	3.70	(1.60)	329	(88)			101.1	(0.2)
11	12.6	(4.1)	71.6	(14.8)	3.48	(1.61)	336	(133)	289	(354)	101.7	(0.1)
12	15.2	(5.0)	71.0	(14.5)	2.52	(1.07)	341	(142)	297	(353)	101.6	(0.2)
13	14.9	(4.1)	71.4	(11.5)	3.28	(1.22)	329	(111)	228	(265)	101.0	(0.1)
14	10.3	(2.4)	54.2	(17.0)	7.06	(2.51)	301	(25)	276	(350)	101.1	(0.2)
15	10.4	(4.3)	53.0	(16.9)	5.35	(2.39)	311	(79)	313	(362)	101.6	(0.1)
16	12.6	(5.3)	62.7	(18.0)	3.82	(2.06)	330	(124)	313	(358)	101.8	(0.0)
17	15.9	(5.9)	57.7	(16.9)	2.31	(1.46)	345	(142)	316	(359)	101.6	(0.1)
18	19.4	(6.2)	60.1	(16.6)	1.32	(0.83)	7	(137)	315	(364)	101.5	(0.0)
19	22.8	(7.0)	55.0	(19.8)	1.44	(0.63)	39	(120)	317	(371)	101.4	(0.1)
20	24.6	(6.2)	50.9	(14.8)	1.38	(0.72)	359	(150)	301	(353)	101.1	(0.1)
21	25.8	(5.8)	48.7	(14.6)	1.72	(0.78)	14	(136)	285	(349)	100.7	(0.1)
22	24.8	(6.0)	42.1	(13.9)	2.62	(1.59)	352	(130)	319	(369)	100.7	(0.1)
23	17.3	(4.3)	54.9	(18.0)	3.84	(1.22)	318	(84)	290	(350)	101.0	(0.1)
24	13.6	(3.4)	44.4	(16.6)	3.99	(1.82)	326	(106)	256	(329)	101.3	(0.1)
25	12.9	(5.3)	61.5	(16.7)	3.76	(1.85)	329	(128)	328	(368)	101.4	(0.1)
26	13.8	(5.2)	59.5	(18.1)	2.50	(1.06)	337	(144)	328	(369)	101.2	(0.1)
27	13.1	(4.5)	60.9	(15.9)	3.07	(1.91)	347	(138)	327	(366)	101.3	(0.1)
28	11.3	(3.9)	60.0	(14.2)	3.13	(1.66)	319	(108)	298	(341)	101.6	(0.0)
29	12.7	(4.7)	59.7	(17.2)	3.49	(1.32)	328	(127)	332	(372)	101.6	(0.0)
30	15.5	(5.5)	54.5	(18.1)	2.66	(0.92)	330	(114)	294	(353)	101.4	(0.1)
Avg	15.2		59.1		3.06		346		282		101.3	
n	30		30		30		30		29		30	
SD	4.2		10.5		1.43		129		56		0.3	
Min	10.3		42.0		1.23		7		90		100.7	
Max	25.8		82.1		7.06		359		332		101.8	

Table E1. Daily means (SD) of weather parameters at Site CA1B for May, 2009.

Day	Temp, ºC		RH, %		WS, m s^{-1}		WD, º		SE, W m^{-2}		ATM, kPa	
1	16.7	(2.2)	72.5	(15.1)	2.70	(1.27)	124	(100)	104	(148)	101.4	(0.1)
2	17.5	(1.7)	75.9	(10.8)	1.43	(0.72)	99	(83)	128	(149)	101.6	(0.0)
3	17.9	(2.5)	80.2	(7.2)	2.42	(1.28)	269	(95)	166	(211)	101.5	(0.1)
4	19.6	(4.5)	64.4	(17.0)	1.82	(0.92)	21	(116)	254	(317)	101.4	(0.0)
5	21.1	(3.2)	70.1	(12.5)	2.68	(1.91)	348	(125)	264	(332)	101.5	(0.0)
6	20.0	(4.5)	72.1	(14.4)	4.13	(1.56)	332	(87)	314	(367)	101.5	(0.0)
7	18.5	(4.4)	65.9	(22.0)	5.43	(2.23)	323	(63)	332	(384)	101.2	(0.1)
8	19.2	(5.4)	55.7	(20.2)	4.70	(1.94)	322	(78)	339	(387)	101.0	(0.0)
9	20.8	(5.5)	51.9	(17.6)	3.62	(1.65)	336	(125)	334	(382)	100.9	(0.0)
10	21.6	(5.9)	50.4	(17.3)	3.99	(1.50)	323	(88)	348	(382)	100.9	(0.0)
11	20.2	(5.3)	48.9	(13.6)	4.35	(2.21)	333	(129)	341	(366)	101.0	(0.0)
12	17.8	(5.1)	50.4	(15.6)	4.77	(1.87)	325	(67)	350	(376)	101.2	(0.0)
13	19.5	(5.5)	47.7	(17.6)	5.16	(1.90)	319	(54)	333	(366)	101.2	(0.0)
14	20.0	(4.7)	56.7	(13.0)	4.96	(2.19)	327	(108)	341	(370)	101.0	(0.1)
15	22.6	(5.5)	60.1	(17.3)	3.27	(1.61)	326	(102)	345	(372)	100.8	(0.0)
16	27.0	(6.0)	49.7	(12.2)	1.78	(0.86)	332	(125)	346	(375)	100.7	(0.0)
17	29.5	(5.9)	44.8	(12.6)	1.98	(1.29)	329	(122)	347	(375)	100.7	(0.0)
18	27.2	(4.7)	43.7	(8.8)	3.33	(1.59)	337	(124)	302	(352)	100.7	(0.0)
19	22.0	(4.7)	50.0	(13.1)	4.29	(1.02)	327	(73)	333	(368)	100.8	(0.0)
20	20.6	(5.1)	39.1	(10.3)	3.61	(1.00)	330	(85)	362	(384)	100.8	(0.0)
21	21.8	(6.1)	43.8	(14.1)	3.39	(0.99)	318	(73)	359	(382)	100.7	(0.0)
22	21.6	(5.7)	52.5	(12.9)	3.66	(0.96)	320	(68)	353	(374)	100.7	(0.0)
23	18.4	(5.5)	61.9	(16.2)	4.20	(0.93)	315	(37)	359	(380)	100.9	(0.0)
24	16.9	(5.1)	64.6	(14.6)	4.78	(0.81)	315	(29)	363	(383)	100.9	(0.0)
25	19.1	(6.6)	61.9	(17.9)	3.60	(0.94)	318	(73)	360	(380)	100.7	(0.0)
26	23.7	(6.0)	52.4	(13.6)	2.53	(1.18)	315	(91)	347	(369)	100.6	(0.0)
27	27.0	(5.1)	46.7	(10.9)	2.44	(1.07)	324	(116)	328	(366)	100.6	(0.0)
28	25.9	(5.1)	45.4	(10.1)	3.95	(1.39)	333	(118)	330	(373)	100.8	(0.1)
29	22.0	(4.9)	55.6	(11.2)	4.63	(1.08)	329	(82)	294	(341)	100.9	(0.0)
30	19.8	(5.0)	65.1	(12.4)	4.72	(1.00)	335	(83)	324	(373)	100.9	(0.0)
31	20.0	(5.3)	61.6	(14.5)	4.61	(1.05)	328	(53)	329	(366)	100.8	(0.0)
Avg	21.2		56.8		3.64		329		314		101.0	
n	31		31		31		31		31		31	
SD	3.2		10.4		1.08		74		65		0.3	
Min	16.7		39.1		1.43		21		104		100.6	
Max	29.5		80.2		5.43		348		363		101.6	

Table E1. Daily means (SD) of weather parameters at Site CA1B for June, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	19.3	(4.4)	65.1	(11.7)	4.38	(1.01)	323	(52)	291	(314)	100.8	(0.0)
2											100.7	(0.0)
3											100.8	(0.1)
4											100.9	(0.0)
5	17.4	(3.1)	69.1	(11.2)	2.59	(1.14)	357	(117)	174	(249)	101.0	(0.0)
6	18.4	(4.2)	63.4	(14.4)	3.61	(1.12)	318	(50)	281	(304)	100.9	(0.0)
7	19.5	(5.0)	60.7	(15.4)	3.45	(1.21)	321	(89)	293	(305)	100.7	(0.1)
8	19.4	(4.9)	59.0	(16.4)	4.64	(1.08)	315	(30)	297	(308)	100.7	(0.0)
9	18.1	(4.2)	63.0	(14.4)	4.77	(1.17)	321	(67)	290	(309)	100.9	(0.0)
10	18.6	(3.4)	65.5	(11.4)	4.01	(1.21)	321	(75)	276	(306)	100.9	(0.0)
11	18.6	(4.2)	65.0	(12.5)	3.97	(1.42)	322	(101)	285	(299)	100.9	(0.0)
12	18.6	(4.2)	61.3	(14.3)	4.46	(1.13)	318	(51)	263	(277)	100.9	(0.0)
13	19.4	(3.6)	68.1	(12.2)	3.76	(1.34)	333	(99)	230	(294)	101.0	(0.0)
14	19.0	(4.6)	61.3	(15.7)	3.63	(1.17)	321	(66)	284	(306)	100.9	(0.0)
15	18.9	(3.7)	62.9	(12.9)	3.71	(0.99)	318	(69)	239	(268)	100.8	(0.0)
16	21.2	(5.3)	60.4	(16.6)	3.29	(1.20)	324	(91)	260	(294)	100.7	(0.0)
17	21.1	(4.8)	61.0	(12.7)	3.96	(1.03)	322	(85)	291	(309)	100.6	(0.1)
18	24.7	(6.3)	56.0	(15.0)	3.20	(1.53)	321	(98)	291	(309)	100.3	(0.1)
19	24.6	(5.1)	46.3	(11.7)	3.49	(1.75)	330	(128)	279	(299)	100.2	(0.0)
20	20.3	(5.4)	53.7	(12.8)	2.84	(1.89)	330	(119)	280	(298)	100.4	(0.1)
21	19.0	(4.8)	57.9	(11.9)	3.28	(1.38)	330	(123)	302	(313)	100.5	(0.1)
22	22.3	(5.6)	47.2	(16.9)	3.25	(1.65)	320	(110)	308	(319)	100.3	(0.1)
23	26.3	(6.4)	41.8	(14.5)	1.89	(1.01)	327	(126)	307	(320)	100.3	(0.1)
24	26.2	(5.6)	43.0	(11.4)	3.31	(1.73)	325	(118)	308	(320)	100.6	(0.1)
25	23.0	(4.9)	49.1	(11.9)	3.57	(0.94)	334	(126)	284	(328)	100.7	(0.0)
26	23.2	(6.0)	48.0	(14.4)	3.13	(1.15)	323	(92)	277	(313)	100.7	(0.0)
27	28.2	(6.5)	46.9	(15.2)	2.38	(1.13)	321	(123)	289	(323)	100.6	(0.1)
28	30.8	(5.8)	40.5	(9.2)	2.65	(1.28)	337	(135)	285	(321)	100.4	(0.1)
29	30.5	(5.7)	33.8	(10.3)	3.57	(1.61)	336	(139)	302	(324)	100.3	(0.0)
30	25.8	(6.2)	45.8	(14.9)	3.42	(1.03)	326	(98)	278	(315)	100.4	(0.0)
Avg	21.9		55.4		3.49		326		279		100.7	
n	27		27		27		27		27		30	
SD	3.8		9.5		0.66		9		28		0.2	
Min	17.4		33.8		1.89		315		174		100.2	
Max	30.8		69.1		4.77		357		308		101.0	

Table E1. Daily means (SD) of weather parameters at Site CA1B for July, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	24.8	(5.8)	52.0	(15.2)	4.26	(1.02)	323	(47)	299	(324)	100.5	(0.0)
2	25.2	(6.1)	48.9	(13.5)	3.61	(0.84)	326	(86)	295	(324)	100.7	(0.1)
3	25.0	(6.4)	47.5	(15.2)	3.79	(0.81)	325	(69)	305	(327)	100.9	(0.0)
4	23.6	(5.3)	51.3	(10.3)	3.88	(0.72)	328	(57)	301	(320)	101.0	(0.0)
5	21.3	(5.5)	60.3	(14.7)	4.61	(1.12)	327	(40)	301	(321)	101.0	(0.0)
6	20.5	(6.2)	52.7	(20.1)	4.63	(0.91)	325	(57)	305	(330)	100.9	(0.1)
7	22.0	(5.8)	46.1	(16.5)	3.41	(0.95)	324	(93)	308	(331)	100.8	(0.0)
8	22.5	(5.2)	49.1	(12.7)	3.50	(1.13)	324	(99)	299	(322)	100.9	(0.0)
9	22.5	(5.2)	49.1	(12.5)	3.51	(1.13)	322	(102)	302	(329)	101.0	(0.0)
10	23.0	(5.6)	46.0	(15.0)	3.32	(1.45)	333	(124)	302	(323)	101.0	(0.0)
11	24.4	(3.7)	42.4	(7.2)	3.39	(1.40)	324	(98)	226	(272)	101.1	(0.0)
12	24.6	(4.3)	37.9	(10.3)	3.65	(1.24)	324	(80)	298	(321)	101.1	(0.1)
13	24.6	(6.1)	42.1	(13.8)	4.19	(1.51)	311	(50)	300	(319)	100.8	(0.1)
14	28.3	(5.8)	40.2	(10.7)	2.11	(1.08)	319	(116)	300	(316)	100.7	(0.1)
15	29.4	(5.7)	39.2	(10.4)	2.19	(1.17)	321	(113)	307	(314)	100.9	(0.1)
16	28.5	(5.7)	40.3	(10.3)	3.15	(1.37)	323	(80)	313	(321)	101.0	(0.0)
17	29.0	(5.4)	38.6	(8.5)	3.06	(1.60)	327	(116)	306	(317)	100.9	(0.1)
18	30.2	(5.3)	36.5	(9.6)	2.59	(1.49)	322	(109)	298	(312)	100.7	(0.0)
19	30.2	(5.6)	42.3	(10.7)	2.59	(1.06)	324	(104)	298	(321)	100.7	(0.0)
20	27.6	(5.2)	42.2	(10.4)	3.51	(1.67)	327	(100)	307	(319)	100.8	(0.0)
21	25.2	(5.6)	46.3	(11.3)	3.73	(1.42)	329	(96)	268	(302)	100.8	(0.0)
22	24.5	(5.3)	51.1	(10.3)	3.74	(1.10)	327	(84)	307	(319)	100.7	(0.0)
23	24.1	(5.8)	54.2	(13.1)	3.62	(0.83)	322	(60)	296	(312)	100.7	(0.0)
24											100.8	(0.0)
25											100.9	(0.0)
26											100.8	(0.1)
27											100.6	(0.1)
28	25.4	(5.0)	56.7	(10.0)	3.60	(1.06)	323	(78)	284	(309)	100.5	(0.0)
29	22.9	(5.3)	65.9	(12.4)	4.36	(0.89)	326	(48)	281	(298)	100.6	(0.1)
30	22.4	(5.3)	67.9	(13.2)	4.40	(0.95)	329	(70)	284	(301)	100.8	(0.0)
31	23.2	(5.3)	61.3	(14.0)	3.94	(1.10)	328	(65)	284	(302)	100.8	(0.0)
Avg	25.0		48.5		3.57		324		295		100.8	
n	27		27		27		27		27		31	
SD	2.7		8.3		0.65		4		17		0.2	
Min	20.5		36.5		2.11		311		226		100.5	
Max	30.2		67.9		4.63		333		313		101.1	

Table E1. Daily means (SD) of weather parameters at Site CA1B for August, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	23.8	(5.3)	52.7	(12.2)	3.82	(1.17)	330	(95)	283	(300)	100.9	(0.0)
2	22.0	(5.0)	58.2	(12.4)	4.25	(0.72)	331	(94)	287	(303)	101.0	(0.0)
3	21.3	(5.0)	63.6	(14.4)	4.34	(0.78)	326	(52)	282	(305)	101.1	(0.0)
4	22.0	(5.5)	61.3	(16.3)	4.03	(0.82)	327	(56)			101.1	(0.0)
5	22.0	(4.7)	58.8	(13.4)	4.59	(1.52)	323	(67)	279	(310)	101.1	(0.1)
6	19.7	(3.7)	65.3	(13.1)	2.85	(1.71)	320	(108)	223	(266)	101.2	(0.0)
7	20.6	(4.6)	62.5	(14.4)	3.58	(0.91)	322	(83)	268	(295)	101.1	(0.0)
8	23.4	(5.5)	57.6	(13.5)	3.11	(1.43)	326	(98)	272	(299)	101.0	(0.1)
9	26.4	(5.6)	46.2	(14.2)	2.06	(1.11)	326	(128)	273	(302)	100.9	(0.0)
10	27.6	(5.6)	46.2	(11.9)	2.52	(1.41)	328	(131)	266	(291)	100.9	(0.0)
11	26.2	(4.7)	49.4	(8.5)	3.04	(1.57)	326	(111)	269	(294)	101.0	(0.0)
12	25.6	(5.6)	50.7	(12.2)	3.74	(1.56)	328	(118)	278	(303)	100.9	(0.0)
13	25.9	(4.9)	49.3	(11.4)	3.44	(1.73)	332	(139)	277	(300)	100.9	(0.0)
14	22.3	(4.5)	45.9	(12.2)	3.02	(1.15)	336	(135)	278	(304)	100.9	(0.0)
15	22.6	(6.2)	52.9	(14.9)	3.28	(1.34)	320	(99)	275	(300)	100.8	(0.0)
16	24.5	(5.5)	44.5	(12.6)	2.15	(1.16)	331	(133)	262	(310)	100.7	(0.0)
17	25.2	(5.8)	47.9	(12.8)	2.30	(1.19)	328	(129)	265	(294)	100.5	(0.0)
18	24.6	(5.7)	54.8	(11.8)	3.05	(1.17)	320	(107)	265	(295)	100.5	(0.0)
19	24.7	(4.8)	53.2	(8.1)	3.54	(1.17)	333	(123)	263	(290)	100.6	(0.1)
20	22.0	(5.3)	63.9	(13.7)	4.03	(0.85)	328	(58)	259	(288)	100.7	(0.0)
21	25.3	(6.5)	58.8	(13.4)	2.88	(0.91)	314	(83)	261	(289)	100.6	(0.0)
22	28.5	(4.8)	47.8	(10.6)	1.36	(0.85)	279	(103)	199	(252)	100.6	(0.1)
23	23.8	(4.7)	56.7	(12.0)	2.90	(1.38)	317	(62)	239	(284)	100.8	(0.0)
24	21.4	(5.8)	52.7	(15.0)	3.28	(0.63)	325	(49)	263	(292)	100.9	(0.0)
25	22.9	(6.2)	52.4	(14.3)	2.78	(0.86)	319	(60)	263	(294)	101.0	(0.0)
26	24.2	(6.0)	49.4	(12.4)	2.57	(0.60)	320	(56)	258	(289)	101.1	(0.0)
27	25.3	(5.8)	40.8	(9.3)	3.05	(0.90)	325	(90)	251	(286)	101.1	(0.0)
28	26.9	(5.8)	41.5	(11.9)	2.26	(1.33)	321	(117)	248	(288)	100.8	(0.1)
29	28.3	(6.2)	45.1	(12.8)	2.29	(1.62)	343	(138)	248	(279)	100.6	(0.1)
30	27.7	(5.9)	39.4	(14.4)	2.57	(1.53)	337	(134)	252	(283)	100.5	(0.0)
31	23.0	(4.8)	57.8	(12.3)	3.84	(0.65)	322	(39)	235	(270)	100.8	(0.1)
Avg	24.2		52.5		3.11		325		261		100.8	
n	31		31		31		31		30		31	
SD	2.3		7.0		0.74		10		19		0.2	
Min	19.7		39.4		1.36		279		199		100.5	
Max	28.5		65.3		4.59		343		287		101.2	

Table E1. Daily means (SD) of weather parameters at Site CA1B for September, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	24.8	(5.9)	57.2	(15.5)	2.94	(0.74)	320	(66)	245	(274)	100.9	(0.0)
2	26.9	(4.8)	45.7	(8.5)	3.49	(1.08)	321	(60)	203	(231)	100.8	(0.0)
3	27.7	(5.4)	40.6	(11.5)	3.43	(1.96)	334	(129)	240	(271)	100.8	(0.0)
4	24.0	(5.4)	41.9	(13.2)	3.50	(1.36)	328	(100)	248	(275)	100.8	(0.1)
5	20.9	(5.1)	65.2	(11.6)	4.38	(1.07)	322	(61)	246	(276)	101.1	(0.1)
6	20.8	(3.8)	59.6	(15.9)	3.56	(1.63)	329	(109)	247	(273)	101.1	(0.1)
7	21.3	(4.8)	58.6	(15.2)	3.27	(1.45)	329	(102)	242	(267)	100.7	(0.1)
8	23.3	(6.0)	48.6	(16.4)	1.66	(0.99)	330	(122)	243	(272)	100.7	(0.1)
9	24.1	(4.9)	48.3	(11.9)	2.71	(1.69)	327	(115)	224	(262)	101.0	(0.0)
10	25.5	(5.2)	46.3	(10.5)	2.26	(1.28)	325	(110)	207	(239)	100.9	(0.1)
11	27.6	(5.0)	43.5	(9.0)	2.00	(1.17)	322	(113)	212	(249)	100.5	(0.1)
12	24.1	(3.0)	53.5	(8.2)	3.17	(1.58)	334	(119)	141	(183)	100.4	(0.1)
13	19.9	(3.5)	68.2	(12.6)	3.69	(1.10)	328	(82)	192	(237)	100.8	(0.2)
14	19.8	(2.7)	72.8	(13.3)	3.20	(1.40)	323	(100)	202	(247)	101.2	(0.0)
15	21.4	(4.7)	68.4	(15.5)	1.96	(1.04)	328	(127)	221	(258)	101.2	(0.0)
16	22.6	(4.5)	60.9	(13.4)	2.70	(1.41)	330	(119)	217	(255)	101.0	(0.1)
17	24.0	(4.8)	62.8	(14.2)	2.37	(1.22)	334	(136)	208	(250)	100.7	(0.1)
18	26.9	(6.5)	53.9	(16.5)	1.17	(0.74)	43	(110)	207	(247)	100.7	(0.1)
19	25.9	(5.0)	50.0	(12.4)	1.91	(1.28)	333	(128)	205	(251)	100.8	(0.0)
20	24.1	(4.9)	58.3	(12.2)	2.55	(1.40)	328	(123)	214	(252)	100.9	(0.0)
21	25.9	(5.5)	52.3	(14.8)	1.56	(0.96)	332	(129)	205	(247)	100.9	(0.0)
22	26.5	(5.9)	44.9	(13.9)	1.48	(0.88)	337	(137)	203	(245)	100.9	(0.0)
23	26.4	(6.2)	41.1	(10.6)	1.63	(1.05)	357	(142)	201	(245)	100.8	(0.0)
24	25.9	(5.7)	41.1	(11.9)	2.10	(1.17)	357	(152)	204	(247)	100.8	(0.0)
25	24.6	(6.4)	46.8	(14.4)	2.10	(1.13)	335	(131)	201	(245)	100.9	(0.0)
26	26.3	(6.6)	45.3	(14.4)	1.22	(0.80)	19	(122)	193	(241)	100.7	(0.1)
27	27.3	(6.5)	45.9	(12.9)	1.18	(0.82)	39	(109)	195	(239)	100.4	(0.0)
28	22.8	(4.2)	48.2	(11.4)	3.12	(1.68)	340	(137)	183	(233)	100.6	(0.2)
29	16.9	(2.2)	52.8	(9.4)	4.38	(1.44)	326	(116)	137	(156)	101.2	(0.2)
30	15.6	(4.6)	50.8	(19.0)	3.92	(2.45)	305	(72)	212	(243)	101.5	(0.1)
Avg	23.8		52.4		2.62		336		210		100.9	
n	30		30		30		30		30		30	
SD	3.1		8.8		0.93		90		26		0.2	
Min	15.6		40.6		1.17		19		137		100.4	
Max	27.7		72.8		4.38		357		248		101.5	

Table E1. Daily means (SD) of weather parameters at Site CA1B for October, 2009.

Day	Temp, °C		RH, %		WS, m s^{-1}		WD, °		SE, W m^{-2}		ATM, kPa	
1	16.9	(6.3)	46.2	(16.4)	1.29	(0.91)	347	(136)	210	(240)	101.1	(0.2)
2	19.1	(6.6)	43.3	(17.2)	1.17	(0.82)	55	(105)	205	(236)	100.4	(0.2)
3	17.3	(3.4)	47.9	(9.2)	3.23	(1.78)	327	(127)	201	(227)	100.3	(0.1)
4	14.0	(3.8)	52.4	(16.1)	1.77	(1.17)	356	(128)	201	(237)	100.7	(0.2)
5	14.0	(4.7)	53.6	(17.3)	2.27	(1.47)	329	(115)	199	(233)	101.0	(0.0)
6	15.9	(5.4)	47.3	(13.7)	1.71	(1.15)	330	(118)	197	(231)	100.9	(0.0)
7	18.0	(5.5)	44.1	(15.0)	1.57	(0.99)	10	(129)	187	(223)	101.1	(0.1)
8	16.5	(4.6)	61.0	(14.3)	2.56	(1.03)	336	(121)	188	(220)	101.3	(0.0)
9	16.7	(5.0)	64.5	(16.9)	2.86	(1.36)	327	(105)	189	(224)	100.9	(0.2)
10	17.2	(4.9)	63.1	(14.6)	2.20	(1.14)	333	(123)	185	(221)	100.6	(0.0)
11	14.7	(3.5)	71.9	(10.7)	3.65	(1.34)	334	(86)	178	(213)	100.4	(0.0)
12	16.2	(3.6)	66.0	(13.2)	2.45	(1.43)	130	(100)	132	(167)	100.1	(0.1)
13	16.0	(1.0)	79.6	(9.6)	8.36	(2.14)	131	(5)			100.5	(0.4)
14											101.3	(0.1)
15											101.4	(0.1)
16											101.2	(0.1)
17											101.0	(0.0)
18											101.1	(0.0)
19											101.2	(0.0)
20											101.2	(0.0)
21	16.4	(4.3)	74.3	(11.3)	1.27	(0.98)	41	(112)				
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Avg	16.3		58.2		2.60		357		189		100.9	
n	14		14		14		14		12		20	
SD	1.4		11.6		1.75		129		20		0.4	
Min	14.0		43.3		1.17		10		132		100.1	
Max	19.1		79.6		8.36		356		210		101.4	

Table E2. Animal characteristics.

Table E2. Daily means of animal characteristics at Site CA1B for September, 2007.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21		0.07			0.07	
22		0.06			0.06	
23		0.06			0.06	
24		0.06			0.06	
25		0.07			0.07	
26		0.08			0.08	
27		0.10			0.10	
28	21,078	0.12	1.6	21,078	0.12	1.6
29	21,062	0.15	2.0	21,062	0.15	2.0
30	21,046	0.18	2.4	21,046	0.18	2.4
Avg	21,062	0.09	2.0	21,062	0.09	2.0
n	3	10	3	3	10	3
SD	13	0.04	0.3	13	0.04	0.3
Min	21,046	0.06	1.6	21,046	0.06	1.6
Max	21,078	0.18	2.4	21,078	0.18	2.4

Table E2. Daily means of animal characteristics at Site CA1B for October, 2007.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	21,030	0.21	2.9	21,030	0.21	2.9
2	21,013	0.25	3.5	21,013	0.25	3.5
3	20,997	0.30	4.1	20,997	0.30	4.1
4	20,981	0.34	4.7	20,981	0.34	4.7
5	20,965	0.40	5.4	20,965	0.40	5.4
6	20,949	0.45	6.2	20,949	0.45	6.2
7	20,933	0.51	7.0	20,933	0.51	7.0
8	20,917	0.57	7.8	20,917	0.57	7.8
9	20,901	0.63	8.6	20,901	0.63	8.6
10	20,885	0.70	9.5	20,885	0.70	9.5
11	20,869	0.76	10.4	20,869	0.76	10.4
12	20,853	0.83	11.4	20,853	0.83	11.4
13	20,837	0.91	12.4	20,837	0.91	12.4
14	20,821	0.98	13.4	20,821	0.98	13.4
15	20,805	1.05	14.4	20,805	1.05	14.4
16	20,789	1.13	15.4	20,789	1.13	15.4
17	20,773	1.21	16.5	20,773	1.21	16.5
18	20,757	1.29	17.5	20,757	1.29	17.5
19	20,741	1.37	18.6	20,741	1.37	18.6
20	20,725	1.45	19.7	20,725	1.45	19.7
21	20,709	1.53	20.8	20,709	1.53	20.8
22	20,693	1.61	21.9	20,693	1.61	21.9
23	20,677	1.70	23.0	20,677	1.70	23.0
24	20,660	1.78	24.1	20,660	1.78	24.1
25	20,644	1.86	25.2	20,644	1.86	25.2
26	20,628	1.94	26.2	20,628	1.94	26.2
27	20,612	2.02	27.3	20,612	2.02	27.3
28	20,596	2.10	28.4	20,596	2.10	28.4
29	20,580	2.18	29.4	20,580	2.18	29.4
30	20,564	2.26	30.4	20,564	2.26	30.4
31	20,548	2.33	31.4	20,548	2.33	31.4
Avg	20,789	1.18	16.0	20,789	1.18	16.0
n	31	31	31	31	31	31
SD	143	0.66	8.8	143	0.66	8.8
Min	20,548	0.21	2.9	20,548	0.21	2.9
Max	21,030	2.33	31.4	21,030	2.33	31.4

Table E2. Daily means of animal characteristics at Site CA1B for November, 2007.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,532	2.41	32.4	20,532	2.41	32.4
2	20,516	2.48	33.4	20,516	2.48	33.4
3	3,417			854	2.55	1.4
4	0			0		
5	0			0		
6	0			0		
7	0			0		
8	0			0		
9	0			0		
10	0			0		
11	0			0		
12	0			0		
13	0			0		
14	0			0		
15	13,766			14,539		
16	21,276	0.07	1.0	21,079	0.07	0.9
17	21,218	0.06	0.8	21,024	0.06	0.8
18	21,166	0.06	0.8	20,993	0.06	0.8
19	21,122	0.06	0.8	20,971	0.06	0.8
20	21,096	0.07	0.9	20,942	0.07	0.9
21	21,073	0.08	1.1	20,923	0.08	1.1
22	21,047	0.10	1.3	20,903	0.10	1.3
23	21,028	0.12	1.6	20,885	0.12	1.6
24	21,002	0.15	2.0	20,868	0.15	2.0
25	20,987	0.18	2.5	20,850	0.18	2.5
26	20,979	0.21	2.9	20,838	0.22	2.9
27	20,966	0.25	3.5	20,831	0.26	3.5
28	20,954	0.30	4.1	20,822	0.30	4.1
29	20,942	0.35	4.7	20,812	0.35	4.7
30	20,929	0.40	5.4	20,798	0.40	5.4
Avg	12,467	0.43	5.8	12,333	0.55	5.6
n	30	17	17	30	18	18
SD	10,048	0.74	10.0	10,076	0.87	9.8
Min	0	0.06	0.8	0	0.06	0.8
Max	21,276	2.48	33.4	21,079	2.55	33.4

Table E2. Daily means of animal characteristics at Site CA1B for December, 2007.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,927	0.45	6.2	20,790	0.45	6.2
2	20,920	0.51	7.0	20,784	0.51	7.0
3	20,912	0.57	7.8	20,777	0.57	7.8
4	20,901	0.63	8.6	20,767	0.63	8.6
5	20,891	0.70	9.5	20,759	0.70	9.5
6	20,884	0.76	10.5	20,746	0.77	10.4
7	20,881	0.83	11.4	20,739	0.84	11.4
8	20,876	0.91	12.4	20,733	0.91	12.4
9	20,873	0.98	13.4	20,730	0.98	13.4
10	20,867	1.06	14.5	20,722	1.06	14.4
11	20,865	1.13	15.5	20,719	1.14	15.4
12	20,858	1.21	16.6	20,713	1.21	16.5
13	20,853	1.29	17.7	20,705	1.29	17.6
14	20,847	1.37	18.7	20,700	1.37	18.7
15	20,835	1.45	19.8	20,691	1.46	19.7
16	20,826	1.53	20.9	20,686	1.54	20.8
17	20,820	1.62	22.1	20,679	1.62	21.9
18	20,811	1.70	23.2	20,669	1.70	23.0
19	20,804	1.78	24.3	20,664	1.78	24.2
20	20,796	1.86	25.4	20,655	1.86	25.2
21	20,791	1.94	26.5	20,645	1.95	26.3
22	20,784	2.02	27.6	20,633	2.03	27.4
23	20,778	2.10	28.6	20,624	2.11	28.5
24	20,770	2.18	29.7	20,616	2.18	29.5
25	20,764	2.26	30.8	20,607	2.26	30.6
26	20,755	2.34	31.8	20,597	2.34	31.6
27	20,744	2.41	32.8	20,585	2.41	32.6
28	20,734	2.48	33.8	20,574	2.49	33.5
29	20,722	2.55	34.7	20,561	2.56	34.5
30	20,705	2.62	35.6	20,539	2.63	35.4
31	13,803			20,529	2.69	36.2
Avg	20,600	1.51	20.6	20,675	1.55	21.0
n	31	30	30	31	31	31
SD	1,242	0.67	9.1	73	0.69	9.3
Min	13,803	0.45	6.2	20,529	0.45	6.2
Max	20,927	2.62	35.6	20,790	2.69	36.2

Table E2. Daily means of animal characteristics at Site CA1B for January, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	0			18,802	2.75	37.0
2	0			0		
3	0			0		
4	0			0		
5	0			4,762		
6	0			9,134	0.07	0.4
7	9,308			14,405	0.06	0.6
8	21,214	0.07	1.0	21,053	0.06	0.8
9	21,175	0.06	0.8	21,001	0.06	0.8
10	21,128	0.06	0.8	20,965	0.06	0.9
11	21,112	0.06	0.8	20,942	0.08	1.1
12	21,089	0.06	0.9	20,920	0.09	1.3
13	21,068	0.08	1.0	20,890	0.12	1.6
14	21,056	0.09	1.3	20,873	0.14	2.0
15	21,030	0.11	1.6	20,860	0.17	2.4
16	21,016	0.14	1.9	20,843	0.21	2.9
17	20,997	0.17	2.4	20,833	0.25	3.4
18	20,985	0.21	2.8	20,825	0.29	4.0
19	20,979	0.25	3.4	20,819	0.34	4.6
20	20,963	0.29	4.0	20,805	0.39	5.3
21	20,944	0.34	4.6	20,795	0.44	6.0
22	20,932	0.39	5.3	20,783	0.50	6.8
23	20,910	0.44	6.0	20,774	0.56	7.6
24	20,894	0.50	6.8	20,768	0.62	8.5
25	20,880	0.56	7.6	20,765	0.69	9.4
26	20,859	0.62	8.4	20,754	0.76	10.3
27	20,850	0.68	9.3	20,741	0.83	11.2
28	20,832	0.75	10.2	20,727	0.90	12.2
29	20,813	0.82	11.2	20,710	0.97	13.2
30	20,805	0.89	12.2	20,702	1.05	14.2
31	20,792	0.97	13.2	20,696	1.12	15.2
Avg	16,536	0.36	4.9	17,643	0.50	6.8
n	31	24	24	31	27	27
SD	8,358	0.29	4.0	6,786	0.55	7.5
Min	0	0.06	0.8	0	0.06	0.4
Max	21,214	0.97	13.2	21,053	2.75	37.0

Table E2. Daily means of animal characteristics at Site CA1B for February, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,779	1.04	14.2	20,686	1.20	16.3
2	20,764	1.12	15.2	20,667	1.28	17.4
3	20,751	1.20	16.3	20,646	1.36	18.4
4	20,735	1.27	17.3	20,628	1.44	19.5
5	20,724	1.35	18.4	20,620	1.52	20.6
6	20,714	1.44	19.5	20,610	1.60	21.7
7	20,702	1.52	20.6	20,594	1.69	22.8
8	20,695	1.60	21.7	20,586	1.77	23.9
9	20,682	1.68	22.8	20,577	1.85	25.0
10	20,667	1.76	23.9	20,565	1.93	26.0
11	20,650	1.84	25.0	20,551	2.01	27.1
12	20,643	1.92	26.1	20,544	2.09	28.2
13	20,631	2.01	27.1	20,533	2.17	29.2
14	20,617	2.09	28.2	20,518	2.25	30.3
15	20,607	2.16	29.3	20,512	2.33	31.3
16	20,597	2.24	30.3	20,500	2.40	32.3
17	20,571	2.32	31.3	20,468	2.47	33.2
18	20,554	2.39	32.3	20,446	2.55	34.1
19	20,518	2.47	33.2	20,427	2.61	35.0
20	20,484	2.54	34.1	20,364	2.68	35.8
21	19,631	2.61	35.0	19,516		
22	0			0		
23	0			0		
24	0			0		
25	0			0		
26	0			0		
27	0			0		
28	12,414			12,416		
29	21,247	0.07	1.0	21,258	0.07	1.0
Avg	16,082	1.76	23.8	16,008	1.87	25.2
n	29	22	22	29	21	21
SD	8,352	0.60	8.0	8,312	0.60	8.0
Min	0	0.07	1.0	0	0.07	1.0
Max	21,247	2.61	35.0	21,258	2.68	35.8

Table E2. Daily means of animal characteristics at Site CA1B for March, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	21,217	0.06	0.8	21,237	0.06	0.8
2	21,185	0.06	0.8	21,197	0.06	0.8
3	21,160	0.06	0.8	21,164	0.06	0.8
4	21,138	0.07	0.9	21,137	0.07	0.9
5	21,125	0.08	1.1	21,115	0.08	1.1
6	21,108	0.10	1.3	21,101	0.10	1.3
7	21,087	0.12	1.6	21,084	0.12	1.6
8	21,073	0.14	2.0	21,079	0.14	2.0
9	21,056	0.18	2.4	21,067	0.18	2.4
10	21,042	0.21	2.9	21,057	0.21	2.9
11	21,024	0.25	3.5	21,048	0.25	3.5
12	21,008	0.29	4.1	21,032	0.29	4.1
13	20,990	0.34	4.7	21,024	0.34	4.7
14	20,972	0.39	5.4	21,020	0.39	5.4
15	20,952	0.45	6.1	21,001	0.45	6.2
16	20,937	0.50	6.9	20,977	0.50	6.9
17	20,925	0.56	7.7	20,962	0.56	7.8
18	20,909	0.63	8.6	20,952	0.63	8.6
19	20,891	0.69	9.5	20,938	0.69	9.5
20	20,868	0.76	10.4	20,922	0.76	10.4
21	20,840	0.83	11.3	20,901	0.83	11.4
22	20,807	0.90	12.3	20,879	0.90	12.3
23	20,781	0.98	13.3	20,859	0.98	13.3
24	20,747	1.05	14.3	20,842	1.05	14.4
25	20,729	1.13	15.3	20,824	1.13	15.4
26	20,710	1.21	16.4	20,810	1.21	16.5
27	20,696	1.29	17.4	20,798	1.29	17.5
28	20,678	1.37	18.5	20,783	1.37	18.6
29	20,663	1.45	19.6	20,765	1.45	19.7
30	20,647	1.53	20.7	20,751	1.53	20.8
31	20,635	1.61	21.8	20,733	1.61	21.9
Avg	20,923	0.62	8.5	20,970	0.62	8.5
n	31	31	31	31	31	31
SD	174	0.50	6.7	138	0.50	6.8
Min	20,635	0.06	0.8	20,733	0.06	0.8
Max	21,217	1.61	21.8	21,237	1.61	21.9

Table E2. Daily means of animal characteristics at Site CA1B for April, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,622	1.69	22.9	20,717	1.69	23.0
2	20,611	1.77	24.0	20,699	1.77	24.1
3	20,598	1.86	25.1	20,683	1.86	25.2
4	20,581	1.94	26.1	20,668	1.94	26.2
5	20,564	2.02	27.2	20,652	2.02	27.3
6	20,548	2.10	28.3	20,635	2.10	28.4
7	20,528	2.18	29.3	20,613	2.18	29.4
8	20,517	2.25	30.3	20,591	2.25	30.4
9	20,501	2.33	31.3	20,573	2.33	31.4
10	20,481	2.41	32.3	20,553	2.41	32.4
11	20,463	2.48	33.3	20,536	2.48	33.4
12	20,463	2.55	34.2	20,536	2.55	34.3
13	20,463	2.62	35.1	20,536	2.62	35.3
14	20,463	2.69	36.0	20,536	2.69	36.2
15	2,558			4,706		
16	0			0		
17	0			0		
18	0			0		
19	0			0		
20	0			0		
21	0			0		
22	16,433	0.08	1.1	12,968		
23	21,259	0.07	0.9	21,360	0.07	1.0
24	21,249	0.06	0.8	21,320	0.06	0.8
25	21,231	0.06	0.8	21,294	0.06	0.8
26	21,220	0.06	0.8	21,274	0.06	0.8
27	21,205	0.07	0.9	21,250	0.07	0.9
28	21,188	0.08	1.1	21,218	0.08	1.1
29	21,178	0.10	1.4	21,190	0.10	1.3
30	21,161	0.12	1.7	21,174	0.12	1.6
Avg	15,870	1.37	18.5	15,876	1.43	19.3
n	30	23	23	30	22	22
SD	8,604	1.07	14.3	8,546	1.05	14.2
Min	0	0.06	0.8	0	0.06	0.8
Max	21,259	2.69	36.0	21,360	2.69	36.2

Table E2. Daily means of animal characteristics at Site CA1B for May, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	21,150	0.15	2.1	21,157	0.15	2.0
2	21,135	0.18	2.5	21,147	0.18	2.4
3	21,129	0.22	3.0	21,142	0.21	2.9
4	21,121	0.26	3.6	21,133	0.25	3.5
5	21,110	0.30	4.2	21,120	0.30	4.1
6	21,100	0.35	4.9	21,107	0.34	4.7
7	21,094	0.40	5.6	21,095	0.39	5.4
8	21,085	0.46	6.3	21,082	0.45	6.2
9	21,082	0.52	7.1	21,070	0.51	7.0
10	21,072	0.58	8.0	21,056	0.57	7.8
11	21,060	0.64	8.8	21,045	0.63	8.7
12	21,045	0.71	9.7	21,033	0.69	9.6
13	21,025	0.77	10.7	21,007	0.76	10.5
14	21,019	0.84	11.6	20,992	0.83	11.4
15	21,010	0.92	12.6	20,978	0.90	12.4
16	20,998	0.99	13.6	20,969	0.98	13.4
17	20,988	1.07	14.7	20,953	1.05	14.5
18	20,976	1.14	15.7	20,942	1.13	15.5
19	20,961	1.22	16.8	20,927	1.21	16.6
20	20,949	1.30	17.9	20,915	1.29	17.7
21	20,931	1.38	19.0	20,900	1.37	18.7
22	20,917	1.46	20.1	20,887	1.45	19.8
23	20,901	1.54	21.2	20,873	1.53	20.9
24	20,888	1.63	22.3	20,856	1.61	22.0
25	20,873	1.71	23.4	20,842	1.69	23.1
26	20,856	1.79	24.5	20,827	1.78	24.2
27	20,840	1.87	25.6	20,811	1.86	25.3
28	20,818	1.95	26.6	20,793	1.94	26.4
29	20,800	2.03	27.7	20,774	2.02	27.5
30	20,781	2.11	28.8	20,749	2.10	28.6
31	20,765	2.19	29.8	20,726	2.18	29.6
Avg	20,983	1.05	14.5	20,965	1.04	14.3
n	31	31	31	31	31	31
SD	113	0.63	8.6	127	0.63	8.6
Min	20,765	0.15	2.1	20,726	0.15	2.0
Max	21,150	2.19	29.8	21,157	2.18	29.6

Table E2. Daily means of animal characteristics at Site CA1B for June, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,750	2.27	30.9	20,695	2.26	30.6
2	20,733	2.34	31.9	20,671	2.33	31.6
3	20,714	2.42	32.9	20,649	2.41	32.6
4	20,700	2.49	33.8	20,622	2.48	33.5
5	20,675	2.56	34.7	20,590	2.55	34.4
6	18,952	2.63	35.6	12,440		
7	0			0		
8	0			0		
9	0			0		
10	0			0		
11	0			0		
12	0			0		
13	0			0		
14	13,274			14,185		
15	21,222	0.07	1.0	21,261	0.07	0.9
16	21,212	0.06	0.8	21,242	0.06	0.8
17	21,169	0.06	0.8	21,213	0.06	0.8
18	21,137	0.06	0.8	21,191	0.06	0.8
19	21,114	0.07	0.9	21,171	0.07	0.9
20	21,100	0.08	1.1	21,159	0.08	1.1
21	21,093	0.10	1.3	21,150	0.10	1.3
22	21,080	0.12	1.6	21,137	0.12	1.7
23	21,072	0.15	2.0	21,128	0.15	2.0
24	21,063	0.18	2.4	21,120	0.18	2.5
25	21,047	0.21	2.9	21,109	0.21	3.0
26	21,036	0.25	3.5	21,101	0.25	3.5
27	21,029	0.30	4.1	21,093	0.30	4.1
28	21,026	0.34	4.7	21,089	0.35	4.8
29	21,019	0.40	5.4	21,081	0.40	5.5
30	21,006	0.45	6.2	21,070	0.45	6.2
Avg	15,774	0.80	10.9	15,606	0.71	9.7
n	30	22	22	30	21	21
SD	8,817	1.02	13.8	8,822	0.96	12.9
Min	0	0.06	0.8	0	0.06	0.8
Max	21,222	2.63	35.6	21,261	2.55	34.4

Table E2. Daily means of animal characteristics at Site CA1B for July, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,998	0.51	7.0	21,062	0.51	7.0
2	20,984	0.57	7.8	21,048	0.57	7.9
3	20,970	0.63	8.7	21,037	0.63	8.7
4	20,957	0.70	9.6	21,023	0.70	9.6
5	20,942	0.76	10.5	21,011	0.77	10.5
6	20,916	0.83	11.4	20,989	0.84	11.5
7	20,888	0.91	12.4	20,964	0.91	12.5
8	20,868	0.98	13.4	20,952	0.98	13.5
9	20,850	1.05	14.4	20,938	1.06	14.5
10	20,830	1.13	15.5	20,925	1.13	15.6
11	20,815	1.21	16.5	20,911	1.21	16.6
12	20,801	1.29	17.6	20,892	1.29	17.7
13	20,781	1.37	18.7	20,876	1.37	18.8
14	20,750	1.45	19.7	20,849	1.45	19.9
15	20,717	1.53	20.8	20,830	1.54	21.0
16	20,693	1.61	21.9	20,806	1.62	22.1
17	20,665	1.70	23.0	20,784	1.70	23.2
18	20,640	1.78	24.1	20,764	1.78	24.2
19	20,623	1.86	25.1	20,749	1.86	25.3
20	20,600	1.94	26.2	20,726	1.94	26.4
21	20,551	2.02	27.2	20,695	2.02	27.5
22	20,520	2.10	28.3	20,669	2.10	28.5
23	20,468	2.18	29.3	20,639	2.18	29.5
24	20,410	2.26	30.2	20,604	2.26	30.5
25	20,357	2.33	31.1	20,573	2.34	31.5
26	20,339	2.41	32.1	20,562	2.41	32.5
27	20,270	2.48	33.0	20,516	2.48	33.4
28	20,217	2.55	33.8	20,487	2.56	34.3
29	20,157	2.62	34.7	20,455	2.62	35.2
30	20,002	2.69	35.3	20,426	2.69	36.0
31	19,822	2.75	35.8	20,386	2.76	36.8
Avg	20,626	1.62	21.8	20,779	1.62	22.0
n	31	31	31	31	31	31
SD	301	0.69	9.0	200	0.69	9.2
Min	19,822	0.51	7.0	20,386	0.51	7.0
Max	20,998	2.75	35.8	21,062	2.76	36.8

Table E2. Daily means of animal characteristics at Site CA1B for August, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	4,920			5,090		
2	0			0		
3	0			0		
4	0			0		
5	0			0		
6	0			0		
7	0			0		
8	0			0		
9	0			0		
10	0			0		
11	12,517			12,515		
12	21,415	0.07	1.0	21,422	0.07	1.0
13	21,393	0.06	0.8	21,401	0.06	0.8
14	21,363	0.06	0.8	21,377	0.06	0.8
15	21,340	0.06	0.8	21,357	0.06	0.8
16	21,319	0.06	0.9	21,345	0.06	0.9
17	21,300	0.08	1.1	21,330	0.08	1.1
18	21,282	0.09	1.3	21,317	0.09	1.3
19	21,276	0.12	1.6	21,309	0.12	1.6
20	21,272	0.14	2.0	21,303	0.14	2.0
21	21,265	0.17	2.4	21,300	0.17	2.4
22	21,260	0.21	2.9	21,296	0.21	2.9
23	21,258	0.25	3.5	21,294	0.25	3.5
24	21,254	0.29	4.1	21,289	0.29	4.1
25	21,247	0.34	4.7	21,283	0.34	4.7
26	21,232	0.39	5.4	21,272	0.39	5.4
27	21,221	0.44	6.2	21,267	0.44	6.2
28	21,210	0.50	7.0	21,260	0.50	7.0
29	21,202	0.56	7.8	21,253	0.56	7.8
30	21,197	0.62	8.7	21,247	0.62	8.7
31	21,180	0.69	9.6	21,240	0.69	9.6
Avg	14,288	0.26	3.6	14,315	0.26	3.6
n	31	20	20	31	20	20
SD	9,680	0.20	2.8	9,690	0.20	2.8
Min	0	0.06	0.8	0	0.06	0.8
Max	21,415	0.69	9.6	21,422	0.69	9.6

Table E2. Daily means of animal characteristics at Site CA1B for September, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	21,167	0.76	10.5	21,231	0.76	10.5
2	21,158	0.83	11.5	21,218	0.83	11.5
3	21,147	0.90	12.5	21,206	0.90	12.5
4	21,141	0.97	13.5	21,188	0.97	13.5
5	21,127	1.05	14.5	21,176	1.05	14.6
6	21,121	1.13	15.6	21,164	1.13	15.6
7	21,116	1.20	16.7	21,154	1.20	16.7
8	21,105	1.28	17.7	21,138	1.28	17.8
9	21,092	1.36	18.8	21,130	1.36	18.9
10	21,085	1.44	20.0	21,122	1.44	20.0
11	21,078	1.52	21.1	21,114	1.52	21.1
12	21,072	1.61	22.2	21,105	1.61	22.2
13	21,049	1.69	23.3	21,088	1.69	23.4
14	21,036	1.77	24.4	21,074	1.77	24.5
15	21,016	1.85	25.5	21,058	1.85	25.6
16	20,983	1.93	26.6	21,041	1.93	26.7
17	20,940	2.01	27.7	21,026	2.01	27.8
18	20,905	2.09	28.7	20,990	2.09	28.8
19	20,892	2.17	29.8	20,974	2.17	29.9
20	20,881	2.25	30.8	20,957	2.25	30.9
21	20,868	2.33	31.8	20,929	2.33	31.9
22	20,855	2.40	32.8	20,908	2.40	32.9
23	20,839	2.48	33.8	20,891	2.48	33.9
24	20,817	2.55	34.8	20,861	2.55	34.8
25	20,799	2.62	35.7	20,838	2.62	35.7
26	20,799	2.68	36.6	19,102	2.68	36.6
27	2,600			0		
28	0			0		
29	0			0		
30	0			0		
Avg	18,290	1.73	23.7	18,189	1.73	23.8
n	30	26	26	30	26	26
SD	6,932	0.59	8.0	7,144	0.59	8.0
Min	0	0.76	10.5	0	0.76	10.5
Max	21,167	2.68	36.6	21,231	2.68	36.6

Table E2. Daily means of animal characteristics at Site CA1B for October, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	0			0		
2	0			0		
3	0			0		
4	0			0		
5	0			0		
6	0			0		
7	0			0		
8	0			0		
9	0			0		
10	0			0		
11	0			0		
12	0			0		
13	0			0		
14	0			0		
15	0			0		
16	0			0		
17	0			0		
18	0			0		
19	0			0		
20	15,681			11,089		
21	21,212	0.07	0.9	21,250	0.07	1.0
22	21,192	0.06	0.8	21,232	0.06	0.8
23	21,196	0.06	0.8	21,212	0.06	0.8
24	21,178	0.06	0.8	21,197	0.06	0.8
25	21,175	0.07	0.9	21,186	0.06	0.9
26	21,157	0.08	1.1	21,176	0.08	1.1
27	21,155	0.10	1.4	21,163	0.09	1.3
28	21,150	0.12	1.7	21,151	0.12	1.6
29	21,146	0.15	2.1	21,142	0.14	2.0
30	21,138	0.18	2.5	21,135	0.17	2.4
31	21,129	0.22	3.0	21,128	0.21	2.9
Avg	8,016	0.11	1.5	7,873	0.10	1.4
n	31	11	11	31	11	11
SD	10,131	0.05	0.7	10,057	0.05	0.7
Min	0	0.06	0.8	0	0.06	0.8
Max	21,212	0.22	3.0	21,250	0.21	2.9

Table E2. Daily means of animal characteristics at Site CA1B for November, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	21,122	0.26	3.6	21,123	0.25	3.4
2	21,118	0.30	4.2	21,115	0.29	4.0
3	21,108	0.35	4.8	21,108	0.34	4.7
4	21,106	0.40	5.5	21,103	0.39	5.4
5	21,099	0.46	6.3	21,092	0.44	6.1
6	21,099	0.51	7.1	21,080	0.50	6.9
7	21,089	0.57	7.9	21,076	0.56	7.7
8	21,090	0.64	8.8	21,060	0.62	8.6
9	21,079	0.70	9.7	21,051	0.69	9.5
10	21,076	0.77	10.6	21,037	0.76	10.4
11	21,060	0.84	11.6	21,022	0.83	11.4
12	21,063	0.91	12.6	21,007	0.90	12.4
13	21,053	0.99	13.6	21,000	0.97	13.4
14	21,053	1.06	14.7	20,995	1.05	14.4
15	21,043	1.14	15.7	20,987	1.12	15.5
16	21,043	1.22	16.8	20,978	1.20	16.5
17	21,030	1.30	17.9	20,968	1.28	17.6
18	21,032	1.38	19.0	20,957	1.36	18.7
19	21,023	1.46	20.1	20,950	1.44	19.8
20	21,020	1.54	21.2	20,947	1.52	20.9
21	21,010	1.62	22.4	20,938	1.60	22.0
22	21,011	1.70	23.5	20,927	1.69	23.1
23	21,000	1.79	24.6	20,917	1.77	24.3
24	20,999	1.87	25.7	20,904	1.85	25.4
25	20,985	1.95	26.8	20,895	1.93	26.5
26	20,988	2.03	27.9	20,885	2.01	27.6
27	20,975	2.11	29.0	20,873	2.09	28.6
28	20,977	2.19	30.1	20,862	2.17	29.7
29	20,968	2.27	31.2	20,849	2.25	30.7
30	20,967	2.34	32.2	20,837	2.33	31.8
Avg	21,043	1.22	16.8	20,985	1.21	16.6
n	30	30	30	30	30	30
SD	48	0.64	8.8	85	0.64	8.8
Min	20,967	0.26	3.6	20,837	0.25	3.4
Max	21,122	2.34	32.2	21,123	2.33	31.8

Table E2. Daily means of animal characteristics at Site CA1B for December, 2008.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,955	2.42	33.2	20,824	2.40	32.8
2	20,960	2.49	34.2	20,819	2.47	33.8
3	20,951	2.56	35.2	20,811	2.55	34.7
4	873			867		
5	0			0		
6	0			0		
7	0			0		
8	0			0		
9	0			0		
10	0			0		
11	0			0		
12	9,763			12,392		
13	21,265	0.07	1.0	21,184	0.07	1.0
14	21,232	0.06	0.8	21,139	0.06	0.8
15	21,198	0.06	0.8	21,135	0.06	0.8
16	21,168	0.06	0.8	21,114	0.06	0.8
17	21,138	0.06	0.9	21,106	0.07	0.9
18	21,123	0.08	1.1	21,090	0.08	1.1
19	21,106	0.09	1.3	21,098	0.10	1.3
20	21,095	0.11	1.6	21,088	0.12	1.6
21	21,083	0.14	1.9	21,086	0.14	2.0
22	21,073	0.17	2.4	21,075	0.18	2.4
23	21,064	0.21	2.9	21,072	0.21	2.9
24	21,056	0.25	3.4	21,060	0.25	3.5
25	21,047	0.29	4.0	21,063	0.29	4.1
26	21,036	0.34	4.6	21,053	0.34	4.7
27	21,027	0.39	5.3	21,050	0.39	5.4
28	21,016	0.44	6.1	21,040	0.45	6.2
29	21,006	0.50	6.8	21,038	0.50	7.0
30	20,998	0.56	7.7	21,027	0.56	7.8
31	20,984	0.62	8.5	21,027	0.63	8.6
Avg	15,297	0.54	7.5	15,363	0.54	7.5
n	31	22	22	31	22	22
SD	9,177	0.79	10.9	9,126	0.79	10.7
Min	0	0.06	0.8	0	0.06	0.8
Max	21,265	2.56	35.2	21,184	2.55	34.7

Table E2. Daily means of animal characteristics at Site CA1B for January, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,979	0.68	9.4	21,021	0.69	9.5
2	20,964	0.75	10.3	21,012	0.76	10.5
3	20,956	0.82	11.3	20,998	0.83	11.4
4	20,945	0.89	12.3	20,997	0.90	12.4
5	20,932	0.97	13.3	20,984	0.98	13.4
6	20,920	1.04	14.3	20,983	1.05	14.5
7	20,911	1.12	15.3	20,971	1.13	15.5
8	20,902	1.20	16.4	20,974	1.21	16.6
9	20,894	1.28	17.5	20,960	1.29	17.7
10	20,887	1.36	18.6	20,967	1.37	18.8
11	20,878	1.44	19.7	20,957	1.45	19.9
12	20,867	1.52	20.8	20,955	1.53	21.0
13	20,856	1.60	21.9	20,941	1.61	22.1
14	20,846	1.68	23.0	20,942	1.69	23.2
15	20,833	1.76	24.1	20,932	1.77	24.3
16	20,819	1.85	25.2	20,930	1.86	25.5
17	20,802	1.93	26.3	20,914	1.94	26.6
18	20,787	2.01	27.4	20,915	2.02	27.7
19	20,773	2.09	28.4	20,902	2.10	28.7
20	20,760	2.17	29.5	20,901	2.18	29.8
21	20,750	2.24	30.5	20,884	2.25	30.9
22	20,730	2.32	31.5	20,883	2.33	31.9
23	20,707	2.40	32.5	20,858	2.41	32.9
24	20,686	2.47	33.5	20,861	2.48	33.9
25	20,657	2.54	34.4	20,828	2.55	34.8
26	20,625	2.61	35.3	20,821	2.62	35.8
27	20,625	2.68	36.2	20,821	2.69	36.7
28	11,172			6,940		
29	0			0		
30	0			0		
31	0			0		
Avg	18,499	1.68	22.9	18,453	1.69	23.2
n	31	27	27	31	27	27
SD	6,291	0.61	8.2	6,525	0.61	8.3
Min	0	0.68	9.4	0	0.69	9.5
Max	20,979	2.68	36.2	21,021	2.69	36.7

Table E2. Daily means of animal characteristics at Site CA1B for February, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	0			0		
2	0			0		
3	0			0		
4	0			0		
5	0			0		
6	0			0		
7	0			0		
8	0			0		
9	9,850			10,636		
10	21,454	0.07	1.0	21,230	0.07	1.0
11	21,416	0.06	0.9	21,180	0.06	0.8
12	21,397	0.06	0.8	21,143	0.06	0.8
13	21,384	0.06	0.8	21,117	0.06	0.8
14	21,356	0.06	0.9	21,095	0.06	0.9
15	21,336	0.08	1.1	21,075	0.08	1.1
16	21,317	0.09	1.3	21,061	0.09	1.3
17	21,307	0.11	1.6	21,041	0.12	1.6
18	21,296	0.14	2.0	21,023	0.14	2.0
19	21,269	0.17	2.4	21,008	0.17	2.4
20	21,258	0.21	2.9	20,994	0.21	2.9
21	21,249	0.25	3.4	20,988	0.25	3.4
22	21,218	0.29	4.0	20,975	0.29	4.0
23	21,202	0.34	4.7	20,963	0.34	4.6
24	21,181	0.39	5.4	20,957	0.39	5.3
25	21,159	0.44	6.1	20,944	0.44	6.1
26	21,134	0.50	6.9	20,929	0.50	6.8
27	21,115	0.56	7.7	20,921	0.56	7.7
28	21,091	0.62	8.6	20,908	0.62	8.5
Avg	14,785	0.24	3.3	14,650	0.24	3.3
n	28	19	19	28	19	19
SD	9,585	0.18	2.5	9,461	0.18	2.5
Min	0	0.06	0.8	0	0.06	0.8
Max	21,454	0.62	8.6	21,230	0.62	8.5

Table E2. Daily means of animal characteristics at Site CA1B for March, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	21,072	0.68	9.5	20,898	0.69	9.4
2	21,052	0.75	10.4	20,886	0.75	10.3
3	21,044	0.82	11.3	20,872	0.82	11.3
4	21,028	0.89	12.3	20,855	0.90	12.3
5	21,007	0.97	13.3	20,848	0.97	13.3
6	20,998	1.04	14.3	20,841	1.04	14.3
7	20,978	1.12	15.4	20,826	1.12	15.3
8	20,960	1.20	16.4	20,811	1.20	16.4
9	20,936	1.28	17.5	20,792	1.28	17.4
10	20,917	1.36	18.6	20,774	1.36	18.5
11	20,902	1.44	19.7	20,762	1.44	19.6
12	20,888	1.52	20.8	20,741	1.52	20.7
13	20,873	1.60	21.9	20,723	1.60	21.8
14	20,861	1.68	23.0	20,716	1.69	22.9
15	20,847	1.76	24.1	20,702	1.77	24.0
16	20,829	1.85	25.2	20,691	1.85	25.1
17	20,801	1.93	26.3	20,672	1.93	26.2
18	20,778	2.01	27.4	20,648	2.01	27.2
19	20,747	2.09	28.4	20,615	2.09	28.3
20	20,724	2.17	29.4	20,596	2.17	29.3
21	20,694	2.24	30.5	20,576	2.25	30.3
22	20,658	2.32	31.4	20,549	2.32	31.3
23	20,616	2.40	32.4	20,490	2.40	32.2
24	20,595	2.47	33.3	20,447	2.47	33.1
25	20,552	2.54	34.2	20,392	2.54	34.0
26	20,514	2.61	35.1	20,348	2.61	34.9
27	20,514	2.68	36.0	5,935		
28	0			0		
29	0			0		
30	0			0		
31	0			0		
Avg	18,141	1.68	22.9	17,549	1.65	22.3
n	31	27	27	31	26	26
SD	6,984	0.61	8.2	7,239	0.59	7.9
Min	0	0.68	9.5	0	0.69	9.4
Max	21,072	2.68	36.0	20,898	2.61	34.9

Table E2. Daily means of animal characteristics at Site CA1B for April, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	0			0		
2	0			0		
3	0			0		
4	0			0		
5	0			0		
6	0			0		
7	0			0		
8	0			0		
9	0			0		
10	10,629			10,631		
11	21,218	0.07	1.0	21,242	0.07	1.0
12	21,168	0.06	0.8	21,188	0.06	0.8
13	21,146	0.06	0.8	21,162	0.06	0.8
14	21,120	0.06	0.8	21,130	0.06	0.8
15	21,097	0.06	0.9	21,110	0.06	0.9
16	21,077	0.08	1.1	21,088	0.08	1.1
17	21,042	0.09	1.3	21,056	0.09	1.3
18	21,033	0.12	1.6	21,043	0.12	1.6
19	21,026	0.14	2.0	21,037	0.14	2.0
20	21,016	0.17	2.4	21,027	0.17	2.4
21	21,011	0.21	2.9	21,022	0.21	2.9
22	21,007	0.25	3.4	21,018	0.25	3.4
23	21,002	0.29	4.0	21,014	0.29	4.0
24	20,993	0.34	4.7	20,998	0.34	4.7
25	20,985	0.39	5.3	20,986	0.39	5.3
26	20,976	0.44	6.1	20,975	0.44	6.1
27	20,957	0.50	6.9	20,954	0.50	6.9
28	20,946	0.56	7.7	20,940	0.56	7.7
29	20,933	0.62	8.5	20,931	0.62	8.5
30	20,922	0.69	9.4	20,921	0.69	9.4
Avg	14,377	0.26	3.6	14,382	0.26	3.6
n	30	20	20	30	20	20
SD	9,593	0.20	2.8	9,597	0.20	2.8
Min	0	0.06	0.8	0	0.06	0.8
Max	21,218	0.69	9.4	21,242	0.69	9.4

Table E2. Daily means of animal characteristics at Site CA1B for May, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,914	0.75	10.3	20,913	0.75	10.3
2	20,898	0.82	11.3	20,906	0.82	11.3
3	20,884	0.90	12.3	20,890	0.90	12.3
4	20,869	0.97	13.3	20,870	0.97	13.3
5	20,864	1.04	14.3	20,859	1.04	14.3
6	20,852	1.12	15.3	20,849	1.12	15.3
7	20,843	1.20	16.4	20,834	1.20	16.4
8	20,831	1.28	17.5	20,819	1.28	17.5
9	20,817	1.36	18.6	20,811	1.36	18.5
10	20,800	1.44	19.6	20,796	1.44	19.6
11	20,780	1.52	20.7	20,779	1.52	20.7
12	20,759	1.60	21.8	20,760	1.60	21.8
13	20,736	1.69	22.9	20,742	1.69	22.9
14	20,722	1.77	24.0	20,732	1.77	24.0
15	20,685	1.85	25.1	20,703	1.85	25.1
16	20,667	1.93	26.2	20,693	1.93	26.2
17	20,646	2.01	27.2	20,675	2.01	27.3
18	20,620	2.09	28.3	20,656	2.09	28.3
19	20,585	2.17	29.3	20,633	2.17	29.4
20	20,555	2.25	30.3	20,623	2.25	30.4
21	20,447	2.32	31.2	20,592	2.32	31.4
22	20,379	2.40	32.1	20,553	2.40	32.3
23	20,331	2.47	33.0	20,531	2.47	33.3
24	20,255	2.54	33.8	20,514	2.54	34.2
25	20,220	2.61	34.6	20,499	2.61	35.1
26	20,165	2.68	35.4	20,474	2.68	36.0
27	10,923			9,384		
28	0			0		
29	0			0		
30	0			0		
31	0			0		
Avg	17,679	1.72	23.3	17,680	1.72	23.4
n	31	26	26	31	26	26
SD	7,021	0.59	7.8	7,093	0.59	7.9
Min	0	0.75	10.3	0	0.75	10.3
Max	20,914	2.68	35.4	20,913	2.68	36.0

Table E2. Daily means of animal characteristics at Site CA1B for June, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	0			0		
2	0			0		
3	0			0		
4	0			13,249		
5	13,239			21,190	0.07	1.0
6	21,152	0.07	1.0	21,176	0.06	0.8
7	21,132	0.06	0.8	21,147	0.06	0.8
8	21,115	0.06	0.8	21,118	0.06	0.8
9	21,099	0.06	0.8	21,102	0.07	0.9
10	21,088	0.07	0.9	21,094	0.08	1.1
11	21,077	0.08	1.1	21,086	0.10	1.3
12	21,070	0.10	1.3	21,083	0.12	1.6
13	21,061	0.12	1.6	21,075	0.15	2.0
14	21,049	0.15	2.0	21,068	0.18	2.5
15	21,039	0.18	2.4	21,058	0.21	2.9
16	21,033	0.21	2.9	21,050	0.25	3.5
17	21,026	0.25	3.5	21,033	0.30	4.1
18	21,016	0.30	4.1	21,023	0.34	4.7
19	21,009	0.34	4.7	21,009	0.40	5.4
20	20,999	0.40	5.4	20,997	0.45	6.2
21	20,984	0.45	6.2	20,983	0.51	7.0
22	20,964	0.51	7.0	20,966	0.57	7.8
23	20,948	0.57	7.8	20,949	0.63	8.6
24	20,927	0.63	8.6	20,932	0.70	9.5
25	20,896	0.70	9.5	20,908	0.76	10.5
26	20,874	0.76	10.4	20,875	0.83	11.4
27	20,843	0.83	11.4	20,850	0.91	12.4
28	20,814	0.91	12.4	20,826	0.98	13.4
29	20,788	0.98	13.3	20,806	1.05	14.4
30	20,771	1.05	14.4	20,789	1.13	15.4
Avg	17,934	0.39	5.4	18,648	0.42	5.8
n	30	25	25	30	26	26
SD	7,171	0.32	4.4	6,370	0.34	4.7
Min	0	0.06	0.8	0	0.06	0.8
Max	21,152	1.05	14.4	21,190	1.13	15.4

Table E2. Daily means of animal characteristics at Site CA1B for July, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	20,749	1.13	15.4	20,762	1.21	16.5
2	20,734	1.21	16.4	20,735	1.29	17.5
3	20,708	1.29	17.5	20,714	1.37	18.6
4	20,691	1.37	18.6	20,693	1.45	19.7
5	20,668	1.45	19.7	20,673	1.53	20.8
6	20,648	1.53	20.7	20,655	1.61	21.9
7	20,624	1.61	21.8	20,629	1.70	22.9
8	20,606	1.70	22.9	20,612	1.78	24.0
9	20,586	1.78	24.0	20,595	1.86	25.1
10	20,569	1.86	25.1	20,573	1.94	26.2
11	20,546	1.94	26.1	20,552	2.02	27.2
12	20,514	2.02	27.2	20,541	2.10	28.3
13	20,485	2.10	28.2	20,516	2.18	29.3
14	20,393	2.18	29.1	20,450	2.26	30.3
15	20,358	2.26	30.1	20,431	2.33	31.3
16	20,333	2.33	31.1	20,401	2.41	32.2
17	20,265	2.41	32.0	20,358	2.48	33.1
18	20,208	2.48	32.9	20,321	2.55	34.0
19	20,173	2.55	33.8	20,274	2.62	34.9
20	20,055	2.62	34.5	20,174	2.69	35.6
21	9,148			5,846		
22	0			0		
23	0			0		
24	0			0		
25	0			0		
26	0			0		
27	0			0		
28	0			0		
29	0			0		
30	10,048			14,077		
31	19,265	0.07	0.9	19,284	0.07	0.9
Avg	14,464	1.80	24.2	14,512	1.88	25.2
n	31	21	21	31	21	21
SD	8,931	0.59	7.8	8,995	0.60	7.9
Min	0	0.07	0.9	0	0.07	0.9
Max	20,749	2.62	34.5	20,762	2.69	35.6

Table E2. Daily means of animal characteristics at Site CA1B for August, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	19,232	0.06	0.8	19,266	0.06	0.7
2	19,210	0.06	0.7	19,242	0.06	0.7
3	19,185	0.06	0.7	19,227	0.06	0.7
4	19,144	0.06	0.8	19,215	0.07	0.8
5	19,137	0.08	1.0	19,202	0.08	1.0
6	19,124	0.09	1.2	19,191	0.10	1.2
7	19,102	0.12	1.5	19,182	0.12	1.5
8	19,089	0.14	1.8	19,172	0.15	1.9
9	19,076	0.17	2.2	19,157	0.18	2.3
10	19,071	0.21	2.6	19,141	0.22	2.7
11	19,064	0.25	3.1	19,131	0.26	3.2
12	19,054	0.29	3.6	19,113	0.30	3.8
13	19,046	0.34	4.2	19,103	0.35	4.4
14	19,038	0.39	4.9	19,095	0.40	5.0
15	19,030	0.44	5.5	19,088	0.46	5.7
16	19,021	0.50	6.2	19,082	0.51	6.4
17	19,011	0.56	7.0	19,075	0.57	7.2
18	19,000	0.62	7.8	19,067	0.64	8.0
19	18,995	0.69	8.6	19,057	0.70	8.8
20	18,991	0.76	9.4	19,047	0.77	9.6
21	18,984	0.83	10.3	19,038	0.84	10.5
22	18,980	0.90	11.2	19,033	0.91	11.4
23	18,972	0.97	12.1	19,023	0.99	12.3
24	18,961	1.05	13.0	19,015	1.06	13.2
25	18,956	1.12	14.0	19,009	1.14	14.2
26	18,948	1.20	14.9	18,998	1.22	15.2
27	18,939	1.28	15.9	18,989	1.30	16.2
28	18,928	1.36	16.9	18,978	1.38	17.1
29	18,914	1.44	17.9	18,968	1.46	18.1
30	18,898	1.52	18.9	18,955	1.54	19.1
31	18,885	1.60	19.9	18,935	1.62	20.1
Avg	19,032	0.62	7.7	19,090	0.63	7.8
n	31	31	31	31	31	31
SD	89	0.50	6.1	90	0.50	6.2
Min	18,885	0.06	0.7	18,935	0.06	0.7
Max	19,232	1.60	19.9	19,266	1.62	20.1

Table E2. Daily means of animal characteristics at Site CA1B for September, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	18,878	1.69	20.9	18,922	1.70	21.1
2	18,871	1.77	21.9	18,911	1.79	22.1
3	18,860	1.85	22.9	18,904	1.87	23.1
4	18,852	1.93	23.9	18,892	1.95	24.1
5	18,841	2.01	24.9	18,881	2.03	25.1
6	18,824	2.09	25.8	18,862	2.11	26.1
7	18,810	2.17	26.8	18,846	2.19	27.0
8	18,784	2.25	27.7	18,824	2.27	28.0
9	18,762	2.33	28.6	18,807	2.34	28.9
10	18,735	2.40	29.5	18,781	2.42	29.8
11	18,720	2.47	30.4	18,761	2.49	30.6
12	18,697	2.55	31.2	18,709	2.56	31.4
13	18,662	2.61	32.0	18,657	2.63	32.2
14	10,109			6,996		
15	0			0		
16	0			0		
17	0			0		
18	0			0		
19	0			0		
20	0			0		
21	0			0		
22	0			0		
23	0			0		
24	0			0		
25	0			0		
26	11,259			12,056		
27	19,275	0.07	0.9	19,266	0.07	0.9
28	19,244	0.06	0.8	19,237	0.06	0.8
29	19,226	0.06	0.7	19,224	0.06	0.7
30	19,216	0.06	0.7	19,207	0.06	0.7
Avg	11,421	1.67	20.6	11,358	1.68	20.7
n	30	17	17	30	17	17
SD	8,921	0.93	11.4	8,967	0.93	11.5
Min	0	0.06	0.7	0	0.06	0.7
Max	19,275	2.61	32.0	19,266	2.63	32.2

Table E2. Daily means of animal characteristics at Site CA1B for October, 2009.

Day	House 10			House 12		
	Inventory	Mass, kg	kg m^{-2}	Inventory	Mass, kg	kg m^{-2}
1	19,201	0.07	0.8	19,190	0.07	0.8
2	19,191	0.08	1.0	19,176	0.08	1.0
3	19,184	0.10	1.2	19,165	0.10	1.2
4	19,176	0.12	1.5	19,153	0.12	1.5
5	19,164	0.14	1.8	19,143	0.15	1.8
6	19,162	0.18	2.2	19,142	0.18	2.2
7	19,159	0.21	2.7	19,137	0.21	2.7
8	19,152	0.25	3.2	19,134	0.25	3.2
9	19,146	0.29	3.7	19,128	0.30	3.7
10	19,141	0.34	4.3	19,122	0.34	4.3
11	19,135	0.39	4.9	19,117	0.40	5.0
12	19,128	0.45	5.6	19,113	0.45	5.6
13	19,122	0.50	6.3	19,106	0.51	6.3
14	19,119	0.56	7.1	19,100	0.57	7.1
15	19,114	0.63	7.9	19,088	0.63	7.9
16	19,109	0.69	8.7	19,084	0.70	8.7
17	19,105	0.76	9.5	19,079	0.76	9.5
18	19,100	0.83	10.4	19,072	0.83	10.4
19	19,093	0.90	11.3	19,066	0.91	11.3
20	19,074	0.98	12.2	19,047	0.98	12.2
21	19,065			19,043		
22	19,049			19,035		
23	19,037			19,022		
24	19,031			19,017		
25	19,020			19,005		
26	19,010			18,994		
27	19,002			18,985		
28	18,996			18,981		
29	18,983			18,969		
30	18,977			18,961		
31	18,968			18,955		
Avg	19,094	0.42	5.3	19,075	0.43	5.3
n	31	20	20	31	20	20
SD	69	0.29	3.6	67	0.29	3.6
Min	18,968	0.07	0.8	18,955	0.07	0.8
Max	19,201	0.98	12.2	19,190	0.98	12.2

Table E3. Environmental parameters.

Table E3. Daily means (SD) of environmental parameters at Site CA1B for September, 2007.

Day	House 10				House 12			
	T, °C	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}	T, °C	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}
1		50.7 (5.5)				51.7 (5.7)		
2		50.3 (5.1)				51.0 (4.6)		
3		54.4 (5.1)				54.5 (4.6)		
4		60.0 (4.9)				60.3 (5.1)		
5		60.3 (5.9)				60.4 (6.1)		
6		58.9 (3.8)				59.6 (3.7)		
7		62.4 (3.9)				62.6 (4.0)		
8		66.0 (3.5)				64.9 (3.5)		
9		63.7 (4.0)				62.6 (4.2)		
10		63.6 (3.8)				62.6 (4.0)		
11		61.9 (2.7)				60.7 (2.8)		
12		62.1 (5.1)				61.2 (5.9)		
13		57.0 (9.0)				56.5 (9.3)		
14		60.8 (9.4)				59.9 (10.0)		
15	19.5 (4.3)	64.8 (14.5)	-17.30 (9.33)		19.5 (4.4)	63.8 (15.1)	-11.30 (10.40)	
16	19.9 (4.4)	61.6 (13.7)	-21.40 (0.85)		20.2 (4.3)	59.5 (12.4)	-6.22 (0.53)	
17	21.2 (5.5)	58.2 (14.0)	-20.10 (2.45)		21.5 (5.5)	57.2 (12.9)	-13.80 (6.66)	
18	23.9 (5.8)	53.8 (9.1)	-14.20 (9.59)		24.1 (5.8)	52.8 (8.4)	-14.70 (9.63)	
19	25.3 (2.9)	46.8 (5.2)	-10.70 (11.40)		25.3 (2.8)	47.9 (5.0)	-11.10 (11.20)	
20	24.6 (3.6)	52.5 (5.5)	-8.89 (11.70)		24.9 (3.7)	52.6 (5.9)	-9.14 (11.80)	
21	26.6 (3.0)	57.3 (9.1)	-3.69 (6.79)		27.1 (2.9)	57.8 (9.4)	-3.83 (6.89)	
22	26.4 (2.2)	65.8 (4.4)	-2.72 (5.04)		26.9 (2.1)	66.4 (4.5)	-2.83 (5.19)	
23	26.8 (2.4)	69.0 (7.5)	-3.65 (6.18)		27.2 (2.3)	69.6 (7.5)	-3.69 (6.12)	
24	26.7 (2.8)	67.1 (11.2)	-5.17 (8.26)		27.1 (2.7)	67.8 (11.1)	-5.02 (7.87)	
25	27.0 (3.2)	60.4 (15.2)	-9.07 (11.80)	2.32 (2.68)	27.4 (3.0)	61.1 (15.0)	-8.64 (11.40)	2.34 (2.73)
26	28.0 (3.4)	53.2 (17.2)	-11.50 (12.60)	4.11 (4.72)	33.7 (55.9)	54.0 (17.3)	-10.70 (12.20)	4.09 (4.84)
27	28.1 (2.6)	52.0 (14.0)	-10.50 (11.20)	3.68 (3.82)	28.5 (2.6)	53.1 (13.6)	-9.93 (11.30)	3.52 (3.83)
28	26.5 (1.8)	61.1 (7.2)	-6.23 (9.32)	1.95 (2.47)	26.8 (1.8)	61.3 (7.8)	-6.35 (8.86)	2.13 (2.60)
29	28.0 (2.8)	53.4 (11.7)	-4.74 (7.23)	2.23 (2.76)	30.4 (4.0)	50.3 (13.8)	-5.19 (6.36)	2.22 (2.55)
30	30.2 (1.6)	43.0 (6.3)	-6.79 (7.22)	3.86 (3.54)	32.8 (1.0)	39.0 (3.6)	-7.10 (7.10)	3.93 (3.44)
Mean	25.5	58.4	-9.79	3.02	26.5	58.1	-8.09	3.04
n	16	30	16	6	16	30	16	6
SD	3.0	6.2	5.67	0.87	3.8	6.4	3.51	0.83
Min	19.5	43.0	-21.40	1.95	19.5	39.0	-14.70	2.13
Max	30.2	69.0	-2.72	4.11	33.7	69.6	-2.83	4.09

Table E3. Daily means (SD) of environmental parameters at Site CA1B for October, 2007.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	31.9	(0.9)	48.7	(1.9)	-5.66	(6.52)	3.13	(2.96)	32.5	(0.9)	47.2	(1.5)	-6.79	(6.87)	3.34	(2.98)
2	31.5	(0.7)	45.5	(5.3)	-7.31	(7.12)	4.40	(3.73)	31.8	(0.7)	45.6	(4.6)	-8.06	(7.38)	4.61	(3.81)
3	31.1	(0.8)	42.5	(6.1)	-8.53	(7.25)	5.84	(5.04)	31.5	(0.9)	42.6	(5.4)	-9.01	(7.38)	6.08	(5.07)
4	30.9	(0.8)	46.6	(2.6)	-6.24	(6.49)	3.39	(2.96)	31.4	(0.9)	44.8	(2.9)	-7.04	(6.61)	3.63	(3.00)
5	30.1	(0.5)	49.0	(2.5)	-6.06	(6.59)	3.48	(2.95)	30.7	(0.6)	48.0	(2.9)	-6.33	(6.64)	3.66	(3.07)
6																
7																
8																
9																
10																
11																
12	26.6	(0.3)	62.6	(5.0)	-7.99	(7.72)			27.3	(0.5)	62.1	(4.2)	-10.30	(8.28)		
13	26.5	(0.5)	63.4	(5.9)	-9.84	(6.68)			26.9	(0.6)	62.9	(5.9)	-11.60	(7.56)		
14	26.3	(0.9)	61.7	(7.2)	-13.50	(9.87)	10.40	(6.75)	26.9	(0.8)	60.2	(6.7)	-15.40	(10.40)	10.30	(6.66)
15	25.9	(0.5)	61.2	(5.6)	-10.90	(6.78)	9.16	(5.60)	26.5	(0.5)	60.0	(5.1)	-14.00	(9.34)	9.20	(5.60)
16	25.6	(0.4)	58.3	(6.6)	-11.70	(6.03)	9.14	(4.49)	26.1	(0.4)	57.7	(5.8)	-13.50	(6.59)	9.22	(4.46)
17	25.4	(0.5)	58.7	(7.6)	-11.70	(5.50)	9.74	(4.94)	25.9	(0.6)	58.0	(7.2)	-13.60	(6.44)	9.62	(4.95)
18	25.4	(1.0)	53.7	(9.9)	-19.80	(11.00)	13.70	(7.66)	25.9	(0.9)	53.9	(9.3)	-20.90	(10.70)	13.60	(7.74)
19	25.6	(1.5)	58.0	(7.9)	-20.10	(9.93)	16.50	(8.22)	26.1	(1.5)	57.3	(7.6)	-22.70	(10.10)	16.10	(8.15)
20	24.6	(0.6)	55.6	(9.3)	-17.80	(8.99)	13.00	(6.09)	25.0	(0.7)	56.0	(8.4)	-21.40	(9.31)		
21	24.0	(0.9)	50.6	(9.1)	-18.70	(11.10)	13.30	(7.70)	24.5	(0.8)	51.4	(8.8)	-20.90	(10.90)	13.10	(7.70)
22	24.6	(1.9)	49.2	(11.7)	-15.10	(9.41)	17.30	(10.60)	25.1	(1.9)	50.0	(10.4)	-15.60	(9.46)	17.20	(10.20)
23	24.9	(2.2)	49.0	(8.6)	-15.00	(8.03)	20.20	(11.80)	25.1	(2.5)	50.1	(8.5)	-15.10	(7.88)	20.40	(11.70)
24	24.8	(2.5)	50.8	(7.3)	-14.00	(6.68)	20.30	(9.44)	25.0	(2.5)	51.2	(7.3)	-15.70	(6.32)	22.10	(11.20)
25	24.3	(2.3)	55.2	(5.8)	-14.80	(6.37)	20.40	(9.35)	24.4	(2.3)	55.2	(5.9)	-15.40	(5.71)	20.90	(10.20)
26	23.3	(1.7)	57.1	(6.7)	-15.60	(5.29)	20.90	(9.56)	23.6	(1.9)	55.5	(5.8)	-15.20	(5.79)	18.70	(7.89)
27	23.3	(1.9)	57.3	(7.7)	-16.60	(5.13)	26.00	(11.00)	23.8	(2.0)	57.5	(7.3)	-16.20	(4.79)	26.20	(11.00)
28	23.6	(1.9)	58.1	(5.0)	-18.40	(3.64)	31.40	(9.15)	24.2	(1.9)	57.8	(4.7)	-18.30	(3.50)	31.30	(8.75)
29	22.5	(2.1)	62.4	(5.1)	-18.00	(3.38)	30.80	(9.62)	23.2	(2.1)	60.5	(5.0)	-18.00	(3.57)	30.10	(10.10)
30	21.7	(1.3)	64.5	(4.1)	-17.50	(4.24)			22.2	(1.4)	63.8	(4.0)	-16.70	(3.70)		
31	21.4	(1.6)	66.8	(4.0)	-16.30	(3.54)	21.80	(6.75)	21.8	(1.8)	66.7	(4.2)	-15.90	(3.52)	22.00	(6.58)
Mean	25.8		55.5		-13.50		14.70		26.3		55.0		-14.50		14.80	
n	25		25		25		22		25		25		25		21	
SD	3.0		6.5		4.51		8.37		3.0		6.3		4.55		8.46	
Min	21.4		42.5		-20.10		3.13		21.8		42.6		-22.70		3.34	
Max	31.9		66.8		-5.66		31.40		32.5		66.7		-6.33		31.30	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for November, 2007.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	21.3	(1.9)	66.1	(5.7)	-16.80	(3.14)	22.40	(8.73)	21.7	(2.1)	66.2	(5.9)	-16.30	(2.87)	23.10	(8.55)
2	21.0	(3.0)	64.9	(8.0)	-19.30	(6.01)	33.30	(18.90)	22.2	(2.5)	62.8	(7.3)	-17.60	(4.36)	24.80	(9.63)
3	16.5	(4.5)	61.8	(13.7)	-8.71	(7.83)	20.40	(7.28)	16.5	(5.3)	62.0	(13.9)	-15.90	(8.67)	35.40	(23.80)
4	15.6	(5.2)	59.7	(11.8)	-16.10	(3.06)	19.90	(7.60)	15.9	(5.4)	59.0	(10.1)	-14.60	(6.11)	15.60	(0.45)
5	15.3	(4.8)	61.1	(10.0)	-7.94	(5.90)	24.80	(17.70)	15.8	(5.1)	59.1	(10.0)	-7.40	(5.34)	20.20	(6.75)
6	15.2	(3.7)	67.5	(8.9)	-12.80	(12.70)	20.10	(5.98)	15.5	(3.7)	63.9	(9.2)	-10.80	(11.00)	20.20	(7.18)
7	16.2	(5.7)	62.3	(12.3)	-7.63	(9.10)	18.10	(16.60)	16.5	(5.7)	59.4	(10.4)	-5.86	(8.46)	15.10	(11.60)
8	17.1	(3.4)	67.1	(3.8)	0.54	(0.61)	0.00	(0.00)	17.0	(3.5)	68.0	(4.4)	0.41	(0.46)	0.00	(0.00)
9	19.3	(3.1)	67.4	(3.4)	0.41	(0.32)	0.02	(0.44)	20.1	(3.2)	69.7	(3.4)	0.44	(0.31)	0.00	(0.00)
10	18.3	(2.5)	62.3	(10.4)	-13.70	(10.80)	4.38	(3.52)	18.7	(2.2)	63.9	(11.2)	-14.50	(12.40)	4.20	(3.52)
11	16.3	(2.0)	67.1	(6.3)	-24.70	(2.93)			16.4	(1.9)	68.1	(6.3)	-26.50	(1.87)		
12	16.8	(6.8)	68.9	(3.2)	-13.90	(13.80)	3.54	(3.19)	14.3	(4.8)	64.5	(5.5)	-27.10	(0.91)	7.15	(0.19)
13	22.4	(2.9)	65.1	(4.7)	-2.40	(4.97)	0.84	(1.26)	16.5	(4.3)	66.9	(4.5)	-26.80	(3.86)	7.02	(0.33)
14																
15	23.8	(3.1)	64.5	(3.8)	-2.56	(6.27)	0.80	(1.47)	23.4	(3.0)	69.6	(4.4)	-2.84	(7.01)	0.80	(1.59)
16	23.8	(1.9)	69.8	(3.7)	-2.49	(5.20)	0.83	(1.24)	23.6	(1.9)	73.6	(3.9)	-3.06	(6.53)	0.82	(1.40)
17	23.3	(2.5)	74.1	(4.4)	-2.80	(5.00)	0.92	(1.24)	23.2	(2.5)	77.8	(4.7)	-3.38	(6.32)	0.95	(1.42)
18	23.5	(2.9)	76.1	(5.1)	-3.45	(5.62)	1.06	(1.37)	23.5	(2.9)	79.3	(5.7)	-4.08	(7.02)	1.12	(1.57)
19	23.6	(2.2)	76.8	(4.9)	-4.00	(7.57)	1.16	(1.71)	23.7	(2.2)	80.3	(5.1)	-4.68	(7.46)	1.21	(1.64)
20	21.7	(1.6)	77.4	(3.6)	-3.82	(6.75)	1.22	(1.75)	22.0	(1.7)	79.6	(4.8)	-4.64	(7.66)	1.18	(1.77)
21	21.3	(2.5)	76.2	(5.7)	-4.38	(9.08)	1.35	(2.37)	21.5	(2.5)	76.2	(7.3)	-4.96	(8.57)	1.48	(2.11)
22																
23																
24	32.6	(0.7)	44.9	(1.6)	-5.18	(8.01)	1.87	(2.18)	32.8	(0.7)	44.9	(2.3)	-5.66	(9.54)	1.98	(2.47)
25	31.9	(0.9)	46.8	(2.1)	-3.61	(6.55)	1.94	(2.35)	32.1	(0.8)	48.0	(2.3)	-3.94	(7.57)	1.88	(2.58)
26	30.4	(0.8)	48.9	(3.6)	-3.31	(5.89)	2.17	(2.66)	30.6	(0.9)	50.4	(3.9)	-3.68	(6.66)	2.21	(2.75)
27	29.7	(0.7)	50.1	(3.5)	-3.64	(6.59)	2.56	(3.00)	30.1	(0.7)	51.1	(3.2)	-4.97	(7.12)	2.53	(2.86)
28	29.2	(0.7)	49.7	(4.2)	-4.24	(6.89)	2.60	(3.05)	29.5	(0.8)	50.9	(3.9)	-4.88	(6.96)	2.69	(2.85)
29	28.6	(0.6)	52.0	(4.4)	-4.85	(7.18)	2.91	(3.17)	28.7	(0.8)	52.9	(3.8)	-5.73	(7.59)	2.98	(3.08)
30	28.1	(0.6)	48.5	(4.0)	-4.89	(7.57)	3.10	(3.33)	27.9	(0.6)	50.3	(3.5)	-6.56	(8.08)	3.08	(3.25)
Mean	22.3		62.9		-7.27		7.39		22.2		63.6		-9.09		7.60	
n	27		27		27		26		27		27		27		26	
SD	5.4		9.7		6.26		9.66		5.6		10.2		7.88		9.52	
Min	15.2		44.9		-24.70		0.00		14.3		44.9		-27.10		0.00	
Max	32.6		77.4		0.54		33.30		32.8		80.3		0.44		35.40	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for December, 2007.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	27.4	(0.6)	49.4	(4.0)	-6.02	(7.30)	3.35	(3.25)	27.7	(0.6)	50.6	(3.5)	-6.25	(7.96)	3.40	(3.30)
2	27.1	(0.7)	49.9	(4.0)	-6.83	(7.08)	3.56	(3.12)	27.3	(0.6)	50.9	(3.2)	-7.11	(7.94)	3.69	(3.26)
3	27.0	(0.8)	48.7	(4.2)	-7.35	(6.53)	4.07	(3.00)	27.1	(0.6)	49.7	(3.8)	-8.46	(7.54)	4.32	(3.17)
4	26.8	(0.6)	58.3	(6.2)	-7.04	(6.25)	4.23	(2.90)	26.8	(0.6)	60.2	(6.5)	-8.55	(7.34)	4.07	(3.07)
5	26.7	(0.5)	61.9	(3.4)	-7.22	(6.98)	4.93	(3.97)	26.5	(0.5)	63.2	(3.3)	-8.83	(8.15)	4.99	(4.07)
6	26.5	(0.5)	62.8	(3.2)	-7.92	(8.10)	4.87	(4.42)	26.5	(0.5)	63.2	(2.7)	-8.01	(8.95)	4.84	(4.40)
7	26.4	(0.6)	61.1	(3.8)	-7.56	(7.37)	5.80	(4.47)	26.3	(0.5)	61.6	(3.4)	-9.08	(7.91)	5.62	(4.25)
8	26.0	(0.4)	55.8	(3.3)	-8.35	(7.00)	6.30	(4.38)	25.9	(0.6)	56.9	(2.8)	-9.48	(7.87)	6.09	(4.36)
9	25.5	(0.5)	55.6	(3.5)	-8.10	(7.25)	6.01	(4.42)	25.5	(0.5)	55.5	(3.1)	-9.38	(8.03)	6.00	(4.38)
10	25.0	(0.5)	58.1	(2.6)	-9.13	(7.00)	6.61	(4.30)	25.3	(0.5)	57.6	(2.6)	-10.50	(7.80)	6.55	(4.24)
11																
12	25.4	(0.8)	56.9	(3.1)	-8.61	(7.84)	6.17	(4.69)	25.3	(0.9)	57.8	(3.1)	-9.71	(8.75)	6.18	(4.65)
13	25.5	(0.7)	56.4	(3.4)	-9.05	(6.96)	6.67	(4.36)	25.5	(0.8)	57.6	(2.8)	-10.50	(8.01)	5.89	(4.07)
14	25.5	(0.6)	56.8	(3.5)	-9.64	(6.44)	6.92	(4.04)	25.4	(0.8)	56.8	(2.9)	-11.00	(7.41)	4.90	(2.89)
15	25.3	(0.9)	58.9	(3.1)	-10.20	(6.34)	7.34	(3.91)	25.3	(0.7)	58.2	(2.9)	-12.00	(7.31)	5.27	(2.87)
16	25.0	(0.8)	59.6	(3.1)	-11.00	(5.78)	7.97	(3.67)	25.1	(0.7)	58.9	(2.9)	-12.50	(6.48)	5.63	(2.61)
17	25.2	(0.5)	63.6	(2.2)	-11.30	(6.63)	7.53	(3.88)	25.0	(0.5)	63.5	(2.8)	-12.50	(7.16)	5.36	(2.77)
18	25.1	(0.4)	66.1	(2.3)	-11.40	(7.10)	8.50	(4.95)	25.1	(0.6)	66.7	(2.5)	-12.00	(7.54)	8.06	(5.05)
19	24.7	(0.7)	63.6	(3.1)	-16.70	(9.66)	9.57	(4.65)	24.9	(0.7)	64.3	(2.6)	-16.30	(9.17)	9.94	(4.85)
20	23.9	(0.7)	63.7	(5.1)	-19.30	(9.74)	9.97	(4.44)	23.9	(0.8)	63.9	(4.1)	-19.00	(9.81)	9.93	(4.60)
21	22.9	(0.7)	59.2	(2.4)	-20.90	(11.40)	9.44	(4.53)	22.8	(0.7)	59.7	(2.2)	-19.90	(11.60)	9.63	(4.99)
22	22.6	(0.8)	60.6	(3.4)	-23.10	(12.80)	9.57	(4.63)	22.4	(1.0)	60.7	(3.1)	-21.70	(12.70)	10.00	(5.19)
23	22.3	(0.9)	64.2	(3.4)	-23.50	(13.30)	9.66	(4.77)	22.4	(0.9)	63.2	(3.4)	-22.00	(12.80)	10.10	(5.12)
24	22.2	(1.0)	65.0	(4.1)	-25.40	(12.30)	10.50	(4.51)	22.2	(1.1)	64.1	(3.7)	-24.10	(11.70)	10.00	(4.38)
25	21.5	(0.8)	64.0	(3.6)	-25.40	(11.30)	10.30	(3.87)	21.5	(0.9)	63.2	(3.8)	-23.30	(11.40)	10.60	(4.69)
26	21.4	(0.9)	61.6	(6.1)	-28.00	(10.40)	11.40	(3.67)	21.0	(1.1)	61.8	(5.7)	-26.90	(10.20)	11.00	(3.80)
27	20.8	(0.6)	61.4	(3.8)	-27.40	(11.10)	11.10	(3.74)	20.3	(0.8)	62.3	(3.5)	-26.00	(10.50)	11.70	(4.03)
28	20.8	(0.3)	68.8	(1.7)	-27.80	(10.30)	10.80	(3.38)	20.6	(0.5)	69.1	(2.0)	-25.80	(9.32)	11.60	(3.72)
29	21.7	(0.9)	68.4	(2.5)	-29.80	(8.08)	12.00	(3.26)	21.7	(0.9)	68.5	(2.4)	-28.00	(7.19)	12.40	(2.90)
30	21.8	(0.7)	69.1	(1.6)	-31.90	(4.75)	12.20	(1.49)	21.8	(0.7)	69.7	(1.6)	-29.50	(4.20)	12.60	(1.43)
31	21.2	(0.9)	65.2	(2.3)	-31.10	(5.73)	11.90	(1.82)	19.2	(3.5)	67.9	(11.0)	-15.70	(14.90)	17.50	(22.00)
Mean	24.3		60.5		-15.90		7.97		24.2		60.9		-15.50		7.93	
n	30		30		30		30		30		30		30		30	
SD	2.1		5.2		8.89		2.67		2.3		5.1		7.22		3.35	
Min	20.8		48.7		-31.90		3.35		19.2		49.7		-29.50		3.40	
Max	27.4		69.1		-6.02		12.20		27.7		69.7		-6.25		17.50	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for January, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	18.7	(5.0)	69.5	(3.6)	-29.10	(9.21)	15.00	(11.70)	12.9	(6.3)			-14.40	(10.50)		
2	8.3	(3.7)	78.8	(5.0)	-33.10	(36.20)	12.70	(12.60)	9.8	(5.3)			-6.62	(10.00)		
3	18.5	(8.1)	75.4	(2.4)	-22.20	(32.20)	5.39	(5.71)	17.0	(5.1)			-2.80	(7.69)		
4	23.1	(1.3)	72.5	(3.9)	-5.18	(8.49)	1.03	(1.90)	22.0	(1.1)	72.3	(2.2)	-4.42	(9.25)	1.06	(2.00)
5	21.4	(0.9)	77.1	(1.9)	-2.30	(6.18)	0.79	(1.57)	21.2	(0.5)	75.4	(1.0)	-2.72	(7.10)	0.80	(1.59)
6	21.3	(1.1)	78.1	(2.2)	-2.24	(6.01)	0.80	(1.39)	21.4	(1.2)	74.5	(2.0)	-2.37	(6.38)	0.82	(1.40)
7	20.9	(1.5)	79.3	(2.8)	-2.31	(4.94)	0.84	(1.21)	21.3	(1.5)	73.0	(2.9)	-2.90	(5.46)	0.84	(1.20)
8	19.5	(0.4)	83.5	(1.0)	-2.40	(4.36)	0.84	(1.08)	19.9	(0.2)	78.1	(1.5)	-2.71	(4.96)	0.86	(1.09)
9	20.8	(0.8)	85.7	(0.8)	-2.59	(5.40)	0.82	(1.24)	21.0	(0.8)	84.0	(1.3)	-3.04	(6.07)	0.82	(1.23)
10	21.4	(0.5)	87.5	(0.7)	-2.78	(5.65)	0.94	(1.33)	21.6	(0.4)			-3.24	(6.35)		
11	21.4	(0.6)	89.2	(0.6)	-3.22	(5.54)	1.06	(1.41)	21.8	(0.6)	88.1	(0.6)	-4.01	(6.68)	1.07	(1.42)
12	21.8	(1.2)	87.4	(2.9)	-3.74	(7.41)	1.24	(1.95)	22.6	(1.3)	87.0	(2.6)	-4.82	(9.18)	1.19	(1.83)
13	22.2	(1.3)	86.6	(2.7)	-3.96	(8.64)	1.42	(2.39)	22.6	(1.3)	86.3	(2.9)	-4.98	(10.70)	1.38	(2.34)
14	26.0	(5.6)	74.8	(13.0)	-5.34	(8.53)	1.91	(2.41)	25.6	(5.0)	76.3	(10.8)	-6.39	(10.10)	1.84	(2.34)
15	31.5	(0.6)	59.9	(1.6)	-4.70	(8.56)	1.76	(2.25)	31.1	(0.9)	61.6	(3.6)	-5.58	(9.62)	1.68	(2.14)
16	31.9	(0.5)	55.1	(1.9)	-5.20	(9.41)	1.96	(2.59)	32.0	(0.4)	55.9	(1.3)	-5.45	(10.60)	1.74	(2.53)
17	31.3	(0.9)	50.9	(2.9)	-6.62	(12.00)	2.24	(2.98)	31.3	(0.7)	50.6	(4.6)	-6.28	(13.30)	2.09	(3.34)
18	30.4	(0.8)	55.0	(3.1)	-7.55	(12.50)	2.41	(3.12)	30.4	(0.7)	50.7	(2.7)	-7.20	(12.80)	2.49	(3.46)
19	29.3	(0.8)	57.8	(3.4)	-8.93	(12.90)	2.72	(3.10)	29.5	(0.7)	52.4	(2.6)	-8.61	(12.30)	2.91	(3.32)
20	28.8	(0.6)	59.4	(2.2)	-8.14	(12.30)	2.47	(3.06)	29.1	(0.6)	53.6	(2.2)	-8.10	(11.80)	2.65	(3.30)
21	28.4	(0.5)	62.3	(2.6)	-8.37	(13.80)	2.48	(3.14)	28.7	(0.6)	55.8	(2.6)	-8.05	(13.10)	2.68	(3.44)
22	28.1	(0.5)	62.6	(2.0)	-10.40	(15.30)	2.87	(3.55)	28.4	(0.7)	56.9	(2.7)	-10.30	(14.60)	2.97	(3.74)
23	27.8	(0.4)	63.6	(2.4)	-11.90	(16.40)	3.08	(3.77)	27.9	(0.5)	57.2	(2.6)	-11.30	(15.70)	3.34	(4.09)
24	28.0	(0.5)	61.6	(2.5)	-13.00	(17.70)	3.13	(3.83)	28.2	(0.5)	54.9	(2.8)	-12.30	(17.10)	3.37	(4.12)
25	28.2	(0.4)	58.6	(2.1)	-12.30	(15.00)	3.76	(3.73)	28.1	(0.4)	55.1	(2.2)	-13.70	(16.10)	3.83	(3.78)
26	28.2	(0.4)	55.8	(2.5)	-10.70	(11.30)	4.17	(3.70)	28.4	(0.4)	53.8	(2.3)	-14.10	(14.60)	4.11	(3.62)
27	28.1	(0.4)	61.1	(2.3)	-10.50	(11.60)	4.21	(3.79)	28.2	(0.5)	58.8	(2.0)	-14.00	(14.80)	4.15	(3.71)
28	27.5	(0.5)	57.8	(3.2)	-14.70	(16.80)	4.72	(4.74)	27.6	(0.5)	56.3	(2.6)	-14.70	(17.00)	4.54	(4.82)
29	27.1	(0.5)	59.0	(2.9)	-14.90	(19.30)	4.61	(5.30)	27.5	(0.5)	57.4	(2.9)	-13.10	(18.30)	4.57	(5.58)
30	26.9	(0.6)	58.6	(2.9)	-16.50	(19.50)	5.03	(5.22)	26.8	(0.6)	58.1	(2.4)	-15.50	(18.80)	5.12	(5.55)
31	26.7	(0.6)	62.0	(2.7)	-16.00	(20.10)	4.79	(5.26)	26.5	(0.5)	60.3	(2.4)	-15.00	(19.00)	5.12	(5.62)
Mean	24.9		68.6		-9.70		3.27		24.9		64.6		-8.02		2.52	
n	31		31		31		31		31		27		31		27	
SD	5.0		11.7		7.56		3.14		5.3		12.2		4.45		1.42	
Min	8.3		50.9		-33.10		0.79		9.8		50.6		-15.50		0.80	
Max	31.9		89.2		-2.24		15.00		32.0		88.1		-2.37		5.12	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for February, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	26.2	(0.6)	61.7	(2.9)	-16.70	(18.70)	5.66	(5.44)	25.9	(0.5)	60.6	(2.2)	-16.30	(18.20)	5.90	(5.78)
2																
3																
4																
5	25.5	(0.5)	56.3	(3.9)	-21.30	(15.60)	7.73	(4.86)	24.9	(0.7)	56.9	(3.9)	-20.10	(14.70)	8.25	(5.27)
6	25.1	(0.5)	58.4	(2.2)	-23.20	(14.30)	9.06	(4.89)	24.6	(0.6)	59.7	(2.5)	-21.70	(13.70)	9.28	(5.31)
7	24.8	(0.5)	58.2	(2.8)	-23.50	(13.40)	9.51	(4.76)	24.7	(0.7)	59.8	(3.2)	-21.20	(13.40)	9.55	(5.44)
8	24.5	(0.4)	59.6	(2.8)	-23.30	(12.70)	9.47	(4.48)	24.3	(0.6)	60.4	(3.0)	-21.80	(12.60)	9.78	(4.93)
9	24.3	(0.4)	61.5	(3.3)	-24.40	(12.50)	10.90	(5.49)	24.5	(0.8)	61.2	(3.5)	-22.70	(11.80)	10.80	(5.19)
10	24.3	(0.8)	62.0	(3.9)	-26.20	(12.50)	11.80	(5.69)	24.4	(1.1)	62.3	(4.2)	-23.80	(11.00)	12.00	(5.59)
11	23.9	(0.8)	62.0	(3.6)	-27.90	(12.80)	12.40	(5.80)	23.7	(1.1)	61.9	(4.4)	-25.70	(10.80)	13.00	(5.63)
12	23.0	(1.1)	62.9	(4.5)	-25.50	(9.67)	14.90	(6.98)	22.9	(1.2)	63.2	(4.6)	-23.90	(7.93)	15.30	(6.70)
13	21.9	(0.4)	58.1	(9.5)	-22.50	(7.35)	13.90	(4.67)	22.1	(0.9)	58.5	(8.8)	-22.00	(7.94)	13.00	(4.58)
14	21.2	(0.5)	48.3	(4.1)	-13.50	(8.41)	13.70	(5.15)	21.3	(0.9)	49.9	(3.9)	-13.90	(6.99)	12.80	(5.31)
15	20.5	(0.6)	54.6	(5.7)	-21.40	(8.13)	14.20	(5.43)	20.7	(0.7)	55.4	(6.1)	-20.10	(8.30)	13.80	(5.73)
16	21.0	(1.2)	56.2	(7.2)	-24.90	(8.19)	15.80	(6.00)	21.1	(1.3)	57.2	(7.4)	-23.30	(7.66)	16.10	(6.46)
17	21.1	(1.3)	59.9	(6.8)	-25.20	(7.98)	16.10	(5.96)	21.1	(1.3)	60.1	(6.8)	-23.60	(7.19)	16.30	(6.21)
18	21.3	(1.1)	66.3	(5.0)	-25.30	(7.17)	15.80	(5.50)	21.4	(1.2)	65.1	(4.7)	-23.90	(6.20)	15.90	(5.61)
19	20.8	(0.4)	70.1	(2.8)	-25.10	(4.68)	14.60	(3.24)	20.9	(0.5)	69.4	(3.0)	-23.20	(4.05)	14.50	(2.91)
20	20.7	(1.3)	68.4	(6.0)	-27.60	(3.22)	16.50	(4.04)	20.9	(1.1)	68.6	(5.6)	-25.30	(2.91)	16.50	(3.57)
21	13.4	(2.1)	77.5	(4.4)	-14.20	(9.14)	27.60	(20.20)	19.4	(2.5)	71.6	(3.1)	-24.60	(6.70)	18.40	(15.60)
22	12.0	(1.9)	80.1	(2.9)	-8.65	(6.06)	23.10	(6.90)	13.5	(3.9)	84.3	(4.2)	-5.30	(6.67)	20.50	(19.80)
23	9.7	(2.4)	79.4	(4.5)	-7.80	(4.80)	19.70	(4.26)	9.8	(2.2)	81.4	(5.2)	-11.10	(6.68)	21.60	(6.96)
24	12.3	(1.5)	81.0	(3.6)	-7.05	(1.09)	16.50	(0.11)	12.2	(1.5)	81.7	(3.3)	-11.10	(3.35)	19.60	(3.42)
25	12.6	(3.9)	76.6	(7.7)	-25.40	(14.10)	12.80	(2.99)	12.7	(4.0)	76.2	(8.5)	-24.00	(12.30)	13.30	(2.94)
26	17.2	(8.8)	79.8	(2.0)	-16.30	(17.90)	5.32	(5.66)	16.9	(8.4)	79.1	(2.8)	-14.50	(15.20)	5.91	(6.16)
27	25.2	(2.5)	75.6	(5.2)	-3.25	(8.85)	0.94	(1.77)	24.3	(2.7)	78.6	(5.6)	-3.43	(8.74)	0.96	(1.78)
28	25.2	(2.8)	69.6	(7.6)	-5.77	(11.40)	1.35	(2.04)	24.5	(3.0)	72.1	(8.5)	-6.05	(11.20)	1.43	(2.07)
29	25.4	(2.9)	68.6	(7.6)	-7.49	(11.40)	1.62	(1.98)	25.3	(2.9)	68.7	(8.4)	-8.58	(12.70)	1.75	(2.22)
Mean	20.9		65.9		-19.00		12.40		21.1		66.3		-18.50		12.20	
n	26		26		26		26		26		26		26		26	
SD	4.8		9.1		7.71		6.23		4.4		9.1		6.77		5.57	
Min	9.7		48.3		-27.90		0.94		9.8		49.9		-25.70		0.96	
Max	26.2		81.0		-3.25		27.60		25.9		84.3		-3.43		21.60	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for March, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	24.0	(1.1)	70.4	(4.5)	-5.32	(6.99)	1.24	(1.52)	26.1	(0.5)	64.7	(4.0)	-6.57	(11.40)	1.04	(2.03)
2	24.3	(1.7)	65.0	(5.7)	-8.74	(12.70)	1.79	(2.35)	26.2	(0.8)	59.4	(3.7)	-9.11	(14.40)	1.71	(2.60)
3	24.4	(2.0)	62.0	(8.2)	-12.60	(15.00)	2.53	(2.61)	25.9	(0.9)	57.8	(6.2)	-13.30	(15.50)	2.60	(2.64)
4	24.5	(1.9)	65.5	(7.6)	-8.41	(11.00)	2.12	(2.34)	25.8	(1.0)	61.1	(6.0)	-9.50	(11.70)	2.26	(2.39)
5	26.1	(3.0)	63.5	(8.5)	-6.58	(9.62)	1.83	(2.16)	28.4	(3.1)	56.1	(9.0)	-7.81	(10.80)	2.04	(2.34)
6	28.7	(0.3)	59.4	(3.1)	-8.44	(11.50)	2.18	(2.46)	31.3	(0.5)	52.1	(2.9)	-9.04	(11.70)	2.37	(2.51)
7	30.1	(1.3)	56.2	(4.5)	-10.20	(12.90)	2.50	(2.63)	31.0	(0.5)	52.5	(3.0)	-10.10	(12.90)	2.52	(2.72)
8	30.8	(0.8)	50.7	(4.2)	-9.90	(13.30)	2.79	(3.10)	31.0	(0.6)	47.9	(5.3)	-10.30	(14.00)	2.92	(3.55)
9	30.4	(0.6)	50.1	(2.6)	-10.40	(13.20)	3.16	(3.26)	30.6	(0.6)	46.5	(2.3)	-10.20	(13.80)	3.29	(3.69)
10	30.0	(0.6)	52.7	(4.6)	-14.70	(14.70)	4.18	(3.59)	30.4	(0.6)	48.8	(4.7)	-14.20	(14.50)	4.43	(4.02)
11	29.5	(0.6)	57.6	(2.6)	-11.40	(14.00)	3.38	(3.53)	29.9	(0.7)	52.6	(2.1)	-10.90	(13.30)	3.55	(3.79)
12	29.2	(0.7)	56.7	(3.0)	-13.10	(15.50)	3.62	(3.79)	29.3	(0.5)	52.2	(2.5)	-12.20	(14.40)	3.83	(4.10)
13	28.8	(0.5)	59.3	(4.3)	-14.10	(14.30)	3.95	(3.53)	28.9	(0.6)	56.5	(3.5)	-13.30	(13.80)	4.07	(3.80)
14	28.5	(0.6)	55.3	(3.1)	-13.90	(14.80)	3.80	(3.51)	28.5	(0.5)	51.5	(2.5)	-12.50	(14.00)	3.91	(3.86)
15	28.2	(0.7)	53.9	(2.9)	-14.10	(15.10)	3.91	(3.61)	28.2	(0.5)	50.3	(2.0)	-13.10	(14.60)	4.10	(4.05)
16	28.0	(0.6)	48.8	(3.4)	-12.80	(13.30)	4.18	(3.95)	28.0	(0.7)	45.7	(2.8)	-15.70	(13.50)	4.32	(4.06)
17	28.0	(0.5)	49.3	(5.2)	-17.20	(14.70)	4.96	(3.56)	27.9	(0.5)	46.1	(4.2)	-16.80	(14.20)	5.18	(3.81)
18	28.1	(0.5)	54.5	(5.4)	-22.40	(15.30)	6.61	(4.45)	27.9	(0.6)	52.2	(4.1)	-20.90	(14.80)	6.81	(4.59)
19	28.1	(0.5)	56.7	(5.9)	-18.30	(15.90)	6.25	(5.20)	27.9	(0.5)	55.1	(3.8)	-17.30	(14.50)	6.37	(4.85)
20	28.2	(0.6)	54.3	(5.9)	-14.10	(16.50)	5.61	(5.87)	27.9	(0.5)	53.2	(4.2)	-13.50	(13.50)	5.63	(4.93)
21	28.0	(0.6)	52.9	(4.6)	-14.60	(16.60)	5.68	(5.86)	27.6	(0.6)	52.4	(3.3)	-14.30	(13.50)	5.81	(4.91)
22	27.7	(0.9)	51.2	(6.8)	-15.30	(14.60)	7.15	(5.95)	27.5	(0.8)	51.3	(4.9)	-14.70	(12.40)	7.37	(5.47)
23	27.7	(1.0)	49.8	(7.8)	-17.00	(13.60)	9.25	(6.99)	27.4	(1.1)	50.2	(6.6)	-16.20	(12.70)	9.21	(6.86)
24																
25	26.8	(0.6)	56.5	(6.1)	-16.50	(13.20)	8.84	(6.53)	26.2	(0.8)	57.4	(5.4)	-16.20	(12.80)	8.81	(6.49)
26	26.1	(0.7)	54.4	(6.2)	-17.00	(12.70)	8.41	(5.71)	25.5	(0.8)	55.8	(5.0)	-17.10	(12.50)	8.36	(5.62)
27																
28	25.5	(0.6)	52.1	(8.4)	-19.60	(12.00)	10.20	(5.86)	25.2	(0.8)	53.9	(7.8)	-18.90	(11.10)	10.40	(5.77)
29	25.0	(0.6)	60.2	(4.3)	-21.20	(10.20)	10.30	(4.40)	24.7	(0.7)	62.3	(3.7)	-20.50	(9.77)	10.40	(4.51)
30	24.2	(0.6)	51.2	(6.0)	-21.60	(10.70)	11.20	(5.37)	23.9	(0.8)	53.5	(5.5)	-20.90	(10.40)	11.30	(5.41)
31	23.6	(0.7)	51.2	(6.6)	-19.70	(10.60)	12.60	(6.73)	23.4	(0.8)	52.6	(6.1)	-19.00	(10.40)	12.90	(7.10)
Mean	27.3		55.9		-14.10		5.32		27.7		53.5		-13.90		5.43	
n	29		29		29		29		29		29		29		29	
SD	2.1		5.4		4.45		3.13		2.1		4.6		3.95		3.14	
Min	23.6		48.8		-22.40		1.24		23.4		45.7		-20.90		1.04	
Max	30.8		70.4		-5.32		12.60		31.3		64.7		-6.57		12.90	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for April, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	23.9	(1.2)	48.7	(9.1)	-20.60	(10.50)	15.10	(8.00)	23.7	(1.5)	50.4	(8.8)	-19.80	(10.30)	15.20	(8.50)
2	23.3	(0.8)	53.4	(6.2)	-21.80	(8.83)	15.60	(6.62)	23.0	(1.1)	54.9	(6.3)	-20.90	(8.66)	15.90	(7.02)
3	23.5	(1.9)	53.1	(8.5)	-18.50	(7.57)	19.00	(8.53)	23.4	(2.2)	54.6	(8.2)	-17.40	(7.27)	19.00	(8.66)
4	22.8	(2.0)	49.9	(9.1)	-14.80	(3.87)	20.20	(8.28)	22.9	(2.2)	52.5	(9.3)	-14.70	(4.43)	19.90	(8.13)
5	21.7	(1.5)	52.7	(5.6)	-14.10	(2.98)	19.70	(7.42)	22.1	(1.7)	55.8	(6.8)	-14.20	(2.88)	19.50	(6.93)
6																
7																
8																
9																
10																
11																
12	23.5	(2.9)	57.0	(6.9)	-24.00	(11.40)	36.90	(16.30)	23.7	(3.0)	56.6	(7.1)	-24.70	(12.10)	38.40	(17.70)
13	23.8	(2.7)	53.4	(4.5)	-26.20	(11.80)	40.20	(15.30)	23.9	(2.8)	53.1	(5.1)	-26.00	(12.50)	41.20	(16.60)
14	21.6	(2.3)	51.7	(8.7)	-15.50	(2.97)	25.60	(8.22)	20.9	(3.7)	52.3	(9.4)	-16.50	(3.63)	28.20	(11.40)
15	15.8	(4.3)	57.9	(8.2)	-5.65	(6.91)	15.10	(16.90)	13.8	(5.2)	58.2	(11.3)	-6.37	(7.83)	16.90	(20.30)
16	16.4	(4.6)	52.0	(15.4)	-2.46	(3.10)	15.10	(14.40)	15.8	(4.6)			-2.44	(5.40)		
17	19.0	(5.3)	51.4	(15.4)	-13.40	(12.60)	17.30	(11.70)	18.9	(4.9)			-13.70	(13.50)		
18	19.9	(6.5)	50.2	(12.2)	-17.30	(13.00)	20.20	(19.60)	19.2	(6.5)			-13.70	(9.10)		
19	14.4	(5.1)	49.6	(11.5)	-20.10	(12.70)	7.11	(2.02)	14.0	(5.3)			-21.10	(8.31)		
20	12.5	(5.3)	47.2	(11.1)	-16.40	(14.90)	4.41	(3.25)	13.7	(6.4)	49.4	(7.3)	-8.89	(11.40)	1.65	(2.67)
21	16.3	(5.3)	45.6	(10.2)	-15.30	(13.60)	5.71	(4.69)	16.1	(4.9)	48.8	(8.5)	-14.20	(15.70)	3.62	(3.25)
22	20.5	(4.2)	52.4	(5.6)	-6.07	(9.66)	2.54	(3.85)	21.1	(4.2)	54.7	(5.7)	-6.67	(9.89)	2.06	(2.89)
23	22.2	(2.8)	59.4	(7.4)	-3.43	(6.47)	1.01	(1.68)	22.5	(2.9)	61.0	(7.5)	-4.10	(7.20)	0.97	(1.63)
24	21.3	(3.6)	60.2	(8.9)	-3.53	(4.71)	1.03	(1.32)	21.3	(3.6)	61.8	(10.0)	-4.86	(5.75)	1.00	(1.29)
25	23.9	(4.2)	56.9	(12.4)	-6.72	(11.10)	1.70	(2.39)	23.9	(4.2)	57.8	(14.4)	-8.30	(12.30)	1.80	(2.39)
26	26.3	(4.1)	53.9	(13.0)	-13.00	(14.60)	3.14	(3.20)	26.3	(4.2)	53.9	(13.8)	-14.80	(16.10)	3.57	(3.83)
27	28.2	(4.4)	49.7	(13.5)	-18.20	(16.10)	5.07	(4.51)	28.2	(4.6)	49.8	(13.9)	-19.40	(16.30)	5.32	(4.55)
28	27.1	(3.2)	50.4	(10.9)	-14.50	(13.30)	4.39	(3.99)	27.1	(3.5)	50.1	(11.0)	-15.80	(13.80)	4.37	(3.77)
29	24.4	(2.7)	56.8	(8.7)	-8.18	(9.51)	2.21	(2.63)	24.4	(2.9)	55.4	(9.5)	-9.66	(10.10)	2.26	(2.50)
30	27.1	(5.2)	52.1	(13.4)	-7.11	(8.49)	2.03	(2.47)	26.7	(5.3)	49.9	(14.1)	-8.97	(9.12)	1.92	(2.36)
Mean	21.6		52.7		-13.60		12.50		21.5		54.1		-13.60		12.10	
n	24		24		24		24		24		20		24		20	
SD	4.1		3.7		6.68		10.90		4.2		3.7		6.35		12.30	
Min	12.5		45.6		-26.20		1.01		13.7		48.8		-26.00		0.97	
Max	28.2		60.2		-2.46		40.20		28.2		61.8		-2.44		41.20	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for May, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	30.9	(0.9)	39.9	(5.9)	-5.16	(7.94)	3.00	(3.83)	30.8	(0.7)	38.5	(5.6)	-5.55	(8.04)	3.16	(4.06)
2	30.4	(0.6)	40.4	(6.1)	-5.92	(8.04)	4.35	(4.85)	30.4	(0.5)	39.6	(5.8)	-5.67	(7.73)	4.35	(4.93)
3	29.8	(0.7)	48.4	(5.6)	-5.57	(7.39)	4.12	(4.42)	30.1	(0.6)	46.8	(4.4)	-5.27	(7.03)	4.18	(4.55)
4	29.3	(0.6)	49.7	(6.9)	-7.11	(7.52)	5.93	(5.89)	29.6	(0.5)	48.2	(4.9)	-6.86	(7.17)	5.88	(5.83)
5	29.1	(0.6)	49.2	(7.1)	-8.06	(7.74)	7.22	(6.42)	29.3	(0.6)	48.7	(5.6)	-7.80	(7.59)	7.25	(6.59)
6	29.0	(0.6)	51.9	(6.1)	-8.77	(8.43)	7.67	(7.22)	29.2	(0.6)	51.9	(4.9)	-8.18	(7.93)	7.36	(6.72)
7	28.3	(0.7)	52.3	(4.6)	-7.19	(7.09)	5.12	(4.36)	28.3	(0.5)	51.7	(3.4)	-7.04	(6.73)	5.36	(4.63)
8	28.2	(0.7)	47.5	(7.6)	-11.00	(8.20)	10.10	(8.34)	28.4	(0.8)	47.2	(6.4)	-10.60	(7.65)	10.00	(7.86)
9	28.0	(0.5)	48.1	(6.0)	-9.14	(7.26)	7.67	(5.83)	28.1	(0.7)	47.7	(4.7)	-8.90	(6.85)	7.52	(5.39)
10	28.5	(1.0)	46.1	(7.8)	-12.70	(9.27)	11.80	(9.60)	28.6	(1.2)	45.9	(6.5)	-11.90	(8.65)	11.70	(9.48)
11	28.2	(0.6)	49.5	(6.3)	-11.30	(8.67)	10.40	(8.89)	28.2	(0.8)	50.1	(5.6)	-10.70	(8.35)	10.20	(8.55)
12	28.0	(0.5)	45.3	(8.3)	-9.91	(6.53)	7.47	(5.00)	28.1	(0.8)	46.6	(6.2)	-9.66	(6.35)	7.20	(4.84)
13	28.7	(1.3)	40.5	(11.5)	-11.50	(7.70)	16.20	(13.80)	28.6	(1.6)	41.3	(10.5)	-11.90	(7.95)	16.60	(14.20)
14	29.0	(1.3)	47.3	(5.4)	-12.30	(7.71)	20.20	(15.10)	28.9	(1.7)	47.7	(5.3)	-13.00	(7.89)	20.80	(15.70)
15	29.2	(1.5)	53.7	(5.0)	-14.70	(7.49)	23.90	(15.70)	29.4	(2.1)	53.8	(6.2)	-14.70	(7.47)	23.70	(15.80)
16																
17																
18																
19																
20	27.0	(1.7)	50.1	(7.8)	-15.20	(7.69)	22.40	(15.50)	27.0	(2.0)	51.3	(8.0)	-14.70	(7.39)	22.30	(15.30)
21	25.6	(1.3)	44.9	(9.0)	-14.60	(7.46)	18.30	(11.10)	25.6	(1.7)	46.8	(8.8)	-14.70	(7.17)	18.70	(11.30)
22	25.4	(1.2)	40.0	(6.6)	-15.10	(7.14)	19.80	(10.50)	25.4	(1.6)	41.2	(5.9)	-14.90	(6.19)	20.30	(11.10)
23	25.1	(1.3)	48.1	(6.7)	-15.40	(6.52)	19.80	(10.20)	25.0	(1.6)	49.2	(6.7)	-14.60	(6.67)	20.00	(10.20)
24	23.7	(0.5)	62.1	(3.4)	-13.20	(4.78)	12.60	(3.88)	23.3	(0.6)	63.7	(3.4)	-11.70	(4.40)	12.90	(4.00)
25	23.7	(0.7)	60.1	(6.7)	-16.30	(5.59)	17.10	(7.44)	23.5	(1.0)	61.8	(6.9)	-14.60	(5.17)	17.20	(7.44)
26	24.0	(1.4)	54.8	(6.8)	-15.10	(5.38)	21.60	(10.30)	23.9	(1.8)	56.4	(7.1)	-14.30	(5.54)	21.50	(10.20)
27	23.4	(1.3)	56.6	(6.5)	-16.20	(5.14)	22.10	(10.00)	23.5	(1.6)	58.5	(7.1)	-15.50	(5.65)	22.20	(10.20)
28	23.4	(1.6)	54.5	(7.3)	-16.70	(5.14)	24.40	(11.60)	23.6	(1.9)	56.3	(7.9)	-15.50	(5.27)	24.50	(11.70)
29	23.3	(2.1)	53.8	(8.9)	-19.70	(8.09)	28.30	(14.40)	23.6	(2.2)	55.1	(9.5)	-18.00	(7.02)	29.40	(15.60)
30	23.6	(2.2)	55.4	(8.3)	-22.90	(8.40)	32.10	(14.70)	23.8	(2.5)	56.6	(8.9)	-20.40	(7.03)	33.60	(16.20)
31	23.0	(2.1)	57.9	(7.1)	-21.90	(8.24)	31.10	(14.30)	23.3	(2.2)	58.6	(7.4)	-19.80	(6.98)	32.40	(15.60)
Mean	26.9		49.9		-12.70		15.40		26.9		50.4		-12.10		15.60	
n	27		27		27		27		27		27		27		27	
SD	2.5		5.9		4.68		8.55		2.6		6.4		4.17		8.85	
Min	23.0		39.9		-22.90		3.00		23.3		38.5		-20.40		3.16	
Max	30.9		62.1		-5.16		32.10		30.8		63.7		-5.27		33.60	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for June, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	23.2	(2.4)	55.4	(7.6)	-25.90	(12.10)	34.40	(17.50)	23.4	(2.3)	56.6	(7.6)	-24.00	(12.20)	35.30	(18.20)
2	23.1	(2.6)	55.5	(6.1)	-26.40	(12.70)	35.30	(17.60)	23.2	(2.4)	57.0	(6.2)	-24.50	(12.70)	36.20	(18.40)
3	23.3	(2.2)	58.2	(2.9)	-26.90	(13.00)	38.00	(16.10)	23.6	(2.3)	58.7	(3.0)	-25.20	(12.90)	39.10	(16.70)
4	23.1	(2.2)	48.9	(12.1)	-26.20	(12.30)	36.40	(15.80)	23.5	(2.3)	50.1	(11.5)	-24.00	(11.90)	37.20	(16.70)
5	23.5	(2.5)	53.5	(8.4)	-28.90	(13.60)	39.10	(16.20)	23.5	(2.5)	55.2	(7.7)	-27.30	(13.80)	40.10	(16.60)
6	22.1	(3.3)	49.7	(9.6)	-15.80	(14.10)	28.20	(17.50)	22.6	(2.9)	52.1	(10.0)	-26.30	(12.90)	42.90	(19.30)
7	20.3	(5.9)	54.3	(14.9)	-1.67	(3.16)	5.48	(10.80)	20.1	(6.2)	53.8	(15.9)	-6.51	(11.10)	17.60	(30.30)
8	26.1	(5.7)	49.7	(10.8)	0.58	(0.35)	0.00	(0.00)	26.3	(5.7)	49.7	(11.2)	0.52	(0.40)	0.00	(0.00)
9	28.6	(5.4)	47.0	(9.6)	0.63	(0.35)	0.00	(0.00)	28.5	(5.4)	46.8	(10.1)	0.55	(0.39)	0.00	(0.00)
10	25.1	(3.5)	36.7	(14.4)	-1.71	(2.71)	8.73	(8.28)	24.7	(3.7)	37.3	(14.5)	-13.70	(11.90)	43.60	(33.20)
11	23.7	(5.8)	34.1	(8.2)	-14.50	(13.90)	13.00	(5.16)	23.7	(6.0)	34.0	(9.2)	-25.80	(12.40)	31.10	(26.00)
12	26.1	(7.1)	37.7	(9.5)	-15.50	(13.50)	9.12	(9.44)	26.1	(7.2)	38.4	(9.5)	-15.00	(15.40)	6.41	(5.15)
13	29.7	(5.3)	35.4	(6.7)	-7.08	(6.90)	5.45	(4.68)	29.9	(5.4)	35.6	(6.7)	-7.70	(7.95)	5.84	(5.36)
14	30.0	(3.8)	39.3	(5.9)	-8.83	(9.69)	4.20	(4.25)	30.5	(3.5)	39.5	(5.5)	-9.88	(11.20)	4.23	(4.38)
15	29.6	(4.0)	41.9	(8.1)	-8.99	(9.51)	4.44	(4.42)	30.1	(3.8)	42.6	(8.2)	-10.00	(10.80)	4.48	(4.57)
16	29.0	(4.0)	42.3	(8.2)	-9.98	(9.72)	4.34	(4.00)	29.4	(3.8)	43.2	(8.2)	-11.50	(11.60)	4.39	(4.13)
17	29.2	(3.6)	44.5	(9.3)	-7.65	(7.48)	5.50	(5.76)	29.2	(3.7)	45.3	(9.4)	-7.74	(7.93)	5.50	(5.82)
18	29.7	(3.2)	37.5	(10.2)	-7.50	(7.03)	6.62	(6.37)	29.8	(3.2)	38.3	(10.4)	-7.62	(6.96)	6.69	(6.37)
19	30.2	(3.5)	38.6	(8.5)	-8.33	(7.64)	7.28	(6.40)	30.4	(3.5)	39.3	(8.8)	-7.99	(7.03)	7.33	(6.40)
20	31.2	(3.3)	37.9	(8.3)	-6.56	(6.03)	11.60	(9.34)	31.3	(3.4)	38.8	(8.6)	-6.34	(5.83)	11.40	(9.33)
21	31.4	(2.5)	38.9	(6.7)	-6.53	(5.59)	12.00	(9.85)	31.5	(2.6)	40.0	(7.1)	-6.05	(5.22)	11.50	(9.60)
22	30.2	(2.7)	35.7	(6.7)	-6.79	(6.38)	9.76	(9.02)	30.3	(2.8)	36.6	(7.1)	-6.20	(5.79)	9.62	(9.04)
23	29.8	(2.8)	40.4	(5.3)	-7.27	(6.91)	7.47	(7.33)	29.8	(2.8)	41.0	(5.4)	-6.65	(6.26)	7.44	(7.37)
24	30.9	(1.1)	41.0	(3.2)	-8.49	(8.17)	10.80	(10.60)	30.9	(1.2)	41.6	(3.1)	-7.94	(7.72)	11.00	(10.60)
25	30.3	(1.1)	43.8	(3.4)	-7.78	(8.11)	9.47	(9.02)	30.3	(1.1)	44.5	(3.2)	-7.21	(7.85)	9.62	(9.29)
26	30.2	(1.2)	47.7	(4.0)	-7.61	(7.05)	10.70	(9.50)	30.2	(1.3)	48.3	(3.7)	-7.58	(7.29)	10.80	(9.58)
27	30.3	(1.7)	48.7	(4.8)	-9.96	(7.23)	16.00	(14.60)	30.4	(1.8)	49.0	(4.6)	-9.77	(7.03)	16.10	(14.60)
28	29.6	(1.6)	46.6	(6.0)	-9.32	(8.04)	13.40	(13.10)	29.7	(1.6)	46.8	(5.4)	-9.23	(7.58)	13.70	(13.00)
29	29.5	(1.7)	44.7	(6.4)	-9.89	(7.22)	15.60	(14.00)	29.7	(1.7)	45.0	(5.8)	-10.10	(7.40)	15.70	(13.90)
30	29.4	(1.6)	47.8	(4.5)	-9.95	(7.06)	15.60	(13.50)	29.4	(1.7)	48.2	(4.3)	-10.50	(7.41)	15.80	(13.40)
Mean	27.6		44.5		-11.00		13.90		27.7		45.1		-12.00		16.70	
n	30		30		30		30		30		30		30		30	
SD	3.3		6.7		8.00		11.50		3.3		6.8		7.94		13.80	
Min	20.3		34.1		-28.90		0.00		20.1		34.0		-27.30		0.00	
Max	31.4		58.2		0.63		39.10		31.5		58.7		0.55		43.60	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for July, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	29.1	(1.5)	48.1	(5.8)	-11.00	(8.47)	15.30	(13.20)	29.2	(1.6)	48.7	(5.2)	-11.20	(8.47)	15.30	(13.00)
2	29.4	(1.7)	44.4	(5.6)	-11.70	(7.73)	17.40	(14.00)	29.4	(1.9)	45.2	(5.3)	-11.20	(7.71)	17.60	(14.10)
3	29.4	(1.7)	47.9	(3.4)	-12.20	(8.23)	18.20	(13.90)	29.5	(1.8)	48.3	(3.1)	-12.10	(7.94)	18.50	(14.00)
4	28.5	(1.2)	50.5	(5.8)	-12.70	(8.99)	13.40	(9.90)	28.5	(1.2)	51.1	(5.0)	-11.80	(8.23)	13.60	(9.98)
5	29.0	(1.6)	51.3	(4.6)	-16.60	(9.23)	21.50	(15.30)	29.0	(1.8)	51.8	(4.5)	-14.80	(8.03)	21.90	(15.80)
6	29.2	(1.5)	54.6	(2.1)	-17.30	(8.34)	24.70	(14.50)	29.2	(1.7)	55.3	(2.1)	-15.60	(7.44)	24.90	(15.10)
7	29.8	(1.8)	53.5	(4.1)	-20.70	(8.00)	29.40	(13.10)	29.7	(1.8)	55.0	(4.1)	-17.40	(6.52)	29.30	(13.80)
8	30.6	(2.2)	53.9	(5.1)	-27.30	(9.30)	36.40	(14.30)	30.5	(2.1)	55.7	(5.2)	-24.60	(8.87)	36.50	(15.40)
9	30.5	(2.0)	48.3	(5.0)	-26.60	(8.66)	38.50	(11.90)	30.4	(1.9)	50.4	(5.1)	-24.40	(8.65)	38.50	(13.00)
10	30.0	(2.2)	50.3	(3.7)	-26.60	(9.14)	36.50	(13.90)	30.0	(2.0)	52.8	(4.0)	-22.90	(10.20)	36.40	(14.80)
11	28.3	(2.1)	52.5	(2.7)	-22.30	(8.79)	29.10	(14.70)	28.2	(2.2)	54.0	(2.8)	-16.70	(11.30)	31.00	(13.70)
12	27.9	(2.2)	54.3	(3.7)	-22.70	(9.01)	30.40	(15.00)	28.0	(2.3)	56.0	(4.2)	-21.40	(8.14)	30.50	(15.60)
13	28.2	(2.2)	54.9	(2.8)	-24.90	(9.57)	34.90	(14.20)	28.3	(2.1)	56.5	(2.9)	-23.10	(8.71)	34.90	(14.90)
14	28.0	(2.1)	53.9	(2.3)	-25.90	(8.58)	36.00	(12.80)	28.2	(1.8)	55.9	(2.7)	-23.30	(8.70)	36.00	(13.90)
15	26.9	(2.2)	56.7	(2.7)	-22.50	(9.51)	31.20	(14.60)	27.2	(2.0)	58.5	(3.0)	-21.10	(8.45)	31.60	(15.30)
16	26.9	(2.5)	55.3	(3.2)	-24.10	(9.51)	32.10	(14.30)	27.0	(2.4)	57.5	(3.6)	-22.00	(8.95)	32.60	(14.90)
17	27.0	(2.6)	51.3	(3.7)	-26.10	(9.91)	35.00	(13.80)	27.1	(2.3)	54.1	(3.9)	-23.60	(9.80)	35.40	(14.60)
18	26.3	(2.6)	55.8	(2.4)	-24.70	(10.30)	34.40	(13.70)	26.4	(2.4)	57.7	(2.8)	-23.00	(10.20)	34.70	(14.40)
19	26.3	(2.5)	54.8	(4.4)	-24.60	(10.70)	36.90	(11.10)	26.4	(2.1)	56.3	(4.5)	-24.70	(9.69)	38.30	(12.40)
20	24.8	(2.2)	56.7	(3.2)	-23.10	(8.94)	32.90	(12.90)	25.2	(2.2)	57.4	(3.4)	-22.50	(10.20)	34.00	(15.00)
21	24.1	(2.2)	58.3	(3.8)	-23.40	(9.04)	33.00	(13.20)	24.4	(2.2)	58.9	(4.1)	-21.40	(9.07)	33.00	(14.20)
22	24.3	(2.3)	59.4	(3.6)	-28.30	(13.70)	38.40	(15.10)	24.6	(2.4)	60.0	(3.9)	-26.50	(13.60)	39.20	(15.90)
23	24.8	(1.9)	59.5	(6.2)	-35.20	(13.60)	46.00	(11.50)	25.2	(1.9)	59.6	(5.2)	-34.00	(13.50)	46.60	(12.70)
24	24.6	(1.9)	60.2	(6.2)	-34.00	(13.70)	46.00	(9.52)	25.0	(1.9)	60.1	(4.9)	-32.30	(13.80)	46.80	(10.60)
25	25.0	(2.1)	63.0	(5.5)	-36.20	(14.40)	47.30	(9.44)	25.3	(2.1)	62.7	(4.6)	-34.40	(14.00)	47.90	(10.60)
26	25.1	(1.9)	59.9	(5.3)	-36.10	(14.60)	47.80	(9.30)	25.5	(2.1)	59.2	(4.6)	-34.30	(13.10)	49.10	(10.70)
27	24.7	(1.4)	59.8	(4.2)	-33.60	(15.50)	46.40	(10.20)	25.0	(1.4)	60.0	(3.9)	-30.70	(14.50)	47.80	(11.40)
28	23.9	(2.1)	60.3	(4.9)	-31.90	(14.80)	42.50	(12.20)	24.2	(2.0)	60.4	(4.5)	-29.20	(14.20)	43.60	(14.10)
29	23.8	(2.2)	58.7	(5.1)	-33.10	(14.60)	42.70	(11.10)	24.0	(2.0)	59.5	(5.3)	-30.40	(13.90)	43.40	(13.30)
30	24.2	(2.2)	60.3	(5.9)	-33.70	(14.50)	42.80	(10.50)	24.0	(2.3)	61.5	(6.2)	-31.50	(13.40)	44.20	(12.40)
31	23.6	(2.4)	55.5	(4.9)	-31.70	(17.50)	43.50	(11.90)	24.1	(1.9)	55.4	(7.1)	-31.10	(15.00)	45.20	(11.20)
Mean	26.9		55.0		-25.20		34.20		27.1		56.0		-23.30		34.80	
n	31		31		31		31		31		31		31		31	
SD	2.3		4.4		7.25		9.51		2.1		4.1		6.95		9.78	
Min	23.6		44.4		-36.20		13.40		24.0		45.2		-34.40		13.60	
Max	30.6		63.0		-11.00		47.80		30.5		62.7		-11.20		49.10	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for August, 2008.

Day	House 10				House 12			
	T, °C	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}	T, °C	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}
1	25.9 (6.5)	54.3 (10.2)	-4.11 (5.16)	21.00 (27.60)	25.6 (6.6)	54.0 (9.5)	-6.21 (8.23)	30.60 (34.10)
2	27.1 (4.9)	62.2 (17.7)	-34.10 (28.50)	28.80 (32.90)	27.0 (5.1)		-35.70 (31.00)	
3	26.1 (5.6)	45.6 (9.0)	-63.60 (1.49)	8.06 (0.18)	25.8 (5.8)		-67.60 (1.40)	
4	26.0 (5.8)	46.2 (10.6)	-26.90 (21.80)	13.20 (3.04)	25.5 (5.8)		-28.10 (23.20)	
5	26.0 (5.2)	42.8 (6.6)	-17.30 (2.14)	14.70 (0.38)	25.4 (5.3)		-17.90 (0.89)	
6	28.0 (5.5)	41.9 (6.9)	-8.39 (8.22)	13.50 (15.20)	27.1 (5.6)		-7.67 (8.64)	
7	29.2 (4.3)	39.8 (5.9)	-4.46 (6.42)	3.51 (4.33)	28.5 (4.4)		-4.94 (7.12)	
8	26.7 (4.8)	45.3 (6.0)	-12.30 (6.72)	5.68 (2.89)	26.1 (4.9)		-14.30 (7.46)	
9	25.2 (5.8)	46.9 (9.6)	-14.40 (5.02)	6.31 (1.94)	24.7 (5.9)		-16.70 (5.12)	
10	27.1 (6.1)	46.2 (10.8)	-10.30 (8.19)	4.92 (3.75)	26.5 (6.2)		-11.40 (8.65)	
11	30.6 (3.8)	41.6 (8.1)	-7.66 (9.14)	4.73 (5.31)	30.3 (4.0)		-7.79 (8.82)	
12	31.1 (3.8)	44.4 (7.2)	-10.20 (10.70)	5.31 (5.62)	31.1 (3.8)	38.8 (6.7)	-8.97 (9.57)	5.57 (5.85)
13	31.7 (3.6)	48.5 (7.2)	-11.70 (10.70)	6.15 (5.77)	31.7 (3.6)	42.5 (6.6)	-10.00 (9.69)	6.30 (6.01)
14	31.6 (3.3)	48.9 (7.2)	-12.60 (10.40)	6.75 (5.91)	31.6 (3.2)	43.1 (6.5)	-11.00 (9.65)	6.87 (6.15)
15	31.4 (3.1)	43.7 (7.0)	-7.31 (6.60)	7.81 (6.30)	31.5 (3.0)	38.2 (6.6)	-7.15 (6.79)	7.86 (6.50)
16	31.3 (2.7)	44.5 (6.0)	-7.14 (5.84)	7.56 (6.29)	31.4 (2.7)	38.9 (5.7)	-6.86 (5.97)	7.63 (6.40)
17	29.5 (2.6)	52.2 (8.2)	-7.26 (6.78)	6.37 (5.88)	29.5 (2.7)	46.1 (8.0)	-7.34 (7.01)	6.37 (5.89)
18	28.8 (2.1)	55.3 (6.4)	-5.50 (6.28)	4.18 (4.23)	28.6 (2.2)	48.9 (6.4)	-6.99 (7.03)	4.29 (4.11)
19	28.9 (1.7)	54.6 (5.6)	-6.19 (6.39)	4.36 (3.91)	28.7 (1.8)	48.5 (5.6)	-7.51 (7.16)	4.40 (3.92)
20	29.9 (2.2)	53.8 (5.3)	-5.68 (5.88)	7.02 (5.99)	29.8 (2.4)	47.5 (5.5)	-6.89 (6.74)	7.61 (7.18)
21	30.6 (1.1)	51.8 (5.2)	-7.23 (5.82)	10.90 (9.72)	30.7 (1.2)	45.2 (4.9)	-7.82 (6.90)	11.20 (10.30)
22	30.7 (1.4)	49.4 (5.4)	-8.43 (6.31)	13.60 (11.40)	30.7 (1.6)	43.1 (4.7)	-8.62 (6.33)	13.90 (11.60)
23	30.4 (1.4)	51.7 (4.4)	-7.93 (6.12)	12.60 (11.00)	30.5 (1.6)	45.1 (3.8)	-8.06 (6.26)	12.90 (11.30)
24	30.3 (1.5)	51.4 (4.2)	-9.04 (5.93)	14.30 (11.00)	30.3 (1.6)	45.3 (3.6)	-9.11 (6.57)	14.70 (11.50)
25	29.8 (1.5)	46.4 (5.3)	-9.06 (6.24)	14.40 (11.30)	29.8 (1.7)	40.8 (4.9)	-9.08 (6.76)	14.80 (11.90)
26	29.1 (1.4)	46.3 (5.0)	-9.78 (6.57)	15.70 (13.10)	29.2 (1.5)	40.7 (4.4)	-10.30 (6.95)	15.70 (13.40)
27	29.5 (1.7)	49.0 (4.3)	-11.20 (6.52)	19.80 (14.20)	29.6 (1.8)	43.5 (3.7)	-10.90 (6.21)	19.50 (14.00)
28	29.5 (1.6)	52.2 (3.7)	-12.00 (6.12)	20.60 (13.10)	29.6 (1.7)	46.3 (3.5)	-12.20 (5.97)	20.60 (13.40)
29	29.7 (1.7)	51.4 (3.6)	-13.30 (5.23)	22.90 (13.00)	29.7 (1.8)	46.2 (3.5)	-13.00 (4.94)	22.60 (12.80)
30	29.3 (1.4)	46.1 (4.7)	-11.80 (5.89)	19.60 (13.60)	29.3 (1.5)	42.0 (4.1)	-11.60 (6.26)	19.10 (13.50)
31	28.0 (1.2)	43.3 (8.0)	-9.99 (6.85)	14.20 (11.00)	28.2 (1.3)	39.1 (6.8)	-10.40 (7.03)	14.60 (11.30)
Mean	29.0	48.3	-12.50	11.60	28.8	44.0	-13.00	12.70
n	31	31	31	31	31	21	31	21
SD	1.9	4.9	11.10	6.46	2.1	3.9	11.80	6.80
Min	25.2	39.8	-63.60	3.51	24.7	38.2	-67.60	4.29
Max	31.7	62.2	-4.11	28.80	31.7	54.0	-4.94	30.60

Table E3. Daily means (SD) of environmental parameters at Site CA1B for September, 2008.

Day	House 10				House 12			
	T, °C	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}	T, °C	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}
1	28.1 (1.2)	41.9 (7.7)	-10.50 (5.93)	14.80 (11.40)	28.2 (1.4)	37.5 (6.2)	-11.80 (6.76)	15.80 (12.70)
2	28.3 (1.4)	44.9 (7.3)	-11.90 (6.53)	18.20 (13.40)	28.3 (1.7)	40.5 (6.3)	-12.40 (6.24)	18.60 (13.60)
3	28.3 (1.5)	47.1 (5.8)	-15.00 (8.55)	22.70 (15.50)	28.6 (1.5)	42.2 (4.7)	-15.20 (7.95)	22.40 (15.60)
4	28.3 (1.8)	46.4 (5.0)	-15.20 (9.23)	23.10 (13.90)	28.4 (1.9)	42.6 (4.6)	-15.20 (8.16)	23.70 (14.90)
5	28.3 (1.7)	48.3 (4.3)	-17.60 (9.17)	25.60 (13.30)	28.5 (1.7)	44.5 (3.7)	-16.60 (7.58)	25.90 (14.00)
6	28.3 (1.6)	50.2 (5.5)	-18.20 (8.79)	26.90 (12.80)	28.6 (1.6)	46.1 (4.6)	-17.00 (7.56)	26.60 (13.80)
7	28.0 (1.6)	48.5 (3.5)	-19.00 (8.37)	26.70 (12.20)	28.3 (1.7)	44.5 (2.8)	-17.50 (6.82)	26.70 (13.10)
8	27.2 (1.7)	52.8 (3.4)	-15.80 (8.51)	23.40 (12.90)	27.5 (1.7)	48.2 (3.4)	-16.20 (7.60)	24.00 (13.90)
9	26.6 (1.5)	56.0 (5.2)	-14.30 (8.45)	20.40 (12.40)	26.9 (1.6)	51.2 (5.4)	-14.80 (7.20)	20.80 (12.90)
10	26.7 (2.0)	55.8 (6.5)	-17.90 (11.40)	24.70 (15.30)	27.0 (2.1)	50.6 (6.5)	-17.50 (9.85)	24.80 (15.90)
11	27.2 (2.2)	54.7 (5.2)	-20.30 (11.80)	27.40 (15.30)	27.6 (2.2)	49.2 (5.3)	-19.80 (10.60)	27.70 (16.20)
12	26.6 (2.3)	53.8 (5.7)	-20.60 (11.40)	27.00 (15.20)	27.1 (2.3)	48.4 (5.6)	-19.50 (10.40)	27.10 (16.10)
13	25.8 (2.3)	55.8 (5.6)	-21.90 (10.30)	26.80 (14.50)	26.2 (2.3)	50.1 (5.6)	-19.60 (9.91)	27.30 (15.40)
14	26.0 (2.4)	57.1 (4.5)	-24.70 (10.10)	30.00 (14.00)	26.1 (2.3)	51.4 (4.5)	-21.90 (10.00)	30.40 (15.10)
15	26.1 (2.1)	58.8 (3.2)	-26.20 (10.40)	33.50 (13.20)	26.1 (2.0)	52.8 (3.5)	-24.70 (11.20)	34.80 (15.00)
16	25.7 (2.4)	56.6 (3.8)	-25.20 (9.62)	34.20 (11.40)	25.7 (2.3)	50.9 (3.7)	-23.80 (10.90)	35.30 (13.40)
17	24.2 (2.3)	56.2 (5.8)	-23.20 (8.07)	30.20 (11.90)	24.4 (2.2)	50.9 (5.8)	-21.50 (7.70)	30.60 (12.80)
18	24.0 (2.3)	56.6 (5.8)	-23.70 (8.95)	31.10 (12.50)	24.2 (2.2)	51.4 (5.9)	-22.00 (8.59)	31.40 (13.10)
19	23.8 (2.2)	57.5 (7.3)	-24.50 (8.88)	33.50 (10.70)	24.0 (2.1)	51.9 (6.8)	-22.70 (8.54)	34.20 (11.40)
20	23.7 (2.4)	64.1 (6.3)	-25.00 (9.13)	35.60 (8.89)	23.9 (2.3)	56.9 (5.8)	-23.40 (8.73)	36.30 (9.72)
21	23.8 (2.5)	62.0 (5.7)	-25.70 (9.66)	34.60 (10.50)	24.0 (2.4)	55.3 (5.6)	-24.10 (9.20)	34.70 (11.70)
22	23.7 (2.4)	56.9 (8.0)	-26.70 (9.96)	34.40 (11.40)	23.9 (2.3)	51.5 (7.1)	-24.20 (9.74)	34.50 (12.90)
23	24.1 (2.7)	52.8 (4.4)	-29.80 (11.90)	37.00 (12.20)	24.6 (2.6)	47.9 (4.6)	-27.70 (11.80)	37.60 (13.60)
24	24.3 (2.8)	53.6 (3.9)	-29.70 (11.10)	37.80 (9.48)	24.8 (2.7)	48.6 (3.6)	-28.40 (11.60)	38.80 (11.60)
25	24.8 (2.2)	49.0 (5.2)	-32.30 (11.40)	41.40 (7.13)	25.1 (2.1)	44.7 (4.6)	-30.00 (11.50)	42.40 (8.71)
26	24.8 (2.4)	57.6 (4.1)	-33.50 (12.80)	46.60 (12.70)	24.5 (2.3)	53.1 (3.0)	-32.90 (12.30)	47.80 (12.40)
27	25.6 (6.0)	48.7 (12.0)	-16.10 (13.20)	42.50 (26.20)	25.7 (5.5)	44.6 (10.0)	-9.85 (9.65)	33.60 (19.50)
28	26.0 (5.8)	46.5 (11.1)	-2.64 (0.37)	16.10 (0.33)	26.0 (5.9)	42.0 (10.3)	-2.29 (0.45)	16.30 (0.35)
29	23.5 (4.3)	56.9 (8.4)	-6.46 (4.31)	28.20 (23.20)	23.7 (4.2)	51.1 (7.3)	-6.15 (3.73)	26.10 (22.60)
30	23.4 (4.4)		-3.49 (4.95)		22.6 (3.8)	58.7 (6.9)	-2.30 (3.62)	22.90 (25.20)
Mean	25.8	53.3	-19.90	29.50	26.0	48.6	-18.70	29.30
n	30	29	30	29	30	30	30	30
SD	1.7	5.2	7.75	7.60	1.8	4.8	7.34	7.41
Min	23.4	41.9	-33.50	14.80	22.6	37.5	-32.90	15.80
Max	28.3	64.1	-2.64	46.60	28.6	58.7	-2.29	47.80

Table E3. Daily means (SD) of environmental parameters at Site CA1B for October, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	25.5	(3.0)			0.56	(0.47)			23.1	(2.9)	56.7	(8.6)	0.64	(0.31)	0.00	(0.00)
2	24.5	(1.0)			-2.07	(8.46)			22.9	(2.0)	68.5	(9.1)	-0.22	(3.05)	2.35	(8.21)
3	23.1	(1.7)	74.9	(5.6)	0.72	(0.29)	0.00	(0.00)	21.9	(1.8)	67.6	(7.4)	0.77	(0.28)	0.00	(0.00)
4	22.1	(1.5)	76.5	(3.6)	0.75	(0.80)	0.00	(0.00)	21.0	(1.6)	70.3	(4.2)	0.82	(0.38)	0.00	(0.00)
5	21.2	(2.2)	70.7	(7.6)	0.76	(0.34)	0.00	(0.00)	20.2	(2.2)	63.6	(9.0)	0.73	(0.34)	0.00	(0.00)
6	22.2	(2.5)	70.2	(8.4)	0.67	(0.28)	0.00	(0.00)	21.2	(2.6)	63.2	(9.4)	0.69	(0.30)	0.00	(0.00)
7	23.0	(2.9)	67.1	(9.6)	0.59	(0.40)	0.66	(1.59)	22.2	(3.0)	59.7	(9.9)	0.56	(0.45)	0.68	(1.12)
8	22.8	(3.0)	63.9	(9.4)	0.60	(0.38)	0.91	(1.82)	22.1	(3.0)	56.8	(9.7)	0.57	(0.42)	0.93	(1.39)
9	20.3	(2.3)	53.1	(12.9)	-2.54	(5.02)	8.87	(14.00)	19.4	(2.3)	45.8	(13.6)	-2.67	(4.59)	9.96	(14.70)
10	19.0	(1.3)	49.7	(6.9)	-0.22	(1.15)	0.94	(1.89)	17.8	(1.3)	43.7	(7.1)	-0.55	(1.47)	0.94	(1.88)
11	17.4	(2.1)	44.5	(6.5)	-0.37	(1.03)	0.96	(1.91)	16.3	(2.2)	38.9	(7.0)	-0.77	(1.23)	0.98	(1.95)
12	16.1	(3.4)	42.1	(6.5)	-0.14	(0.68)	0.94	(1.88)	15.5	(3.3)	37.1	(6.8)	-0.17	(0.92)	0.97	(1.94)
13	17.6	(5.9)	40.6	(8.5)	-1.53	(4.05)	10.40	(14.70)	16.8	(6.3)	35.4	(8.4)	-0.24	(2.26)	10.00	(22.40)
14	19.8	(6.1)	41.2	(4.7)	0.42	(0.49)	0.93	(1.45)	19.5	(6.4)	35.6	(4.8)	0.56	(0.46)	0.95	(1.90)
15	20.7	(6.5)	43.1	(5.1)	-1.31	(3.09)	1.60	(4.84)	20.3	(6.6)	37.4	(4.6)	-1.03	(3.76)	1.43	(4.49)
16	21.8	(6.4)	46.5	(4.8)	-2.88	(4.37)	0.86	(1.06)	21.4	(6.4)	40.3	(4.6)	-2.46	(6.01)	0.83	(1.55)
17	22.1	(6.2)	48.0	(4.8)	-3.27	(4.75)	0.85	(1.08)	21.7	(6.3)	42.0	(4.5)	-2.75	(5.39)	0.85	(1.29)
18	23.2	(4.1)	50.2	(3.7)	-2.80	(5.04)	0.84	(1.22)	22.8	(4.1)	43.9	(3.8)	-2.52	(4.36)	0.89	(1.17)
19	24.2	(3.6)	51.0	(5.1)	-2.78	(6.03)	0.82	(1.42)	23.7	(3.6)	44.9	(5.4)	-2.43	(3.77)	0.88	(1.08)
20	23.6	(3.3)	54.4	(5.1)	-3.12	(7.11)	0.83	(1.60)	22.8	(3.3)	48.9	(5.3)	-2.97	(4.76)	0.91	(1.20)
21	23.9	(3.4)	58.3	(6.9)	-4.32	(8.02)	1.05	(1.68)	23.2	(3.5)	52.7	(7.0)	-4.25	(7.14)	1.13	(1.60)
22	24.6	(4.8)	57.7	(10.8)	-7.40	(10.70)	1.62	(1.91)	23.9	(4.8)	52.4	(11.6)	-7.64	(10.90)	1.79	(2.07)
23	24.9	(4.4)	55.7	(12.3)	-11.90	(14.00)	2.52	(2.67)	24.2	(4.5)	50.1	(12.7)	-13.00	(14.80)	2.86	(2.94)
24	24.7	(4.7)	55.4	(12.5)	-14.00	(15.60)	2.84	(2.93)	24.1	(4.7)	48.5	(12.5)	-14.80	(16.00)	3.23	(3.20)
25	25.0	(4.7)	55.7	(13.1)	-14.00	(14.10)	3.44	(3.38)	24.4	(4.7)	48.6	(12.6)	-13.40	(13.50)	3.89	(3.82)
26	25.4	(4.5)	56.1	(13.1)	-13.30	(13.60)	3.33	(3.21)	24.8	(4.6)	49.1	(12.6)	-12.80	(13.40)	3.58	(3.54)
27	24.8	(3.5)	61.1	(8.5)	-11.20	(13.10)	2.65	(2.83)	24.3	(3.4)	54.0	(8.9)	-11.00	(12.70)	2.85	(2.99)
28	28.3	(4.6)	55.0	(12.5)	-13.00	(13.50)	3.40	(3.25)	28.5	(4.5)	47.4	(12.1)	-12.00	(12.20)	3.65	(3.44)
29	31.5	(0.7)	45.9	(2.9)	-11.70	(13.30)	3.73	(3.74)	30.8	(0.9)	39.8	(3.0)	-11.70	(13.10)	3.87	(3.74)
30	30.4	(0.5)	53.2	(4.5)	-7.12	(11.30)	2.74	(3.47)	29.8	(0.3)	46.6	(3.9)	-7.70	(11.60)	2.82	(3.41)
31	30.1	(0.4)	59.8	(3.2)	-9.01	(11.90)	3.20	(3.66)	29.2	(0.4)	52.9	(3.1)	-8.89	(12.50)	3.08	(3.68)
Mean	23.4		55.2		-4.35		2.10		22.6		49.8		-4.21		2.14	
n	31		29		31		29		31		31		31		31	
SD	3.6		9.7		5.15		2.36		3.6		9.7		5.22		2.40	
Min	16.1		40.6		-14.00		0.00		15.5		35.4		-14.80		0.00	
Max	31.5		76.5		0.76		10.40		30.8		70.3		0.82		10.00	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for November, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	29.7	(0.4)	60.0	(2.4)	-10.30	(13.70)	3.47	(4.06)	28.8	(0.4)	52.7	(2.1)	-10.60	(14.60)	3.48	(4.10)
2	29.6	(0.5)	61.4	(3.2)	-13.20	(14.30)	4.35	(4.20)	28.7	(0.4)	54.3	(2.1)	-12.90	(14.70)	4.29	(4.28)
3	29.3	(0.4)	62.8	(3.9)	-9.79	(13.30)	3.40	(3.95)	28.3	(0.4)	55.7	(3.9)	-9.73	(13.90)	3.39	(4.07)
4	29.0	(0.4)	58.4	(4.3)	-12.60	(13.70)	4.18	(4.09)	28.0	(0.4)	51.3	(3.7)	-12.90	(13.40)	4.37	(3.98)
5	28.6	(0.6)	58.7	(3.5)	-11.30	(13.50)	3.81	(4.02)	27.5	(0.5)	51.5	(2.8)	-11.70	(12.00)	4.13	(3.68)
6	28.1	(0.6)	60.2	(4.4)	-14.10	(13.60)	4.63	(3.90)	27.0	(0.5)	53.0	(4.0)	-14.30	(13.50)	4.85	(4.04)
7																
8																
9																
10																
11	27.0	(0.4)	62.3	(3.9)	-12.40	(10.80)	8.27	(6.42)	26.7	(0.5)	56.0	(3.5)	-16.50	(14.50)	7.82	(6.30)
12	27.0	(0.5)	61.2	(4.6)	-13.10	(10.30)	9.05	(6.49)	26.6	(0.6)	55.9	(4.3)	-17.50	(13.60)	8.64	(6.12)
13	27.1	(0.7)	60.6	(4.2)	-15.60	(12.00)	10.40	(7.64)	26.7	(0.8)	55.4	(4.3)	-19.70	(14.70)	10.00	(7.15)
14	26.6	(0.6)	61.6	(3.2)	-16.30	(10.80)	11.20	(7.43)	26.4	(0.8)	55.9	(3.4)	-20.60	(13.50)	10.80	(7.03)
15	26.7	(1.1)	60.2	(4.8)	-17.20	(10.70)	13.10	(8.52)	26.5	(1.3)	54.3	(4.7)	-22.70	(13.80)	12.50	(8.01)
16	26.7	(1.5)	57.0	(5.2)	-19.00	(10.90)	14.10	(8.76)	26.4	(1.7)	52.3	(5.2)	-24.40	(13.80)	13.50	(8.23)
17	26.4	(1.6)	56.8	(5.5)	-19.50	(10.20)	14.50	(8.42)	26.1	(1.7)	51.7	(5.3)	-23.20	(11.50)	14.30	(8.41)
18	26.2	(1.6)	57.7	(5.5)	-20.10	(10.40)	14.30	(8.14)	25.8	(1.6)	52.3	(5.2)	-23.60	(11.40)	14.00	(8.23)
19	25.3	(0.8)	62.1	(3.9)	-18.50	(9.78)	12.50	(7.12)	25.1	(0.8)	56.2	(4.0)	-23.10	(11.70)	12.20	(7.00)
20	25.3	(0.7)	63.0	(2.8)	-18.00	(9.64)	13.40	(7.40)	25.0	(0.8)	57.5	(2.8)	-21.50	(11.80)	12.90	(7.34)
21	24.3	(0.9)	61.0	(2.7)	-16.00	(10.50)	12.00	(7.13)	23.7	(1.0)	55.4	(2.6)	-17.40	(11.90)	11.60	(7.43)
22	23.7	(1.1)	62.5	(3.9)	-16.40	(9.53)	12.90	(7.21)	23.3	(1.3)	56.7	(3.8)	-17.80	(10.50)	12.70	(7.37)
23	23.1	(1.2)	63.7	(3.9)	-16.90	(9.09)	13.40	(7.16)	22.7	(1.3)	57.5	(3.8)	-18.10	(9.72)	13.30	(7.17)
24	22.5	(0.9)	63.9	(3.6)	-18.30	(8.63)	14.00	(6.44)	22.2	(1.1)	58.3	(3.3)	-19.60	(9.32)	13.80	(6.40)
25	22.2	(0.7)	63.4	(3.5)	-20.50	(7.71)	15.70	(5.94)	22.3	(1.0)	58.9	(3.6)	-21.60	(8.96)	14.80	(5.98)
26	22.1	(0.4)	70.9	(2.0)	-22.10	(5.03)	16.20	(3.90)	21.8	(0.6)	65.9	(1.5)	-23.30	(5.85)	16.40	(4.12)
27	21.1	(0.9)			-22.40	(2.36)			21.4	(0.6)	66.3	(1.3)	-24.00	(2.34)	17.00	(1.53)
28	20.7	(0.6)	70.4	(1.9)	-22.50	(2.38)	17.70	(2.40)	20.7	(0.7)	63.5	(2.2)	-24.80	(3.02)	18.20	(2.42)
29	20.6	(1.0)	68.3	(2.6)	-21.40	(5.37)	17.20	(5.21)	20.6	(1.0)	62.7	(2.8)	-22.40	(6.88)	16.70	(6.02)
30	21.0	(1.2)	68.6	(2.3)	-22.00	(6.76)	17.70	(5.90)	20.5	(1.2)	64.2	(2.5)	-22.90	(6.73)	17.30	(6.15)
Mean	25.4		62.3		-16.90		11.30		24.9		56.7		-19.10		11.30	
n	26		25		26		25		26		26		26		26	
SD	2.9		3.8		3.81		4.69		2.6		4.4		4.54		4.63	
Min	20.6		56.8		-22.50		3.40		20.5		51.3		-24.80		3.39	
Max	29.7		70.9		-9.79		17.70		28.8		66.3		-9.73		18.20	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for December, 2008.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	20.5	(0.4)	71.9	(1.9)	-21.30	(4.57)	15.80	(2.63)	20.0	(0.4)	66.8	(1.2)	-22.20	(4.79)	15.80	(2.67)
2	21.0	(0.6)	72.7	(1.2)	-22.80	(3.55)	17.80	(3.37)	20.9	(0.6)	66.7	(1.4)	-24.00	(4.07)	17.40	(3.34)
3	20.0	(1.8)	71.5	(2.3)	-23.30	(4.05)	21.00	(13.70)	20.0	(2.3)	66.5	(2.6)	-24.10	(3.94)	21.60	(14.50)
4	12.4	(3.3)	84.6	(7.6)	-9.89	(8.78)	28.40	(24.70)	10.8	(2.2)	76.1	(4.1)	-10.80	(9.23)	40.90	(28.60)
5	8.2	(2.6)	91.1	(2.3)	-14.70	(0.46)	16.30	(0.15)	7.6	(2.7)	79.9	(2.5)	-7.40	(0.58)	17.00	(0.43)
6	8.5	(0.6)	83.5	(2.3)	-14.70	(0.31)	16.30	(0.04)	7.8	(0.6)	79.3	(2.0)	-7.65	(0.48)	16.70	(0.10)
7	9.0	(1.7)	79.5	(3.4)	-20.70	(6.63)	10.20	(4.02)	8.9	(1.9)	75.0	(4.5)	-20.10	(8.34)	10.40	(4.21)
8	8.8	(2.4)	82.7	(3.8)	-7.85	(9.94)	7.65	(8.98)	8.4	(2.1)	77.9	(3.6)	-7.76	(11.10)	4.84	(3.88)
9	13.0	(3.3)	79.8	(1.7)	-2.26	(5.59)	0.86	(1.71)	12.9	(3.7)	73.4	(7.1)	-2.78	(6.42)	1.17	(2.22)
10	14.6	(5.2)	80.0	(1.9)	-2.37	(5.96)	0.84	(1.68)	14.5	(5.2)	75.5	(2.6)	-2.50	(6.60)	0.85	(1.69)
11	19.6	(1.7)	78.7	(2.3)	-2.32	(6.21)	0.81	(1.63)	19.6	(1.7)	75.0	(2.8)	-2.35	(6.71)	0.82	(1.64)
12	19.7	(1.8)	76.0	(1.3)	-2.67	(6.58)	0.81	(1.61)	19.6	(1.7)	72.9	(2.3)	-2.79	(7.25)	0.81	(1.61)
13	19.5	(1.1)	75.6	(3.0)	-3.10	(6.62)	0.80	(1.54)	19.4	(1.3)	73.2	(3.8)	-3.65	(7.20)	0.82	(1.43)
14	17.4	(1.1)	80.9	(2.4)	-2.90	(6.19)	0.87	(1.40)	16.8	(1.1)	79.5	(1.8)	-2.96	(6.46)	0.89	(1.30)
15	18.7	(1.6)	82.6	(1.3)	-3.31	(6.48)	1.02	(1.47)	18.0	(1.7)	81.0	(1.1)	-3.55	(6.65)	1.03	(1.41)
16	19.1	(1.3)	85.1	(1.1)	-4.53	(6.99)	1.23	(1.60)	18.3	(1.5)	82.2	(0.7)	-5.02	(8.65)	1.23	(1.74)
17	18.4	(1.3)	83.2	(3.2)	-5.05	(6.64)	1.45	(1.78)	17.8	(1.3)	79.8	(3.5)	-6.12	(9.90)	1.42	(2.20)
18	19.0	(1.8)	82.8	(2.6)	-4.32	(6.48)	1.46	(1.82)	18.1	(2.0)	79.8	(2.5)	-4.56	(10.00)	1.42	(2.38)
19	20.1	(0.8)	82.3	(1.1)	-4.83	(7.20)	1.62	(2.02)	19.3	(0.9)	79.9	(1.2)	-5.25	(10.70)	1.57	(2.53)
20	19.2	(1.1)	86.1	(1.0)	-5.31	(7.90)	1.71	(2.16)	18.1	(1.0)	82.6	(0.3)	-5.72	(11.60)	1.62	(2.66)
21	28.9	(5.6)	67.3	(11.3)	-5.86	(9.16)	2.02	(2.48)	28.1	(5.9)	62.2	(12.1)	-6.08	(10.80)	2.00	(2.60)
22	30.9	(0.8)	56.5	(2.8)	-5.91	(9.40)	2.82	(3.57)	30.6	(0.7)	50.1	(2.9)	-7.07	(11.80)	2.57	(3.39)
23	29.8	(0.4)	57.0	(1.6)	-5.89	(10.10)	2.85	(3.83)	29.7	(0.5)	49.3	(1.5)	-7.56	(13.00)	2.77	(3.69)
24	29.6	(0.4)	58.3	(2.3)	-6.39	(9.83)	2.91	(3.64)	29.2	(0.6)	50.9	(2.4)	-8.14	(12.50)	2.84	(3.53)
25	29.2	(0.5)	56.2	(3.2)	-7.97	(10.10)	3.20	(3.95)	28.8	(0.5)	50.2	(2.8)	-11.20	(13.10)	3.11	(3.83)
26	28.7	(0.4)	55.9	(2.5)	-6.98	(9.70)	3.32	(3.81)	28.5	(0.6)	48.4	(2.4)	-9.15	(12.60)	3.21	(3.66)
27	28.4	(0.4)	56.8	(2.6)	-7.73	(9.24)	3.70	(3.62)	27.8	(0.4)	49.7	(3.0)	-9.69	(11.70)	3.59	(3.52)
28	28.1	(0.4)	57.6	(2.5)	-8.79	(10.10)	4.11	(3.94)	27.4	(0.4)	50.0	(2.8)	-11.40	(12.60)	4.05	(3.79)
29	28.0	(0.4)	59.3	(2.8)	-9.95	(10.50)	4.55	(4.09)	27.3	(0.5)	52.1	(3.1)	-12.70	(14.00)	4.34	(4.11)
30	27.6	(0.4)	62.4	(3.2)	-9.53	(10.30)	4.39	(3.99)	27.0	(0.4)	55.5	(3.6)	-11.80	(14.30)	4.08	(4.10)
31	27.4	(0.4)	63.8	(2.6)	-9.77	(11.10)	4.39	(4.21)	26.8	(0.4)	57.6	(2.9)	-12.10	(14.00)	4.19	(4.03)
Mean	20.7		73.0		-8.48		5.97		20.3		67.7		-8.97		6.29	
n	31		31		31		31		31		31		31		31	
SD	7.0		11.1		6.09		7.09		7.0		12.3		6.07		8.62	
Min	8.2		55.9		-23.30		0.80		7.6		48.4		-24.10		0.81	
Max	30.9		91.1		-2.26		28.40		30.6		82.6		-2.35		40.90	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for January, 2009.

Day	House 10								House 12							
	T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	27.2	(0.4)	63.9	(2.0)	-10.70	(10.80)	4.73	(4.02)	26.5	(0.5)	58.3	(2.3)	-13.10	(13.50)	4.50	(3.83)
2	27.1	(0.4)	66.2	(2.2)	-11.70	(10.50)	5.02	(3.82)	26.4	(0.4)	60.1	(2.4)	-14.20	(12.90)	4.80	(3.65)
3	26.3	(0.6)	65.1	(1.4)	-12.00	(9.64)	5.30	(3.73)	25.8	(0.7)	58.6	(1.5)	-15.20	(12.10)	5.13	(3.56)
4	25.8	(0.4)	64.2	(2.4)	-11.90	(10.30)	5.23	(3.99)	25.2	(0.5)	58.8	(2.7)	-15.00	(12.80)	5.09	(3.85)
5	25.8	(0.4)	65.1	(1.5)	-10.30	(10.90)	5.90	(5.38)	25.3	(0.4)	60.7	(1.8)	-12.40	(13.10)	5.74	(5.23)
6	25.5	(0.5)	64.5	(1.5)	-10.50	(11.10)	6.50	(5.81)	25.1	(0.5)	60.4	(1.7)	-12.50	(13.40)	6.31	(5.65)
7	25.2	(0.5)	67.1	(2.0)	-8.82	(11.70)	5.54	(6.04)	25.1	(0.7)	62.9	(2.2)	-10.50	(14.10)	5.33	(5.86)
8	24.4	(0.5)	65.1	(2.8)	-11.30	(11.00)	6.95	(6.03)	24.7	(0.4)	60.4	(2.1)	-13.70	(13.90)	6.72	(5.94)
9	23.7	(0.8)			-16.60	(10.70)			24.2	(0.7)	57.1	(3.8)	-19.80	(13.40)	9.60	(5.80)
10	23.1	(0.8)			-15.30	(11.30)			23.8	(0.7)	57.4	(3.6)	-18.30	(13.40)	9.16	(5.97)
11	23.4	(0.8)	61.8	(2.9)	-16.50	(10.70)	11.00	(5.97)	23.5	(0.6)	57.8	(3.0)	-19.70	(12.50)	10.10	(5.87)
12	23.5	(0.5)	61.3	(3.5)	-18.00	(9.71)	12.30	(6.72)	23.4	(0.6)	56.9	(4.1)	-21.70	(11.40)	11.80	(6.32)
13	23.3	(0.5)	60.9	(4.3)	-19.50	(9.22)	14.10	(7.66)	23.3	(0.8)	56.2	(4.8)	-23.10	(10.80)	13.40	(7.11)
14	23.0	(0.8)	61.2	(3.3)	-17.90	(8.17)	14.00	(6.73)	23.0	(0.9)	56.6	(3.7)	-21.40	(9.66)	13.50	(6.43)
15	22.5	(0.8)	60.9	(3.3)	-16.50	(6.91)	15.20	(7.23)	22.7	(0.9)	55.8	(3.6)	-20.30	(8.50)	14.70	(6.87)
16	22.1	(1.1)	60.5	(5.2)	-17.50	(6.99)	16.60	(7.29)	22.4	(1.0)	56.9	(5.3)	-20.40	(7.95)	15.50	(7.09)
17	21.6	(1.2)	59.8	(5.0)	-18.00	(7.41)	16.90	(7.42)	21.9	(1.2)	56.3	(5.2)	-20.90	(8.46)	16.10	(7.39)
18	21.6	(1.3)	59.3	(5.0)	-19.00	(7.05)	17.60	(7.45)	21.8	(1.4)	55.1	(5.4)	-22.00	(7.64)	17.20	(7.33)
19	21.5	(1.6)	59.8	(5.0)	-19.40	(5.72)	17.80	(6.51)	21.5	(1.7)	55.4	(5.3)	-22.40	(5.86)	17.60	(6.36)
20	20.9	(1.5)	57.5	(6.6)	-22.20	(7.21)	17.50	(5.68)	21.0	(1.5)	55.6	(5.2)	-23.00	(5.92)	17.50	(5.93)
21	20.6	(0.5)	60.2	(3.8)	-22.90	(2.95)	16.10	(3.02)	21.0	(0.6)	61.7	(2.6)	-22.80	(2.74)	16.10	(3.10)
22	20.7	(0.4)	67.9	(1.5)	-22.60	(1.49)	18.50	(2.23)	21.0	(0.5)	66.4	(1.1)	-23.00	(1.64)	17.80	(2.47)
23	20.6	(0.4)	71.5	(0.9)	-23.80	(2.01)	19.20	(1.86)	20.9	(0.5)	68.8	(0.9)	-23.60	(2.07)	18.90	(1.84)
24	20.8	(0.5)	68.8	(3.3)	-23.70	(3.17)	20.50	(3.41)	21.2	(0.5)	66.1	(3.1)	-24.00	(2.90)	20.50	(3.18)
25	19.9	(0.5)	60.2	(3.1)	-22.60	(1.57)	17.80	(2.63)	20.4	(0.4)	59.0	(2.8)	-23.20	(1.28)	17.90	(2.56)
26	19.5	(0.7)	61.3	(3.1)	-23.10	(1.13)	16.70	(3.09)	19.9	(0.7)	59.1	(3.2)	-23.60	(1.56)	16.80	(3.03)
27	18.7	(1.7)	58.8	(5.8)	-23.60	(1.22)	16.20	(2.80)	18.2	(1.4)	57.1	(4.7)	-23.80	(1.40)	16.30	(2.76)
28	11.4	(3.0)	77.1	(10.0)	-13.60	(9.44)	27.80	(25.40)	12.8	(3.4)	69.5	(9.5)	-13.80	(10.30)	24.00	(25.40)
29	11.6	(5.2)	74.1	(10.0)	-6.11	(6.22)	12.90	(6.63)	11.4	(5.5)	75.4	(10.8)	-2.99	(3.48)	12.80	(7.01)
30	17.7	(3.8)	73.9	(3.3)	-2.14	(4.90)	1.39	(2.41)	18.0	(3.8)	71.7	(2.6)	-2.31	(5.20)	1.30	(2.40)
31	18.5	(2.4)	76.7	(2.9)	-1.73	(4.95)	0.85	(1.67)	18.7	(2.4)	74.1	(2.2)	-1.73	(5.34)	0.86	(1.69)
Mean	21.8		64.6		-15.80		12.60		21.9		60.8		-17.60		12.00	
n	31		29		31		29		31		31		31		31	
SD	3.7		5.4		6.13		6.48		3.5		5.6		6.44		6.02	
Min	11.4		57.5		-23.80		0.85		11.4		55.1		-24.00		0.86	
Max	27.2		77.1		-1.73		27.80		26.5		75.4		-1.73		24.00	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for February, 2009.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	18.4	(2.7)	75.4	(2.8)	-1.81	(5.00)	0.84	(1.69)	18.6	(2.7)	73.0	(2.2)	-1.77	(5.29)	0.85	(1.71)
2	17.9	(3.2)	74.7	(3.4)	-1.57	(4.81)	0.81	(1.76)	18.1	(3.1)	72.4	(2.7)	-1.54	(4.36)	0.83	(1.57)
3	17.8	(3.3)	73.5	(4.0)	-1.71	(4.93)	0.84	(1.67)	17.9	(3.3)	71.3	(2.8)	-1.69	(3.22)	0.89	(1.11)
4	16.8	(2.2)	71.9	(5.3)	-2.16	(4.94)	7.40	(14.70)	16.9	(2.2)	69.4	(4.9)	-1.74	(3.30)	4.89	(10.30)
5	15.1	(2.1)	75.8	(2.3)	-1.84	(4.32)	4.01	(10.70)	15.3	(1.8)	73.1	(1.9)	-1.25	(4.29)	0.89	(1.34)
6	15.5	(1.6)	75.8	(1.0)	-2.02	(5.43)	0.82	(1.55)	15.5	(1.6)	73.7	(1.3)	-1.99	(5.75)	0.85	(1.70)
7	19.1	(4.0)	79.4	(3.1)	-2.34	(6.05)	0.82	(1.63)	19.0	(4.0)	77.7	(3.5)	-2.42	(6.23)	0.84	(1.67)
8	19.6	(1.8)	75.8	(4.6)	-1.71	(6.06)	0.81	(1.61)	19.3	(1.8)	73.8	(5.4)	-2.18	(6.55)	0.82	(1.64)
9	18.7	(1.9)	73.3	(2.5)	-2.44	(6.58)			18.7	(2.0)	71.3	(3.3)	-3.00	(6.85)	0.82	(1.61)
10	19.3	(3.0)	76.8	(3.0)	-2.80	(7.34)	0.84	(1.68)	19.1	(3.1)	74.8	(3.7)	-2.81	(6.72)	0.87	(1.43)
11	20.2	(1.6)	78.9	(2.4)	-3.09	(8.02)	0.89	(1.79)	20.0	(1.7)	76.9	(3.4)	-2.99	(6.26)	0.96	(1.37)
12	20.7	(1.5)	83.0	(1.7)	-3.64	(8.89)			20.7	(1.6)	82.2	(1.9)	-3.59	(6.19)	1.06	(1.39)
13	20.4	(1.6)	82.5	(2.9)	-3.36	(8.24)	1.16	(2.05)	20.1	(1.6)	80.9	(3.3)	-3.33	(7.42)	1.20	(1.84)
14	20.2	(1.4)	82.9	(2.6)	-3.18	(5.52)	1.19	(1.53)	19.8	(1.4)	79.7	(3.8)	-3.13	(5.83)	1.20	(1.56)
15	18.9	(0.6)	81.2	(1.6)	-5.32	(7.25)	1.46	(1.82)	18.4	(0.9)	77.1	(2.5)	-5.05	(7.35)	1.45	(1.81)
16	19.8	(0.9)	82.6	(1.2)	-6.19	(8.34)	1.66	(2.04)	19.7	(1.0)	78.8	(1.9)	-5.47	(7.95)	1.67	(2.06)
17	25.4	(6.2)	72.8	(11.7)	-6.55	(10.20)	1.76	(2.34)	25.7	(6.6)	68.1	(12.2)	-5.74	(9.62)	1.75	(2.29)
18	31.8	(0.4)	57.8	(2.3)	-6.91	(11.50)	2.07	(2.70)	31.9	(0.4)	53.6	(1.6)	-5.88	(10.50)	2.11	(2.76)
19	31.4	(0.9)	52.3	(3.4)	-7.44	(10.70)	3.03	(3.45)	31.2	(0.8)	49.2	(3.3)	-7.05	(10.10)	3.10	(3.61)
20	30.5	(0.5)	55.1	(3.1)	-5.20	(8.63)	2.72	(3.49)	30.2	(0.5)	52.3	(2.7)	-5.50	(9.12)	2.68	(3.50)
21	29.9	(0.5)	57.7	(3.0)	-5.62	(9.11)	2.92	(3.52)	29.8	(0.4)	54.6	(2.4)	-5.83	(9.47)	2.93	(3.53)
22	29.4	(0.5)	62.1	(3.4)	-6.45	(9.90)	3.04	(3.58)	29.6	(0.5)	57.7	(3.0)	-6.63	(10.10)	3.03	(3.62)
23	28.9	(0.5)	65.1	(1.7)	-8.09	(10.20)	3.80	(3.99)	28.9	(0.4)	61.0	(1.7)	-8.44	(10.70)	3.76	(3.99)
24	28.5	(0.5)	60.5	(3.0)	-9.63	(9.99)	4.46	(4.03)	28.4	(0.5)	56.5	(2.7)	-10.30	(10.40)	4.53	(4.06)
25	28.1	(0.4)	59.7	(5.5)	-10.80	(10.40)	4.89	(4.12)	28.0	(0.4)	56.2	(5.0)	-11.10	(9.96)	4.93	(4.06)
26	28.0	(0.4)	61.7	(4.0)	-11.60	(10.20)	5.28	(4.06)	27.8	(0.4)	59.3	(4.1)	-11.70	(10.20)	5.22	(4.06)
27	27.8	(0.4)	59.9	(3.0)	-10.90	(9.60)	5.11	(3.85)	27.5	(0.5)	56.2	(3.0)	-11.40	(9.89)	5.12	(3.85)
28	27.6	(0.4)	62.0	(2.0)	-12.60	(9.86)	5.76	(3.92)	27.3	(0.4)	59.3	(1.9)	-12.30	(9.78)	5.46	(3.83)
Mean	23.1		70.4		-5.25		2.63		23.0		67.5		-5.21		2.31	
n	28		28		28		26		28		28		28		28	
SD	5.4		9.5		3.36		1.87		5.3		10.0		3.43		1.64	
Min	15.1		52.3		-12.60		0.81		15.3		49.2		-12.30		0.82	
Max	31.8		83.0		-1.57		7.40		31.9		82.2		-1.25		5.46	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for March, 2009.

Day	House 10								House 12							
	T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	27.3	(0.4)	64.0	(1.3)	-14.70	(9.95)	6.39	(3.77)	27.1	(0.3)	62.0	(1.1)	-13.80	(9.84)	5.82	(3.81)
2	27.5	(0.5)	60.8	(3.0)	-15.50	(9.10)	8.16	(4.47)	27.2	(0.6)	60.4	(2.6)	-16.90	(9.33)	7.37	(3.77)
3	26.8	(0.5)	58.8	(2.0)	-12.00	(9.99)	7.54	(5.64)	26.9	(0.4)	58.4	(1.6)	-13.40	(10.70)	6.91	(5.01)
4	26.6	(0.6)	56.6	(3.8)	-12.10	(10.40)	7.54	(5.83)	26.3	(0.6)	56.0	(2.8)	-12.20	(10.50)	7.41	(5.80)
5	26.2	(0.7)	54.8	(3.7)	-12.60	(10.30)	7.88	(5.64)	26.1	(0.7)	54.5	(3.2)	-13.10	(10.80)	7.80	(5.73)
6	25.8	(0.6)	55.4	(4.2)	-13.10	(10.00)	8.29	(5.65)	25.6	(0.7)	55.2	(3.4)	-13.60	(10.80)	8.12	(5.86)
7	25.4	(0.7)	56.2	(4.5)	-13.00	(10.50)	8.14	(5.80)	25.2	(0.8)	55.1	(4.0)	-13.60	(10.00)	8.12	(5.53)
8	25.2	(0.8)	54.1	(5.2)	-15.10	(10.40)	9.77	(6.08)	25.1	(0.8)	53.1	(4.5)	-15.80	(10.70)	9.51	(5.74)
9	24.6	(0.6)	53.3	(5.3)	-13.80	(11.30)	8.40	(5.99)	24.2	(0.5)	52.5	(4.1)	-14.60	(12.30)	8.34	(6.09)
10	24.6	(0.8)	54.2	(7.1)	-16.50	(13.50)	8.56	(5.81)	24.3	(0.7)	53.4	(5.8)	-14.90	(11.40)	8.77	(5.90)
11	24.7	(0.6)	54.7	(6.6)	-16.80	(12.10)	9.12	(5.87)	24.4	(0.7)	54.5	(5.3)	-15.40	(10.50)	9.34	(5.87)
12	24.6	(0.5)	55.2	(5.8)	-18.90	(11.60)	11.60	(7.28)	24.6	(0.7)	54.8	(5.0)	-17.70	(10.40)	11.70	(6.93)
13	24.3	(0.8)	56.5	(5.7)	-18.30	(10.90)	13.20	(8.17)	24.5	(1.1)	55.7	(5.2)	-16.00	(8.36)	12.90	(7.39)
14	23.7	(0.6)	58.6	(4.6)	-15.00	(8.09)	11.10	(5.62)	24.0	(0.9)	58.7	(4.1)	-14.20	(7.56)	11.10	(5.65)
15	23.7	(0.6)	58.6	(5.6)	-19.10	(7.94)	15.80	(7.68)	24.1	(0.9)	58.1	(5.6)	-17.90	(8.00)	15.50	(7.70)
16	23.8	(1.0)	61.6	(5.2)	-19.90	(6.79)	18.20	(7.86)	24.3	(1.2)	60.3	(5.3)	-19.00	(6.04)	17.80	(7.72)
17	23.1	(1.2)	60.9	(6.0)	-21.20	(6.56)	19.40	(7.87)	23.6	(1.0)	59.6	(5.5)	-19.00	(4.29)	19.90	(8.12)
18	22.7	(2.0)	59.5	(5.1)	-19.40	(5.40)	21.30	(7.27)	23.4	(1.9)	58.1	(4.7)	-17.00	(4.25)	21.40	(7.54)
19	23.4	(2.3)	59.0	(6.6)	-20.70	(8.63)	24.90	(13.00)	23.9	(2.3)	57.6	(6.4)	-18.20	(7.20)	25.00	(13.20)
20	22.9	(2.0)	60.9	(4.9)	-20.80	(8.15)	25.10	(12.40)	23.3	(2.2)	58.9	(5.1)	-18.10	(7.29)	25.10	(12.80)
21	21.6	(0.9)	63.4	(5.4)	-19.30	(5.59)	20.20	(7.50)	22.1	(0.9)	61.8	(5.0)	-16.30	(5.04)	19.90	(7.81)
22	20.5	(0.6)	59.7	(6.1)	-18.50	(6.40)	16.70	(4.50)	21.0	(0.6)	59.5	(5.0)	-15.40	(5.84)	16.00	(5.61)
23	20.1	(0.8)	53.6	(7.4)	-18.90	(6.78)	17.50	(6.60)	20.6	(0.9)	54.1	(6.5)	-16.00	(6.44)	17.50	(7.10)
24	21.3	(1.6)	57.4	(7.3)	-18.60	(7.37)	19.50	(9.07)	21.8	(1.6)	56.8	(6.6)	-16.30	(6.90)	19.50	(9.29)
25	22.1	(1.9)	58.2	(7.4)	-18.30	(6.13)	22.70	(10.60)	22.6	(1.9)	57.7	(6.8)	-16.10	(5.56)	22.40	(10.70)
26	23.0	(2.3)	56.2	(10.1)	-23.30	(8.04)	28.30	(13.40)	23.2	(2.1)	55.1	(9.7)	-19.80	(6.85)	29.10	(14.40)
27	21.4	(4.0)	59.6	(9.8)	-9.76	(9.88)	17.30	(17.50)	22.1	(3.2)	54.1	(9.5)	-22.20	(6.74)	32.70	(16.20)
28	21.7	(4.2)	62.6	(13.1)	-13.90	(15.50)	31.00	(33.00)	18.0	(5.5)	63.9	(15.5)	-26.20	(6.87)	71.50	(4.87)
29	13.9	(3.9)	51.7	(20.6)	-38.20	(6.82)	63.70	(5.03)	13.5	(3.9)	51.3	(19.5)	-31.40	(2.51)	70.20	(1.31)
30	14.2	(5.9)	74.8	(14.5)	-9.70	(18.80)	15.50	(23.70)	13.5	(5.2)	72.5	(14.0)	-9.56	(15.60)	22.00	(30.50)
31	18.6	(2.9)	59.0	(14.4)	-4.58	(4.49)	10.80	(7.54)	17.6	(2.7)	59.3	(15.1)	-1.58	(1.97)	10.60	(7.75)
Mean	23.1		58.4		-16.80		16.60		23.0		57.5		-16.30		18.70	
n	31		31		31		31		31		31		31		31	
SD	3.2		4.3		5.59		10.90		3.4		4.1		4.85		15.40	
Min	13.9		51.7		-38.20		6.39		13.5		51.3		-31.40		5.82	
Max	27.5		74.8		-4.58		63.70		27.2		72.5		-1.58		71.50	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for April, 2009.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	18.7	(4.3)	61.3	(7.7)	-5.14	(5.08)	7.22	(7.99)	18.2	(4.3)	58.4	(8.8)	-2.69	(2.59)	7.65	(8.45)
2	18.7	(3.3)	60.5	(12.3)	-12.30	(9.40)	9.90	(6.99)	18.3	(3.2)	59.1	(11.8)	-11.10	(8.51)	10.20	(7.19)
3	14.0	(3.9)	49.8	(15.8)	-19.60	(2.73)	15.10	(0.29)	13.6	(3.8)	48.7	(13.6)	-17.70	(1.72)	15.50	(0.23)
4	13.6	(5.3)	45.1	(13.3)	-18.20	(1.10)	15.10	(0.27)	13.1	(5.3)	45.1	(11.6)	-17.60	(0.92)	15.40	(0.32)
5	15.9	(6.9)	44.8	(17.0)	-17.70	(0.95)	15.00	(0.45)	15.4	(6.8)	44.9	(14.5)	-18.20	(0.80)	15.10	(0.38)
6	18.1	(6.9)	43.8	(14.4)	-18.10	(0.93)	14.80	(0.44)	17.5	(6.9)	44.4	(12.3)	-20.00	(8.56)	17.90	(8.78)
7	16.3	(3.6)	55.7	(6.9)	-8.25	(11.00)	17.20	(21.90)	14.7	(2.8)	58.5	(7.9)	-12.40	(13.20)	22.70	(21.80)
8	20.6	(4.5)	57.2	(3.2)	-1.85	(3.52)	0.96	(2.48)	19.8	(4.9)	60.2	(3.3)	-1.72	(5.06)	0.85	(1.58)
9	21.7	(1.2)	58.9	(1.5)	-2.00	(3.75)	0.89	(1.80)	21.4	(1.2)	60.0	(2.0)	-2.11	(5.66)	0.83	(1.56)
10	21.7	(2.2)	59.6	(3.5)	-2.23	(4.39)	0.88	(1.47)	21.2	(2.2)	60.2	(4.1)	-2.67	(6.04)	0.82	(1.59)
11	22.2	(3.4)	62.1	(5.4)	-2.24	(4.19)	0.87	(1.19)	21.8	(3.3)	63.4	(6.6)	-2.72	(6.54)	0.83	(1.66)
12	24.3	(4.2)	65.4	(7.3)	-2.68	(5.11)	1.03	(1.40)	23.9	(4.2)	66.3	(9.4)	-3.54	(8.43)	1.07	(2.01)
13	24.0	(3.0)	69.1	(5.1)	-3.02	(5.13)	1.10	(1.41)	23.6	(3.0)	69.6	(6.3)	-3.56	(8.70)	1.05	(2.06)
14	21.4	(1.8)	62.3	(10.7)	-6.06	(6.65)	1.13	(1.79)	20.9	(2.0)	63.0	(10.7)	-6.96	(7.97)	1.12	(2.19)
15	21.7	(2.7)	62.3	(7.8)	-4.41	(7.50)	1.19	(2.25)	21.3	(2.8)	61.9	(8.9)	-5.00	(7.74)	1.21	(2.31)
16	23.0	(3.2)	66.8	(9.0)	-4.86	(8.77)	1.52	(2.43)	22.8	(3.3)	65.2	(9.8)	-4.95	(8.07)	1.59	(2.34)
17	24.8	(3.8)	63.7	(11.9)	-7.33	(10.70)	2.22	(2.82)	24.7	(3.8)	61.8	(12.5)	-7.12	(10.00)	2.31	(2.81)
18	28.6	(4.5)	56.5	(13.1)	-11.10	(10.70)	3.88	(3.50)	28.2	(4.3)	55.2	(12.6)	-10.10	(10.00)	3.93	(3.55)
19	32.0	(0.9)	47.4	(8.1)	-13.30	(12.20)	8.08	(8.20)	31.0	(1.3)	47.5	(8.4)	-13.60	(12.50)	8.36	(8.28)
20	31.8	(1.4)	47.4	(6.8)	-14.00	(13.40)	9.41	(8.46)	31.3	(1.8)	47.1	(6.7)	-13.60	(13.20)	9.31	(8.46)
21	31.7	(1.7)	48.4	(8.4)	-12.80	(14.20)	9.78	(8.84)	31.6	(1.8)	47.7	(7.4)	-12.00	(12.90)	9.80	(8.81)
22	31.4	(1.6)	43.7	(8.0)	-12.70	(13.70)	11.00	(9.61)	31.3	(1.9)	43.0	(6.9)	-13.70	(11.90)	11.50	(8.65)
23	30.0	(0.5)	47.5	(4.6)	-12.50	(12.40)	4.96	(4.31)	29.7	(0.4)	44.6	(3.7)	-14.50	(11.70)	5.89	(4.42)
24	29.5	(0.5)	43.8	(4.2)	-9.81	(10.60)	3.92	(3.61)	29.2	(0.4)	42.7	(4.0)	-9.60	(11.10)	3.89	(4.00)
25	29.0	(0.5)	47.3	(4.2)	-12.90	(11.90)	4.96	(3.90)	28.7	(0.5)	45.7	(4.3)	-12.70	(12.10)	5.09	(4.30)
26	28.5	(0.4)	49.6	(6.4)	-13.90	(12.50)	5.50	(4.43)	28.3	(0.4)	47.0	(5.4)	-13.40	(12.10)	5.76	(4.82)
27	28.3	(0.5)	49.9	(5.7)	-14.50	(12.20)	5.63	(4.32)	28.0	(0.4)	47.4	(4.5)	-14.00	(12.10)	5.82	(4.57)
28	27.8	(0.5)	51.6	(4.5)	-13.30	(12.00)	5.06	(4.04)	27.5	(0.4)	48.2	(4.3)	-12.50	(11.80)	5.04	(4.29)
29	27.8	(0.5)	51.1	(5.9)	-15.10	(11.90)	5.95	(4.30)	27.5	(0.6)	47.0	(5.0)	-14.10	(11.80)	6.08	(4.80)
30	27.6	(0.6)	51.0	(6.8)	-18.80	(13.20)	7.40	(4.84)	27.6	(0.6)	48.6	(5.5)	-16.50	(11.70)	7.31	(5.06)
Mean	24.2		54.1		-10.40		6.38		23.7		53.4		-10.40		6.80	
n	30		30		30		30		30		30		30		30	
SD	5.5		7.6		5.64		5.04		5.6		8.2		5.47		5.75	
Min	13.6		43.7		-19.60		0.87		13.1		42.7		-20.00		0.82	
Max	32.0		69.1		-1.85		17.20		31.6		69.6		-1.72		22.70	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for May, 2009.

Day	House 10				House 12			
	T, ºC	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}	T, ºC	RH, %	ΔP, Pa	Airflow, dsm^3 s^{-1}
1	27.3 (0.4)	62.7 (5.9)	-17.90 (11.10)	6.75 (3.91)	27.2 (0.5)	59.3 (5.4)	-16.20 (11.20)	6.47 (4.11)
2	27.1 (0.3)	66.2 (4.1)	-16.30 (12.60)	7.27 (5.20)	27.5 (0.5)	62.5 (3.5)	-14.70 (12.30)	6.96 (5.35)
3	27.0 (0.4)	66.2 (2.6)	-21.20 (13.30)	9.67 (5.31)	27.5 (0.5)	62.5 (2.2)	-18.60 (11.40)	9.49 (5.32)
4	27.2 (0.7)	58.0 (7.5)	-27.10 (13.60)	13.50 (6.56)	27.3 (0.8)	55.7 (7.0)	-24.30 (12.20)	13.50 (7.02)
5	26.9 (1.0)	62.8 (5.7)	-20.90 (9.80)	18.60 (11.30)	27.6 (0.9)	59.0 (5.4)	-17.90 (9.39)	17.90 (11.70)
6	27.0 (1.3)	61.6 (5.8)	-17.80 (8.18)	20.20 (13.10)	27.5 (1.4)	57.8 (5.6)	-14.80 (7.97)	20.10 (13.70)
7	26.1 (1.0)	57.2 (10.5)	-16.00 (7.30)	18.50 (12.30)	26.7 (1.1)	54.3 (9.1)	-13.40 (6.59)	18.50 (12.40)
8	26.3 (1.4)	51.5 (9.5)	-19.00 (8.01)	21.10 (13.30)	26.8 (1.5)	49.7 (8.6)	-15.50 (7.53)	21.20 (14.00)
9	26.7 (2.1)	49.7 (9.7)	-22.70 (10.40)	26.10 (17.00)	27.1 (2.0)	48.2 (8.7)	-20.00 (10.80)	26.00 (17.10)
10	26.5 (2.3)	49.2 (7.4)	-23.90 (9.51)	28.30 (16.40)	27.1 (2.1)	48.3 (7.3)	-21.10 (10.00)	27.90 (16.60)
11	26.1 (2.0)	48.5 (6.9)	-24.00 (9.82)	27.00 (16.40)	26.6 (2.1)	46.9 (6.7)	-20.50 (10.30)	26.90 (16.90)
12	25.1 (1.8)	47.7 (8.9)	-23.00 (8.16)	25.50 (15.10)	25.7 (1.8)	46.5 (8.2)	-19.50 (8.63)	25.30 (15.60)
13	25.1 (2.0)	47.9 (8.9)	-25.50 (8.49)	30.00 (15.60)	25.9 (2.1)	46.3 (8.5)	-22.20 (9.50)	29.70 (16.40)
14	25.0 (2.1)	54.4 (5.7)	-26.60 (7.82)	31.60 (14.70)	25.7 (2.1)	51.7 (5.5)	-22.90 (9.25)	31.10 (15.90)
15	24.8 (1.9)	63.9 (3.8)	-28.80 (7.57)	36.20 (12.90)	25.7 (1.6)	59.2 (3.6)	-26.40 (9.03)	35.10 (14.00)
16	25.5 (2.2)	65.7 (5.1)	-35.70 (9.73)	43.60 (10.80)	26.1 (1.9)	61.2 (4.4)	-33.00 (10.10)	42.90 (12.50)
17	26.2 (1.8)	66.1 (4.4)	-38.00 (9.78)	48.00 (5.70)	26.6 (1.7)	61.6 (3.9)	-36.20 (9.69)	49.00 (6.50)
18	25.4 (1.4)	61.7 (6.6)	-38.70 (8.26)	48.80 (5.65)	25.9 (1.3)	58.0 (5.9)	-35.90 (9.39)	49.90 (6.89)
19	23.4 (1.9)	59.5 (8.7)	-28.10 (10.40)	42.20 (6.73)	24.1 (1.9)	55.4 (7.1)	-28.00 (9.22)	41.40 (8.49)
20	23.0 (2.3)	48.7 (4.2)	-29.50 (7.63)	37.80 (10.80)	23.8 (2.0)	47.2 (3.7)	-27.70 (8.55)	36.70 (12.30)
21	23.2 (2.2)	55.4 (5.4)	-29.70 (8.42)	38.60 (9.99)	24.0 (1.9)	52.2 (4.5)	-27.90 (9.10)	38.10 (11.40)
22	23.5 (2.4)	60.9 (3.7)	-30.30 (8.36)	39.10 (9.41)	24.2 (2.1)	56.6 (3.2)	-28.50 (8.86)	38.30 (10.80)
23	22.5 (2.5)	62.0 (4.3)	-28.00 (8.42)	34.80 (11.30)	23.2 (2.4)	57.4 (4.1)	-25.80 (9.03)	34.60 (11.60)
24	22.1 (2.8)	60.7 (5.9)	-27.60 (8.17)	33.30 (11.70)	22.6 (2.6)	57.0 (5.3)	-25.40 (8.76)	33.70 (11.70)
25	22.7 (3.0)	63.6 (5.0)	-29.60 (8.22)	35.70 (11.10)	23.2 (3.0)	59.2 (4.7)	-27.20 (9.13)	36.10 (11.10)
26	24.2 (2.5)	62.4 (4.8)	-39.20 (11.20)	43.80 (10.80)	24.4 (1.9)	59.7 (4.4)	-36.00 (11.90)	44.50 (12.50)
27	27.5 (4.0)	52.7 (6.1)	-20.70 (12.20)	36.50 (21.80)	26.7 (3.6)	53.8 (4.9)	-25.20 (12.70)	37.80 (21.20)
28	27.4 (4.8)	47.8 (7.7)	-18.90 (11.50)	19.60 (15.10)	27.1 (4.8)	47.1 (7.0)	-17.60 (8.34)	21.20 (19.00)
29	25.6 (4.4)	52.3 (6.2)	-17.20 (9.39)	8.78 (2.31)	25.2 (4.4)	51.2 (6.1)	-11.70 (9.04)	9.36 (2.50)
30	24.5 (4.3)	56.0 (6.3)	-12.00 (0.59)	7.48 (0.16)	24.1 (4.3)	55.1 (6.2)	-6.88 (2.11)	7.97 (0.11)
31	24.1 (4.4)	54.0 (7.7)	-11.80 (1.24)	7.50 (0.13)	23.8 (4.4)	53.3 (7.5)	-6.98 (1.80)	7.96 (0.14)
Mean	25.3	57.3	-24.70	27.30	25.7	54.6	-22.20	27.30
n	31	31	31	31	31	31	31	31
SD	1.6	6.3	7.20	12.90	1.5	5.1	7.66	12.90
Min	22.1	47.7	-39.20	6.75	22.6	46.3	-36.20	6.47
Max	27.5	66.2	-11.80	48.80	27.6	62.5	-6.88	49.90

Table E3. Daily means (SD) of environmental parameters at Site CA1B for June, 2009.

Day	House 10								House 12							
	T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	22.8	(4.5)	56.5	(7.9)	-10.80	(4.49)	18.00	(16.90)	22.2	(4.4)	55.9	(8.5)	-18.80	(10.70)	23.30	(17.70)
2																
3																
4																
5	26.0	(2.7)	59.8	(4.5)	-2.67	(6.86)	0.96	(1.85)	25.9	(2.7)	56.4	(4.6)	-2.44	(5.74)	1.01	(1.49)
6	26.7	(3.4)	59.4	(8.8)	-3.88	(8.25)	1.24	(2.19)	26.5	(3.6)	57.9	(8.7)	-3.58	(6.41)	1.21	(1.69)
7	27.3	(3.6)	56.7	(10.8)	-7.41	(11.20)	2.09	(2.84)	27.2	(3.7)	56.8	(11.1)	-6.19	(9.84)	1.85	(2.57)
8	27.1	(3.3)	54.5	(10.1)	-6.22	(8.50)	2.49	(2.95)	27.2	(3.3)	54.7	(10.8)	-6.87	(9.24)	2.31	(2.83)
9	26.8	(3.1)	55.7	(8.6)	-4.86	(6.76)	2.16	(2.59)	26.7	(3.1)	56.5	(9.4)	-5.77	(7.60)	2.12	(2.52)
10	27.0	(2.5)	57.6	(8.2)	-5.88	(7.59)	2.56	(2.83)	27.1	(2.6)	57.8	(9.2)	-6.74	(8.12)	2.48	(2.63)
11	26.9	(2.8)	58.4	(9.5)	-7.22	(8.52)	3.06	(3.13)	27.0	(2.9)	58.4	(10.7)	-8.23	(8.96)	3.01	(2.89)
12	28.0	(3.4)	55.3	(10.6)	-6.95	(7.64)	3.24	(3.10)	28.0	(3.2)	55.3	(11.1)	-7.09	(7.53)	3.13	(3.00)
13	31.1	(0.4)	52.5	(3.4)	-7.15	(7.73)	3.73	(3.43)	30.9	(0.4)	52.8	(4.4)	-6.10	(7.00)	3.23	(3.07)
14	30.6	(0.6)	48.4	(5.0)	-6.47	(7.86)	4.44	(4.46)	30.5	(0.4)	48.3	(5.2)	-5.11	(6.95)	3.72	(4.23)
15	29.9	(0.5)	51.3	(4.2)	-6.58	(7.90)	4.25	(4.31)	30.0	(0.5)	50.3	(3.2)	-4.76	(7.24)	3.49	(4.27)
16	29.7	(0.9)	50.6	(7.2)	-11.20	(10.30)	8.98	(8.28)	29.9	(0.8)	49.3	(6.1)	-9.47	(9.45)	8.34	(7.97)
17	29.6	(1.0)	50.3	(5.2)	-12.90	(10.40)	9.92	(8.29)	29.8	(1.0)	49.3	(4.3)	-11.00	(9.93)	9.36	(8.26)
18	29.7	(1.8)	52.1	(5.2)	-9.77	(6.64)	17.40	(15.00)	30.2	(1.7)	50.5	(4.6)	-8.73	(6.97)	16.50	(15.00)
19	28.9	(1.9)	47.3	(7.9)	-10.30	(7.13)	18.20	(15.00)	29.6	(2.2)	45.8	(7.0)	-9.63	(7.46)	16.40	(14.30)
20	27.7	(1.2)	48.7	(6.3)	-10.60	(7.71)	12.90	(11.40)	28.0	(1.3)	47.4	(5.0)	-9.30	(7.80)	12.10	(11.10)
21	27.2	(0.8)	50.7	(5.6)	-13.00	(9.13)	12.00	(10.00)	27.5	(0.9)	49.1	(4.3)	-12.10	(9.42)	11.70	(9.67)
22	27.9	(1.7)	47.1	(10.8)	-11.10	(7.34)	17.40	(14.20)	28.1	(1.7)	46.4	(8.5)	-9.97	(7.07)	17.00	(14.30)
23	28.7	(2.1)	46.9	(7.4)	-12.00	(6.41)	22.70	(14.30)	28.7	(1.9)	46.6	(5.9)	-10.90	(5.24)	22.30	(14.30)
24	28.3	(1.9)	49.3	(4.1)	-12.20	(4.62)	23.00	(13.80)	28.7	(1.8)	48.4	(3.8)	-11.40	(5.23)	22.50	(14.30)
25	27.7	(1.7)	49.0	(5.1)	-10.80	(5.43)	19.30	(13.50)	28.0	(1.9)	48.8	(4.9)	-11.00	(6.31)	18.80	(13.50)
26	27.5	(1.5)	49.0	(4.9)	-11.40	(4.98)	20.90	(13.60)	27.8	(1.8)	48.4	(4.9)	-11.60	(5.48)	20.40	(13.60)
27	28.4	(1.6)	55.8	(3.4)	-14.10	(4.09)	31.20	(15.20)	28.7	(1.8)	53.9	(3.6)	-16.00	(4.83)	30.20	(14.90)
28	28.6	(1.6)	56.7	(6.7)	-14.40	(2.46)	35.10	(11.10)	29.0	(1.6)	54.6	(5.3)	-15.90	(2.77)	33.60	(11.60)
29	28.4	(1.6)	50.2	(6.6)	-14.40	(2.73)	35.90	(11.10)	28.9	(1.7)	49.1	(5.4)	-15.80	(3.35)	34.30	(11.70)
30	27.4	(1.7)	51.2	(4.3)	-14.00	(3.43)	30.40	(12.80)	28.0	(1.7)	50.0	(3.6)	-15.30	(3.16)	29.00	(12.50)
Mean	28.0		52.6		-9.58		13.50		28.2		51.8		-9.62		13.10	
n	27		27		27		27		27		27		27		27	
SD	1.6		3.9		3.36		10.90		1.7		4.0		4.08		10.70	
Min	22.8		46.9		-14.40		0.96		22.2		45.8		-18.80		1.01	
Max	31.1		59.8		-2.67		35.90		30.9		58.4		-2.44		34.30	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for July, 2009.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	26.6	(1.2)	57.3	(3.3)	-14.10	(2.72)	30.90	(12.80)	27.3	(1.4)	54.9	(2.4)	-15.20	(3.91)	29.70	(13.20)
2	27.2	(2.0)	53.5	(3.3)	-21.40	(8.15)	34.40	(15.50)	27.8	(2.1)	51.6	(3.3)	-21.30	(7.99)	33.90	(15.80)
3	26.8	(2.2)	53.0	(3.5)	-23.10	(6.98)	35.10	(15.60)	27.5	(2.1)	50.7	(3.6)	-22.50	(6.86)	34.50	(15.90)
4	26.3	(2.0)	54.6	(2.5)	-22.40	(6.78)	34.00	(15.20)	27.0	(2.0)	52.1	(2.4)	-21.40	(6.86)	33.40	(15.60)
5	25.7	(2.0)	57.4	(4.0)	-21.90	(6.57)	32.10	(16.30)	26.3	(2.1)	54.2	(4.0)	-21.00	(6.92)	31.90	(16.50)
6	25.0	(2.0)	51.4	(7.4)	-24.80	(10.20)	34.90	(19.70)	25.7	(2.1)	49.0	(7.0)	-23.80	(10.10)	34.50	(20.40)
7	24.7	(1.8)	50.3	(4.9)	-26.50	(10.70)	38.70	(19.00)	25.5	(1.8)	47.4	(4.9)	-25.80	(10.30)	37.80	(19.70)
8	24.3	(1.7)	55.0	(4.5)	-29.00	(9.27)	41.80	(17.80)	25.1	(1.7)	51.8	(3.8)	-27.70	(9.60)	41.10	(18.80)
9	23.7	(1.6)	57.6	(3.8)	-29.10	(9.63)	42.90	(16.90)	24.5	(1.5)	53.9	(3.0)	-28.50	(9.51)	41.70	(18.80)
10	23.4	(1.6)	57.5	(3.2)	-30.10	(9.66)	45.30	(16.90)	24.2	(1.6)	53.9	(3.2)	-28.40	(10.40)	44.70	(17.90)
11	23.6	(1.2)	57.7	(5.6)	-32.90	(9.73)	53.80	(7.50)	24.4	(1.1)	53.6	(4.7)	-32.20	(8.82)	52.50	(11.20)
12	23.2	(1.3)	55.6	(5.2)	-34.50	(6.93)	54.50	(5.68)	23.9	(1.2)	52.5	(4.2)	-31.70	(9.53)	53.60	(8.31)
13	23.3	(2.2)	60.5	(5.0)	-34.30	(8.67)	52.10	(9.89)	23.9	(1.9)	56.7	(4.0)	-33.70	(7.61)	51.30	(12.70)
14	25.3	(2.6)	61.5	(4.1)	-38.40	(1.91)	56.60	(1.52)	25.6	(2.5)	58.2	(3.6)	-36.60	(4.21)	55.80	(3.32)
15	26.2	(2.4)	60.3	(4.5)	-38.90	(1.07)	56.60	(0.98)	26.3	(2.3)	57.6	(4.2)	-38.80	(1.07)	57.60	(0.97)
16	25.9	(2.5)	60.4	(4.8)	-38.60	(1.48)	56.80	(1.14)	25.8	(2.5)	57.7	(4.6)	-38.10	(1.97)	57.70	(1.68)
17	26.2	(2.4)	59.7	(5.7)	-38.90	(0.89)	56.80	(0.74)	26.1	(2.4)	57.0	(5.7)	-38.70	(0.79)	57.90	(0.67)
18	26.6	(2.6)	60.3	(6.4)	-39.40	(0.92)	56.20	(0.71)	26.4	(2.5)	57.7	(6.6)	-39.20	(0.94)	57.30	(0.74)
19	26.9	(3.1)	65.1	(3.3)	-39.30	(0.70)	56.00	(0.77)	26.7	(2.9)	62.3	(3.2)	-39.10	(0.71)	57.00	(0.79)
20	25.2	(2.5)	61.6	(3.6)	-39.60	(1.06)	56.50	(0.80)	25.1	(2.5)	59.0	(3.4)	-39.10	(0.87)	57.70	(0.69)
21	26.5	(4.9)	54.1	(7.8)	-28.20	(13.40)	37.00	(25.50)	24.2	(3.7)	57.9	(8.3)	-47.00	(32.30)	40.90	(22.80)
22	27.0	(4.3)	53.2	(8.6)	-17.20	(16.80)	22.00	(24.60)	24.9	(5.6)	56.4	(11.3)	-35.10	(35.00)	24.60	(25.90)
23	26.9	(5.5)	50.1	(8.7)	-18.70	(5.32)	14.20	(1.11)	26.7	(5.6)	49.7	(8.3)	-28.70	(5.39)	13.10	(0.85)
24																
25																
26																
27																
28	29.9	(3.9)	49.1	(5.2)	-3.91	(5.56)	3.92	(4.81)	29.7	(4.2)	48.3	(5.7)	-4.96	(7.02)	4.02	(5.00)
29	28.5	(4.1)	52.5	(4.9)	-4.44	(6.51)	2.74	(3.43)	28.1	(4.4)	51.6	(5.4)	-5.15	(7.82)	2.90	(3.84)
30	28.7	(3.6)	54.0	(5.9)	-7.06	(8.59)	3.50	(3.82)	28.9	(3.6)	51.6	(5.8)	-6.74	(8.82)	3.57	(4.05)
31	28.9	(3.6)	52.4	(7.2)	-7.01	(8.77)	3.58	(4.07)	29.3	(3.5)	51.1	(7.7)	-7.55	(9.60)	3.73	(4.20)
Mean	26.0		56.1		-26.10		37.50		26.2		54.0		-27.30		37.60	
n	27		27		27		27		27		27		27		27	
SD	1.8		4.0		11.30		18.20		1.6		3.6		11.40		18.30	
Min	23.2		49.1		-39.60		2.74		23.9		47.4		-47.00		2.90	
Max	29.9		65.1		-3.91		56.80		29.7		62.3		-4.96		57.90	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for August, 2009.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	29.3	(3.6)	49.3	(8.2)	-7.11	(8.20)	4.00	(4.27)	29.5	(3.5)	48.8	(8.7)	-7.13	(8.91)	4.16	(4.63)
2	28.1	(3.3)	50.8	(7.8)	-8.37	(9.14)	4.64	(5.20)	28.6	(3.2)	50.0	(8.2)	-8.38	(10.10)	4.37	(5.15)
3	27.5	(3.4)	54.0	(8.5)	-8.71	(9.33)	4.37	(4.81)	27.9	(3.3)	53.3	(8.6)	-9.87	(11.20)	4.21	(4.55)
4	27.9	(3.8)	52.5	(10.1)	-8.52	(9.22)			27.9	(3.9)	52.7	(11.0)	-9.36	(10.60)		
5	28.7	(2.8)	50.9	(8.2)	-6.84	(6.89)			28.4	(3.1)	51.0	(9.1)	-7.87	(8.12)		
6	28.0	(2.5)	54.9	(7.4)	-5.71	(6.88)			27.8	(2.8)	54.6	(8.2)	-6.08	(7.04)		
7	28.0	(2.7)	53.8	(7.9)	-6.79	(7.28)			27.9	(2.8)	53.7	(8.8)	-7.10	(7.50)		
8	29.4	(2.5)	51.0	(7.9)	-5.69	(6.23)	9.91	(9.86)	29.5	(2.6)	50.0	(8.3)	-5.58	(6.57)	9.93	(9.93)
9	31.1	(2.2)	43.7	(7.1)	-6.88	(5.95)	13.30	(11.70)	31.4	(2.1)	42.2	(6.4)	-6.81	(6.23)	13.30	(11.70)
10	31.1	(2.2)	46.4	(5.1)	-8.21	(6.79)	15.00	(12.10)	31.3	(2.0)	44.6	(4.4)	-7.68	(6.30)	14.90	(12.00)
11	30.7	(1.7)	47.3	(2.6)	-9.33	(7.00)	14.30	(11.30)	30.7	(1.8)	45.9	(2.7)	-8.61	(6.16)	14.50	(11.20)
12	30.3	(1.7)	47.6	(3.4)	-9.55	(6.91)	14.60	(11.30)	30.5	(1.7)	46.3	(3.2)	-8.62	(5.82)	14.70	(11.20)
13	29.9	(1.8)	47.5	(3.9)	-10.70	(6.63)	18.00	(14.60)	30.1	(1.8)	46.5	(3.8)	-9.70	(6.02)	18.00	(14.70)
14	28.7	(1.5)	42.4	(7.1)	-10.10	(7.19)	13.40	(11.30)	28.9	(1.5)	41.7	(6.0)	-9.18	(6.68)	13.50	(11.40)
15	28.7	(2.0)	46.6	(5.4)	-10.50	(6.81)	16.50	(14.00)	29.0	(1.9)	45.4	(4.7)	-9.56	(6.54)	16.50	(13.90)
16	28.6	(1.7)	44.9	(5.8)	-11.20	(6.54)	17.70	(14.20)	28.8	(1.7)	44.0	(5.0)	-10.60	(5.94)	17.70	(13.90)
17	28.5	(1.7)	48.9	(5.1)	-11.50	(6.11)	19.70	(14.30)	29.1	(1.7)	46.8	(4.4)	-10.90	(5.92)	19.50	(14.30)
18	28.2	(1.5)	54.7	(3.9)	-11.80	(6.40)	19.50	(14.00)	28.8	(1.5)	51.3	(3.1)	-11.00	(6.36)	19.30	(14.20)
19	27.8	(1.4)	55.3	(3.1)	-12.50	(5.79)	20.30	(13.80)	28.6	(1.3)	51.8	(2.5)	-11.50	(5.86)	19.80	(13.70)
20	27.4	(1.4)	57.2	(3.4)	-12.00	(5.89)	18.40	(13.60)	28.0	(1.3)	53.8	(2.9)	-10.80	(5.52)	18.10	(13.70)
21	27.6	(1.5)	61.4	(4.3)	-13.60	(5.47)	23.20	(13.20)	28.3	(1.4)	57.1	(3.3)	-12.50	(5.27)	23.70	(13.90)
22	27.4	(1.1)	59.1	(5.6)	-13.40	(3.75)	30.70	(11.10)	28.0	(1.0)	55.2	(5.0)	-13.90	(3.88)	30.40	(11.20)
23	26.8	(1.3)	56.7	(4.3)	-13.40	(4.86)	24.00	(12.50)	27.5	(1.2)	53.4	(3.6)	-12.80	(4.48)	23.60	(12.50)
24	26.2	(1.4)	51.4	(4.0)	-11.90	(6.03)	22.30	(13.90)	27.0	(1.3)	48.7	(3.6)	-11.20	(5.60)	21.90	(13.70)
25	26.3	(1.3)	54.2	(2.9)	-12.90	(5.84)	26.00	(15.60)	26.9	(1.2)	51.3	(2.6)	-12.50	(5.79)	25.20	(15.70)
26	26.1	(1.3)	55.8	(3.1)	-13.80	(5.40)	28.00	(15.40)	26.7	(1.2)	53.1	(2.6)	-13.30	(5.56)	27.20	(15.60)
27	25.9	(1.3)	53.0	(5.1)	-14.70	(4.17)	30.00	(14.20)	26.0	(1.4)	51.0	(4.4)	-14.50	(4.49)	29.50	(14.90)
28	26.2	(1.7)	54.1	(3.9)	-24.20	(10.10)	42.60	(20.90)	26.2	(1.7)	52.2	(3.5)	-24.60	(10.50)	42.80	(21.10)
29	26.6	(2.2)	59.0	(5.5)	-26.20	(8.86)	46.20	(19.80)	26.5	(1.9)	57.9	(5.7)	-26.00	(9.89)	45.60	(20.10)
30	25.8	(1.5)	53.5	(5.6)	-26.10	(8.25)	48.30	(16.20)	26.0	(1.3)	51.7	(5.3)	-26.10	(8.98)	46.50	(18.00)
31	24.8	(1.4)	60.8	(3.0)	-24.00	(8.23)	43.20	(19.00)	25.0	(1.3)	58.3	(2.9)	-23.50	(9.53)	42.30	(19.80)
Mean	28.0		52.2		-12.10		21.80		28.3		50.5		-11.80		21.50	
n	31		31		31		27		31		31		31		27	
SD	1.6		4.9		5.59		11.90		1.6		4.3		5.56		11.60	
Min	24.8		42.4		-26.20		4.00		25.0		41.7		-26.10		4.16	
Max	31.1		61.4		-5.69		48.30		31.4		58.3		-5.58		46.50	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for September, 2009.

Day	House 10								House 12							
	T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, ºC		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	24.9	(1.6)	65.4	(3.2)	-26.30	(7.97)	46.40	(17.60)	25.1	(1.4)	63.0	(3.2)	-26.20	(9.36)	45.70	(18.70)
2	25.2	(1.6)	62.5	(6.5)	-28.60	(8.34)	55.40	(10.70)	25.1	(1.4)	60.6	(6.7)	-29.20	(8.66)	54.20	(12.10)
3	24.8	(1.8)	60.2	(5.1)	-29.00	(7.66)	57.30	(7.85)	24.7	(1.6)	58.5	(5.5)	-29.00	(8.55)	56.40	(8.57)
4	23.3	(1.7)	55.5	(6.2)	-25.60	(9.25)	50.80	(13.00)	23.4	(1.5)	53.7	(6.0)	-26.30	(8.89)	49.50	(14.20)
5	23.0	(2.2)	66.9	(5.5)	-27.10	(7.80)	48.60	(17.30)	23.0	(2.0)	65.4	(6.6)	-26.90	(8.53)	48.00	(17.60)
6	22.4	(1.7)	63.0	(5.5)	-24.10	(10.60)	49.10	(15.20)	22.4	(1.6)	61.5	(5.5)	-23.90	(11.00)	47.60	(16.10)
7	22.0	(2.1)	66.1	(3.4)	-23.60	(11.60)	49.60	(13.80)	21.9	(2.1)	64.3	(3.4)	-23.50	(11.90)	48.90	(14.20)
8	22.0	(1.9)	63.5	(3.8)	-25.90	(10.90)	51.80	(12.90)	21.8	(1.9)	62.5	(4.0)	-26.00	(11.40)	50.80	(13.30)
9	22.9	(1.9)	64.2	(3.9)	-28.60	(9.73)	55.10	(10.60)	22.7	(1.7)	63.5	(4.5)	-28.50	(10.80)	54.00	(11.80)
10	23.5	(2.0)	64.2	(5.5)	-32.10	(6.99)	57.40	(7.17)	23.3	(2.0)	63.5	(5.4)	-31.80	(8.83)	55.40	(8.63)
11	24.7	(2.0)	64.6	(6.6)	-34.90	(1.64)	60.50	(1.62)	24.5	(2.0)	63.5	(6.8)	-35.90	(2.77)	59.70	(2.19)
12	23.6	(1.4)	66.8	(8.0)	-33.30	(4.42)	59.80	(4.57)	23.5	(1.3)	65.3	(8.7)	-34.00	(5.47)	59.20	(4.95)
13	21.7	(1.2)	70.0	(2.9)	-26.00	(11.80)	51.00	(13.70)	21.9	(1.2)	66.5	(2.9)	-26.50	(12.00)	50.50	(13.60)
14	21.8	(2.4)	69.2	(7.9)	-12.40	(9.12)	36.80	(14.20)	21.9	(1.9)	66.2	(5.8)	-12.70	(10.60)	41.80	(16.00)
15	21.7	(4.3)	74.3	(8.7)	-13.30	(6.11)	35.40	(26.40)	21.5	(4.4)	69.3	(10.0)	-4.47	(3.65)	35.40	(26.60)
16	21.9	(3.4)	77.6	(9.1)	-16.60	(13.10)	19.20	(19.20)	21.8	(3.5)	67.5	(7.4)	-7.66	(6.60)	21.40	(22.50)
17	23.9	(3.8)	66.4	(9.3)	-18.90	(12.70)	20.00	(11.90)	24.0	(4.3)	63.4	(10.4)	-16.60	(6.76)	24.00	(14.80)
18	25.9	(5.4)	58.2	(12.1)	-14.90	(10.60)	28.80	(13.50)	26.0	(5.4)	57.7	(10.9)	-21.90	(10.50)	14.00	(2.42)
19	26.2	(5.0)	53.8	(9.1)	-42.40	(19.90)	18.30	(13.30)	26.2	(4.7)	52.6	(9.8)	-30.50	(0.75)	12.90	(0.18)
20	25.7	(4.3)	57.6	(7.7)	-56.80	(1.10)	9.02	(0.14)	25.1	(4.4)	56.6	(8.1)	-30.60	(0.65)	13.00	(0.15)
21	26.4	(4.8)	54.2	(10.9)	-24.70	(27.80)	12.90	(3.32)	26.0	(5.0)	53.9	(10.6)	-30.30	(0.96)	12.90	(0.15)
22	27.2	(5.7)	48.1	(10.5)	-5.09	(7.31)	12.50	(12.60)	27.7	(6.3)	46.6	(11.4)	-15.30	(14.20)	18.70	(23.50)
23	27.7	(6.0)	42.2	(6.9)	-4.43	(6.12)	4.32	(5.43)	27.6	(6.0)	42.2	(7.0)	-4.26	(6.32)	4.29	(5.22)
24	27.8	(5.5)	40.5	(8.0)	-4.68	(6.74)	3.56	(4.29)	27.6	(5.4)	40.8	(7.3)	-4.32	(6.01)	3.53	(4.23)
25	27.4	(5.8)	42.0	(8.0)	-4.29	(7.24)	3.34	(4.40)	27.3	(5.7)	42.1	(7.4)	-4.71	(6.48)	3.48	(4.37)
26	30.1	(4.2)	41.9	(7.4)	-6.12	(7.84)	4.92	(5.45)	30.2	(4.3)	41.8	(7.5)	-8.82	(9.26)	4.83	(5.03)
27	30.2	(4.2)	45.5	(6.9)	-6.66	(7.59)	5.23	(5.63)	30.1	(4.4)	45.9	(8.0)	-9.81	(10.10)	5.05	(5.27)
28	28.6	(3.2)	46.4	(8.4)	-7.22	(9.17)	2.89	(3.08)	28.3	(3.1)	48.0	(9.4)	-8.97	(11.90)	2.98	(3.63)
29	25.7	(1.8)	49.7	(3.5)	-4.26	(6.12)	1.69	(2.08)	25.7	(2.2)	51.5	(4.1)	-4.82	(9.26)	1.61	(2.71)
30	24.2	(3.0)	53.4	(8.4)	-5.16	(6.69)	1.78	(2.20)	24.4	(2.9)	55.4	(8.9)	-5.63	(9.10)	1.70	(2.71)
Mean	24.9		58.5		-20.40		30.40		24.8		57.1		-19.60		30.10	
n	30		30		30		30		30		30		30		30	
SD	2.5		10.1		12.90		21.90		2.5		8.6		10.60		21.50	
Min	21.7		40.5		-56.80		1.69		21.5		40.8		-35.90		1.61	
Max	30.2		77.6		-4.26		60.50		30.2		69.3		-4.26		59.70	

Table E3. Daily means (SD) of environmental parameters at Site CA1B for October, 2009.

Day	House 10								House 12							
	T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}		T, °C		RH, %		ΔP, Pa		Airflow, dsm^3 s^{-1}	
1	25.2	(4.2)	51.0	(11.1)	-6.10	(7.62)	2.49	(2.65)	25.4	(4.1)	53.0	(11.7)	-5.48	(7.90)	2.39	(2.81)
2	26.4	(3.7)	46.9	(12.9)	-8.33	(8.57)	3.75	(3.47)	26.4	(3.5)	48.6	(13.1)	-7.63	(8.09)	3.70	(3.50)
3	26.0	(2.6)	48.8	(6.9)	-6.78	(7.57)	2.88	(2.79)	26.2	(2.5)	49.9	(6.9)	-6.40	(7.21)	2.89	(2.88)
4	29.6	(4.1)	45.0	(7.8)	-5.27	(6.96)	2.61	(2.64)	29.1	(3.8)	45.7	(8.1)	-4.87	(6.49)	2.66	(2.72)
5	31.4	(0.9)	39.4	(3.0)	-4.57	(6.68)	2.92	(3.33)	31.0	(0.6)	40.5	(2.4)	-4.20	(6.40)	2.76	(3.43)
6	30.3	(0.5)	38.4	(2.5)	-6.36	(7.64)	4.22	(4.06)	30.1	(0.6)	38.7	(2.5)	-5.28	(6.82)	4.07	(4.34)
7	29.8	(0.6)	40.1	(5.1)	-7.14	(8.08)	4.85	(4.67)	29.7	(0.5)	40.4	(4.3)	-5.72	(7.07)	4.35	(4.44)
8	29.3	(0.5)	46.3	(4.5)	-8.07	(8.38)	5.25	(4.63)	29.4	(0.3)	44.6	(3.6)	-6.84	(7.20)	5.42	(4.76)
9	28.9	(0.5)	49.2	(4.8)	-8.07	(8.32)	5.65	(5.12)	29.1	(0.4)	47.0	(3.7)	-6.99	(7.45)	5.50	(4.87)
10	28.5	(0.6)	50.3	(5.4)	-8.75	(8.56)	6.25	(5.67)	28.6	(0.4)	47.6	(4.4)	-7.61	(7.62)	6.23	(5.46)
11	28.2	(0.5)	51.7	(2.7)	-7.95	(8.69)	5.76	(5.39)	28.1	(0.5)	49.6	(2.2)	-7.32	(8.39)	5.51	(5.72)
12	27.7	(0.5)	51.8	(2.1)	-8.72	(8.47)	6.29	(5.34)	27.5	(0.4)	50.6	(1.8)	-7.30	(8.01)	5.79	(5.70)
13	26.7	(0.7)	58.2	(4.2)	-7.31	(9.57)	5.88	(5.96)	26.6	(0.7)	57.5	(4.6)	-6.93	(8.19)	5.83	(5.40)
14																
15																
16																
17																
18																
19																
20																
21			59.2	(3.5)							56.6	(3.7)				
22																
23																
24																
25																
26																
27																
28																
29																
30																
31																
Mean	28.3		48.3		-7.19		4.52		28.2		47.9		-6.35		4.39	
n	13		14		13		13		13		14		13		13	
SD	1.8		6.1		1.27		1.39		1.6		5.5		1.08		1.34	
Min	25.2		38.4		-8.75		2.49		25.4		38.7		-7.63		2.39	
Max	31.4		59.2		-4.57		6.29		31.0		57.5		-4.20		6.23	

Table E4. Particulate matter concentrations.

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for September, 2007.

Day	PM_{10} Concentration, $\mu g\ dsm^{-3}$			$PM_{2.5}$ Concentration, $\mu g\ dsm^{-3}$			TSP Concentration, $\mu g\ dsm^{-3}$		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29			308 (146)						
30			1050 (863)						
Avg			681						
n	0	0	2	0	0	0	0	0	0
SD			373						
Min			308						
Max			1050						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for October, 2007.

Day	PM$_{10}$ Concentration, µg dsm^{-3}			PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1			1740 (1130)						
2			1810 (1260)						
3			1710 (1250)						
4			1980 (1220)						
5			2110 (1100)						
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
Avg			1870						
n	0	0	5	0	0	0	0	0	0
SD			151						
Min			1710						
Max			2110						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for November, 2007.

Day	PM$_{10}$ Concentration, µg dsm^{-3}			PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1									
2									
3									
4									
5									
6									
7									
8		270 (344)							
9		114 (115)							
10		99 (131)							
11	11.7 (7.5)	20 (31)							
12	21.5 (9.0)	45 (38)							
13	27.4 (10.2)	52 (32)							
14									
15	49.8 (19.9)	273 (277)							
16	12.7 (5.3)	151 (27)							
17	26.8 (25.9)	166 (27)							
18	24.3 (13.9)	163 (33)							
19	13.0 (6.1)	139 (57)							
20	23.5 (22.5)	264 (144)							
21	25.5 (10.8)	353 (168)	487 (219)						
22									
23									
24	44.5 (16.4)	434 (194)	542 (242)						
25	66.7 (15.8)	1880 (1670)	1960 (1680)						
26	65.4 (13.4)	2970 (2140)	3620 (2460)						
27	55.0 (20.4)	2390 (1610)	2730 (1860)						
28	48.1 (25.3)	2000 (1270)	2240 (1470)						
29	99.6 (19.7)	1760 (1080)	1960 (1230)						
30	44.5 (21.0)	1410 (893)	1570 (982)						
Avg	38.8	748	1890						
n	17	20	8	0	0	0	0	0	0
SD	23.0	913	981						
Min	11.7	20	487						
Max	99.6	2970	3620						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for December, 2007.

Day	PM$_{10}$ Concentration, µg dsm^{-3}			PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	23.0 (5.8)								
2	25.8 (14.2)	1480 (928)	1680 (945)						
3	30.9 (18.6)	1370 (787)	1650 (946)						
4	32.6 (18.0)	1300 (866)	1560 (958)						
5	25.4 (10.2)	1070 (623)	1390 (801)						
6	39.0 (20.4)	1020 (597)	1240 (717)						
7	23.5 (12.0)	1030 (636)	1180 (695)						
8	26.4 (10.3)	1240 (698)	1460 (828)						
9	24.6 (10.1)	1320 (810)	1680 (961)						
10									
11									
12							51.7 (23.1)	3370 (1970)	3900 (2400)
13							67.4 (25.4)	3390 (1930)	3610 (1940)
14							58.7 (28.7)	3340 (2000)	3700 (2180)
15							81.2 (21.0)	3270 (1820)	3390 (1840)
16							82.3 (41.5)	3180 (1730)	3150 (1840)
17							41.7 (25.3)	3080 (1600)	3870 (3900)
18							25.3 (26.4)	2810 (1320)	3290 (1680)
19									
20	35.8 (19.9)	1560 (788)	2000 (981)						
21	33.1 (13.0)	1960 (1040)	2490 (1210)						
22	37.6 (16.8)	1810 (956)	2330 (1300)						
23	41.3 (12.8)	1600 (845)	2020 (1030)						
24	56.7 (23.8)	1430 (707)	1790 (807)						
25	33.2 (12.4)	1420 (728)	1710 (863)						
26	51.9 (12.7)	1530 (763)	1520 (713)						
27	36.0 (13.6)	1660 (416)	1090 (453)						
28	20.9 (7.7)	1550 (566)	1370 (957)						
29	33.1 (13.8)	1750 (384)	1980 (451)						
30	45.5 (11.2)								
31	38.7 (22.6)								
Avg	34.0	1450	1670				58.3	3210	3560
n	21	18	18	0	0	0	7	7	7
SD	9.2	255	370				19.3	190	267
Min	20.9	1020	1090				25.3	2810	3150
Max	56.7	1960	2490				82.3	3390	3900

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for January, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	29.4 (14.8)								
2	44.0 (16.8)								
3	79.0 (109.0)								
4	12.5 (9.6)								
5	12.1 (7.8)								
6	8.2 (6.1)	115 (33)	51 (17)						
7	12.0 (6.1)	216 (106)	177 (219)						
8	18.2 (6.3)	208 (42)	188 (35)						
9	25.8 (12.1)		248 (89)						
10	32.3 (15.2)	182 (11)							
11	14.1 (7.1)	188 (30)	276 (32)						
12	23.0 (8.6)	211 (37)	259 (34)						
13	21.2 (5.2)	199 (25)	281 (47)						
14	28.9 (14.3)	269 (68)	353 (65)						
15	21.3 (8.0)	338 (107)	347 (108)						
16	23.4 (8.9)	446 (184)	412 (164)						
17	24.5 (8.2)	672 (359)	753 (482)						
18	45.1 (13.1)	864 (450)	1400 (787)						
19	52.0 (22.7)	902 (462)	1460 (785)						
20	32.8 (15.5)	1010 (509)	1560 (845)						
21	14.0 (6.0)	1060 (546)	1460 (781)						
22	11.8 (5.2)	856 (551)	1260 (914)						
23	14.2 (8.6)	988 (623)	1210 (797)						
24	7.9 (5.1)	1080 (728)	1310 (898)						
25	9.7 (5.1)	1050 (625)	1320 (800)						
26	17.2 (7.8)	1250 (673)	1570 (862)						
27	18.1 (14.7)	1200 (638)	1510 (810)						
28		1430 (721)	1690 (904)						
29	16.1 (6.3)	1540 (733)	1830 (937)						
30	21.0 (7.2)	1600 (826)	2120 (1120)						
31	19.7 (5.6)	1420 (743)	1550 (817)						
Avg	23.6	772	984						
n	30	25	25	0	0	0	0	0	0
SD	14.9	485	637						
Min	7.9	115	51						
Max	79.0	1600	2120						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for February, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1									
2									
3									
4									
5				13.6 (6.3)	136 (159)	153 (128)			
6				16.0 (7.2)	117 (57)	111 (47)			
7				15.2 (6.3)	116 (57)	122 (48)			
8				19.1 (7.2)	129 (65)	128 (64)			
9				32.9 (15.7)	133 (71)	124 (56)			
10				31.5 (11.7)	133 (70)	128 (60)			
11				26.1 (8.3)	127 (70)	122 (62)			
12				32.4 (12.4)	122 (68)	114 (60)			
13				17.4 (13.7)	118 (75)	115 (62)			
14				6.8 (3.8)	145 (80)	129 (68)			
15				15.1 (7.5)	144 (92)	139 (77)			
16				21.5 (7.7)	169 (74)	130 (55)			
17				23.5 (8.3)	132 (70)	125 (61)			
18				30.9 (11.5)	100 (56)	137 (53)			
19									
20	41.4 (24.1)								
21	24.4 (24.4)								
22	8.7 (7.0)								
23	10.2 (8.1)								
24	9.6 (6.0)								
25									
26		71 (78)	70 (62)						
27		53 (39)	61 (27)						
28		166 (195)	162 (203)						
29		199 (66)	167 (49)						
Avg	18.9	122	115	21.6	130	127			
n	5	4	4	14	14	14	0	0	0
SD	12.7	62	50	7.9	16	11			
Min	8.7	53	61	6.8	100	111			
Max	41.4	199	167	32.9	169	153			

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for March, 2008.

Day	PM$_{10}$ Concentration, µg dsm^{-3}						PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient		**House 10**		**House 12**		**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	10.6	(4.9)	242	(47)	234	(54)						
2	11.4	(5.9)	349	(58)	344	(63)						
3	28.0	(16.5)	385	(80)	397	(53)						
4	30.9	(8.4)	357	(51)	360	(55)						
5	21.1	(7.1)	384	(57)	355	(50)						
6	37.2	(14.4)	361	(64)	348	(59)						
7	40.0	(8.0)	380	(179)	414	(176)						
8	20.9	(12.1)	321	(193)	345	(215)						
9	25.8	(12.1)	767	(386)	618	(316)						
10	31.7	(12.7)	790	(436)	766	(425)						
11	28.2	(13.4)	839	(452)	948	(503)						
12	34.8	(12.5)	1060	(579)	1030	(549)						
13	19.5	(8.0)	901	(508)	909	(483)						
14	25.1	(13.8)	1120	(708)	1150	(700)						
15	21.4	(9.4)	1330	(828)	1230	(735)						
16	44.3	(42.1)	1670	(1110)	1800	(1160)						
17	26.1	(7.8)	1320	(944)	1410	(998)						
18	33.2	(14.7)	907	(358)	1010	(401)						
19	27.5	(13.8)	828	(328)	868	(313)						
20	29.9	(9.2)	859	(454)	823	(356)						
21	38.4	(14.7)	1180	(738)	1010	(583)						
22	38.3	(16.7)	1190	(885)	1000	(627)						
23	79.4	(66.3)	1040	(800)								
24												
25	34.3	(14.0)										
26	38.3	(14.1)	1380	(685)	1360	(714)						
27												
28	39.4	(14.8)	1260	(667)	1310	(736)						
29	35.7	(15.3)	1100	(568)	1090	(568)						
30	38.2	(12.3)	1210	(679)	1210	(671)						
31	56.1	(26.8)	1150	(742)	1160	(730)						
Avg	32.6		882		871							
n	29		28		27		0	0	0	0	0	0
SD	13.0		390		404							
Min	10.6		242		234							
Max	79.4		1670		1800							

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for April, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}						PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient		House 10		House 12		Ambient	House 10	House 12	Ambient	House 10	House 12
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	59.4	(31.8)	1080	(667)	975	(617)						
2	66.3	(31.5)	1100	(645)	1050	(629)						
3	62.6	(38.1)	971	(388)	910	(356)						
4	60.0	(17.7)	1110	(433)	1070	(415)						
5	59.0	(18.8)	1760	(1010)	1290	(329)						
6												
7												
8												
9												
10												
11												
12	108.0	(50.6)	1370	(589)	1400	(593)						
13	89.8	(78.7)										
14	118.0	(28.2)										
15	86.3	(57.0)										
16	149.0	(158.0)										
17	131.0	(155.0)										
18	72.9	(84.9)										
19	104.0	(133.0)	173	(392)								
20	21.8	(9.5)	71	(115)	39	(33)						
21	24.1	(10.6)	62	(125)	89	(136)						
22	32.7	(14.6)	288	(312)	411	(477)						
23	19.9	(9.8)	347	(54)	324	(60)						
24	30.1	(9.1)	374	(99)	411	(101)						
25	41.2	(22.7)	358	(72)	438	(96)						
26	40.0	(11.3)	365	(81)	387	(92)						
27	38.6	(33.9)	321	(111)	372	(121)						
28	41.1	(29.4)	369	(118)	467	(95)						
29	34.6	(13.9)	399	(121)	510	(120)						
30	57.1	(50.1)	503	(232)	612	(290)						
Avg	64.5		612		632							
n	24		18		17		0	0	0	0	0	0
SD	35.4		475		393							
Min	19.9		62		39							
Max	149.0		1760		1400							

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for May, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	41.2 (20.3)	442 (260)	586 (341)						
2	51.7 (20.2)	1400 (1090)	1600 (1220)						
3	51.8 (17.3)	1990 (1320)	2010 (1440)						
4	40.2 (17.1)	1440 (964)	1590 (1090)						
5	49.6 (21.8)	1370 (1050)	1270 (894)						
6	53.9 (25.2)	1190 (911)	1170 (799)						
7	49.0 (23.0)	1230 (713)	1260 (722)						
8	52.1 (23.5)	980 (566)	1030 (606)						
9	55.8 (16.5)	1170 (728)	1280 (807)						
10	66.9 (30.4)	1130 (675)	1200 (718)						
11	44.0 (17.0)	1200 (815)	1220 (798)						
12	80.3 (41.9)	1350 (736)	1420 (724)						
13	64.1 (32.1)	1050 (797)	1210 (959)						
14	87.1 (50.2)	901 (645)	918 (644)						
15									
16									
17									
18									
19									
20							110.0 (45.0)	2290 (1480)	2680 (1670)
21							232.0 (261.0)	2940 (1610)	3520 (1800)
22							210.0 (248.0)	2990 (1700)	4270 (2270)
23							101.0 (47.7)	2780 (1850)	3460 (2150)
24							42.0 (26.8)	3280 (1700)	3510 (1730)
25							47.5 (21.7)	2330 (1400)	2500 (1470)
26							53.5 (24.5)	2590 (1580)	
27							66.2 (17.4)	2810 (830)	
28									
29	60.8 (16.6)	1220 (393)	1200 (407)						
30	75.4 (26.5)	1200 (453)	1210 (449)						
31	80.7 (21.5)	1270 (569)	1310 (457)						
Avg	59.1	1210	1260				108.0	2750	3320
n	17	17	17	0	0	0	8	8	6
SD	14.0	299	293				69.5	314	587
Min	40.2	442	586				42.0	2290	2500
Max	87.1	1990	2010				232.0	3280	4270

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for June, 2008.

Day	**PM$_{10}$ Concentration, µg dsm^{-3}**			**PM$_{2.5}$ Concentration, µg dsm^{-3}**			**TSP Concentration, µg dsm^{-3}**		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	87.6 (21.3)	1350 (611)	1430 (606)						
2	140.0 (99.9)	1430 (699)	1540 (731)						
3	166.0 (99.7)	1310 (551)	1340 (472)						
4	243.0 (207.0)	1570 (639)							
5	127.0 (51.8)								
6	174.0 (102.0)								
7	113.0 (94.8)								
8	45.0 (25.3)								
9	69.3 (45.6)								
10									
11	120.0 (138.0)								
12	49.6 (14.0)								
13	58.5 (19.9)	81 (55)	78 (56)						
14	53.9 (23.8)	170 (202)	220 (380)						
15	43.5 (11.4)	200 (66)	243 (90)						
16	49.6 (18.7)	275 (83)	317 (97)						
17	56.9 (24.4)	297 (98)	321 (113)						
18	79.5 (84.0)	317 (125)	349 (202)						
19	73.7 (69.5)	371 (135)	379 (141)						
20	69.6 (56.9)	374 (204)	389 (213)						
21	69.5 (41.8)	336 (245)	383 (256)						
22	64.3 (33.1)	540 (464)	537 (487)						
23	151.0 (70.8)	2650 (2670)	3040 (3450)						
24	202.0 (88.5)	5030 (4640)	4550 (4310)						
25	174.0 (57.7)	4420 (3970)	4090 (3690)						
26	198.0 (103.0)	3480 (3060)	3510 (3090)						
27	218.0 (59.8)	2430 (2350)	2500 (2370)						
28	106.0 (44.7)	2550 (2340)	2650 (2400)						
29	88.0 (40.0)	2080 (1990)	2200 (2010)						
30	79.7 (40.7)	1960 (1780)	1990 (1720)						
Avg	109.0	1510	1530						
n	29	22	21	0	0	0	0	0	0
SD	57.4	1410	1370						
Min	43.5	81	78						
Max	243.0	5030	4550						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for July, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	79.5 (43.7)	2010 (1670)	2060 (1730)						
2	108.0 (51.3)	1560 (1260)	1770 (1380)						
3	68.6 (28.0)	1060 (953)	1210 (1120)						
4	54.0 (24.2)	1100 (824)	1170 (842)						
5	76.5 (32.0)	701 (539)	746 (583)						
6	90.4 (45.4)	578 (402)	613 (411)						
7	116.0 (60.4)	501 (345)	558 (377)						
8	147.0 (56.0)	440 (288)	470 (322)						
9									
10				85.7 (39.7)	96 (68)	135 (43)			
11				34.3 (13.5)	73 (47)	82 (19)			
12				27.2 (12.0)	67 (36)	72 (16)			
13				21.9 (12.2)	55 (35)	64 (18)			
14				19.7 (10.1)	60 (29)	63 (16)			
15				20.8 (8.8)	75 (33)	74 (21)			
16				28.2 (9.8)	77 (40)	86 (30)			
17				17.7 (10.0)	71 (32)	79 (26)			
18				23.9 (11.6)	87 (32)	98 (29)			
19				27.5 (11.6)	86 (12)	90 (13)			
20				18.0 (7.9)	86 (16)	86 (16)			
21				14.5 (7.0)	90 (16)	96 (20)			
22				21.8 (9.8)	92 (20)	86 (16)			
23				26.1 (12.4)	88 (20)	85 (17)			
24				31.5 (9.5)	97 (21)	95 (21)			
25									
26	108.0 (53.7)	908 (377)	890 (358)						
27	101.0 (28.4)	938 (388)	874 (396)						
28	121.0 (26.9)	1100 (441)	1020 (400)						
29	120.0 (37.6)								
30	119.0 (36.9)								
31	186.0 (95.6)								
Avg	107.0	990	1040	27.9	80	86			
n	14	11	11	15	15	15	0	0	0
SD	32.4	447	477	16.3	12	17			
Min	54.0	440	470	14.5	55	63			
Max	186.0	2010	2060	85.7	97	135			

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for August, 2008.

Day	PM$_{10}$ Concentration, µg dsm^{-3}			PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	76.8 (83.1)								
2	110.0 (128.0)								
3	53.1 (37.1)								
4	49.1 (12.9)								
5	42.4 (14.4)								
6	64.4 (29.1)								
7	111.0 (144.0)								
8	49.8 (36.7)								
9	38.1 (19.5)								
10	57.5 (63.7)								
11	51.5 (29.7)								
12	65.3 (29.0)	329 (109)	231 (61)						
13	80.8 (49.5)	353 (98)	342 (98)						
14	78.4 (38.1)	373 (153)	431 (153)						
15	73.8 (44.5)	408 (193)	434 (155)						
16	63.6 (20.3)	433 (186)	455 (171)						
17	38.3 (16.2)	440 (148)	494 (165)						
18	38.3 (24.7)	528 (168)	522 (143)						
19	31.1 (12.6)	691 (404)	669 (388)						
20	53.8 (40.6)	962 (765)	836 (663)						
21	73.1 (46.5)	2310 (2200)	1980 (1800)						
22	104.0 (77.2)	1870 (1770)	1590 (1450)						
23	98.9 (70.1)	2040 (1860)	1850 (1700)						
24	90.4 (54.5)	1780 (1700)	1530 (1380)						
25	86.3 (37.0)	2000 (1940)	1640 (1560)						
26	112.0 (68.5)	1810 (1580)	1560 (1340)						
27	135.0 (85.3)	1250 (1140)	1180 (1060)						
28	135.0 (62.5)	1040 (943)	1010 (883)						
29	122.0 (75.2)	908 (642)	715 (547)						
30	96.8 (30.0)	922 (744)	910 (608)						
31	96.8 (53.6)	1300 (860)	1360 (979)						
Avg	76.7	1090	987						
n	31	20	20	0	0	0	0	0	0
SD	29.2	648	542						
Min	31.1	329	231						
Max	135.0	2310	1980						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for September, 2008.

Day	**PM$_{10}$ Concentration, µg dsm^{-3}**			**PM$_{2.5}$ Concentration, µg dsm^{-3}**			**TSP Concentration, µg dsm^{-3}**		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	119.0 (53.3)	1260 (813)	1200 (763)						
2	130.0 (59.7)	1050 (671)	1090 (686)						
3	131.0 (74.8)	974 (626)	936 (580)						
4	117.0 (79.1)	1030 (738)	905 (561)						
5	126.0 (79.6)	856 (548)	871 (477)						
6	119.0 (82.0)	780 (515)	832 (505)						
7	92.3 (59.8)	723 (465)	771 (482)						
8	107.0 (46.4)	1090 (669)	940 (583)						
9	77.3 (34.1)	1150 (659)	984 (537)						
10	84.7 (52.5)	1010 (706)	972 (616)						
11	115.0 (68.6)	1110 (653)	1180 (641)						
12	108.0 (37.0)	1220 (752)	1370 (877)						
13	162.0 (139.0)	1250 (739)	1390 (842)						
14	105.0 (48.2)	974 (507)	1040 (543)						
15	121.0 (48.7)	896 (426)	934 (442)						
16	109.0 (40.6)	854 (273)	900 (256)						
17	84.2 (24.0)	933 (261)	987 (256)						
18	83.1 (46.1)	943 (342)	979 (371)						
19	69.9 (28.1)	908 (309)	934 (297)						
20	62.0 (28.5)	669 (217)	810 (224)						
21	72.7 (22.9)	771 (302)	802 (245)						
22	116.0 (48.7)	1380 (560)							
23	262.0 (250.0)	1450 (563)							
24	164.0 (67.5)	1280 (459)							
25	165.0 (77.4)								
26	194.0 (74.0)								
27	122.0 (52.3)								
28	80.2 (23.2)								
29	76.8 (35.4)								
30	177.0 (145.0)								
Avg	118.0	1020	992						
n	30	24	21	0	0	0	0	0	0
SD	42.2	204	166						
Min	62.0	669	771						
Max	262.0	1450	1390						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for October, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	142.0 (135.0)								
2	43.3 (45.2)								
3	46.2 (22.4)								
4	14.4 (13.0)								
5	18.0 (10.4)								
6	23.9 (11.6)								
7	38.8 (17.0)								
8	51.6 (44.8)								
9	58.5 (32.7)								
10	35.4 (22.5)								
11	32.6 (13.2)								
12	35.8 (9.9)								
13	136.0 (174.0)								
14	61.7 (27.4)								
15	90.9 (43.8)								
16	89.9 (54.8)								
17	98.8 (42.7)	69 (63)	573 (2910)						
18	72.1 (32.0)	66 (63)	53 (13)						
19	42.2 (24.4)	51 (41)	58 (55)						
20	38.4 (16.3)	346 (649)	248 (322)						
21	58.7 (34.0)	305 (66)	259 (125)						
22	95.6 (27.5)	488 (182)	606 (1660)						
23	92.2 (31.7)	753 (209)	604 (838)						
24	95.2 (44.0)	768 (135)	613 (893)						
25	100.0 (36.4)	791 (203)	674 (779)						
26	73.4 (21.5)	715 (138)	658 (428)						
27	83.6 (29.1)	594 (194)	556 (698)						
28	95.5 (49.7)	664 (362)	513 (365)						
29	113.0 (63.5)	1360 (1150)	1220 (1140)						
30	110.0 (49.1)	3670 (2240)	3590 (2210)						
31	25.3 (10.9)	2660 (1540)	2730 (1840)						
Avg	68.1	887	864						
n	31	15	15	0	0	0	0	0	0
SD	34.3	972	956						
Min	14.4	51	53						
Max	142.0	3670	3590						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for November, 2008.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	22.7 (21.2)	2040 (1130)	2080 (1160)						
2	15.3 (6.4)	1600 (878)	1670 (859)						
3	18.5 (12.3)	1730 (979)	1850 (1060)						
4	19.8 (7.9)	1570 (906)	1550 (939)						
5	23.1 (8.1)	1810 (948)	1710 (953)						
6	27.4 (10.4)	1420 (822)	1270 (811)						
7									
8									
9									
10									
11	28.1 (10.1)	857 (454)	918 (464)						
12	36.0 (11.9)	994 (503)	893 (460)						
13	37.0 (11.8)	1060 (569)	1030 (562)						
14	57.8 (13.3)	1020 (505)	1060 (536)						
15	61.2 (21.8)	984 (514)	1020 (585)						
16	62.3 (30.0)	1160 (640)	1020 (596)						
17									
18							108.0 (37.3)	3030 (1820)	
19							133.0 (120.0)	3360 (1840)	3440 (2060)
20							54.3 (18.7)	3300 (2080)	3020 (1770)
21							70.4 (62.6)	2990 (1430)	3580 (1800)
22								2700 (1310)	3370 (1680)
23								2880 (1490)	3520 (1800)
24									
25		1270 (397)	1490 (342)						
26		1120 (195)	1180 (187)						
27			1220 (206)						
28		1160 (184)	1450 (342)						
29		1360 (277)	1510 (338)						
30		1350 (357)	1510 (303)						
Avg	34.1	1320	1360				91.4	3040	3390
n	12	17	18	0	0	0	4	6	5
SD	16.4	323	332				30.9	230	196
Min	15.3	857	893				54.3	2700	3020
Max	62.3	2040	2080				133.0	3360	3580

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for December, 2008.

Day	PM_{10} Concentration, $\mu g\ dsm^{-3}$			$PM_{2.5}$ Concentration, $\mu g\ dsm^{-3}$			TSP Concentration, $\mu g\ dsm^{-3}$		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1		1430 (238)	1440 (229)						
2		1500 (290)	1470 (322)						
3	37.6 (15.5)								
4	39.7 (17.9)								
5	33.9 (14.5)								
6	35.6 (5.7)								
7	24.5 (9.6)								
8	22.7 (13.5)								
9	31.4 (13.4)								
10	36.9 (12.7)								
11	53.3 (19.5)								
12	62.4 (24.6)								
13	19.8 (22.3)	372 (412)	306 (814)						
14	14.0 (10.8)	451 (185)	381 (214)						
15	7.9 (6.6)	418 (74)	398 (76)						
16	10.3 (6.1)	365 (203)	374 (38)						
17	13.0 (5.4)	378 (421)	330 (67)						
18	18.1 (5.0)	365 (34)	347 (31)						
19	16.4 (10.1)	313 (50)	304 (64)						
20	17.1 (5.8)	355 (169)	308 (142)						
21	14.5 (10.2)	714 (588)	658 (412)						
22	8.3 (8.3)	1370 (791)	1270 (732)						
23	6.3 (5.5)	1510 (824)	1360 (755)						
24	4.5 (5.0)	1570 (855)	1460 (800)						
25	13.4 (12.9)	1490 (810)	1410 (773)						
26	16.9 (6.7)	1580 (901)	1720 (863)						
27	22.2 (10.0)	2030 (1100)	2080 (1120)						
28	20.6 (10.8)	1760 (920)	1840 (966)						
29	31.9 (14.7)	1550 (820)	1680 (892)						
30	21.6 (10.3)	1350 (704)	1520 (800)						
31	18.1 (9.2)	1210 (768)	1270 (773)						
Avg	23.2	1050	1040						
n	29	21	21	0	0	0	0	0	0
SD	13.6	577	607						
Min	4.5	313	304						
Max	62.4	2030	2080						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for January, 2009.

Day	PM$_{10}$ Concentration, μg dsm^{-3}						PM$_{2.5}$ Concentration, μg dsm^{-3}						TSP Concentration, μg dsm^{-3}		
	Ambient		**House 10**		**House 12**		**Ambient**		**House 10**		**House 12**		**Ambient**	**House 10**	**House 12**
	Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)		Mean (SD)	Mean (SD)	Mean (SD)
1	20.4	(7.0)	1050	(528)	1010	(528)									
2	27.5	(7.0)	1050	(552)	1030	(533)									
3	17.8	(6.6)	1030	(530)	1050	(546)									
4	19.2	(11.5)	1220	(648)											
5															
6							18.5	(4.8)	104	(29)	100	(20)			
7							13.9	(6.7)	114	(32)	111	(28)			
8							15.5	(6.8)	113	(39)	118	(41)			
9							9.9	(4.8)			97	(32)			
10							21.4	(10.3)			114	(41)			
11							29.2	(16.1)	126	(36)	117	(39)			
12							30.1	(8.7)	119	(44)	112	(41)			
13							29.1	(12.7)	133	(80)	104	(43)			
14							31.0	(16.5)	141	(61)	117	(48)			
15							24.8	(9.3)	130	(55)	140	(60)			
16							26.6	(13.8)	131	(33)	131	(30)			
17							33.3	(18.6)	139	(32)	128	(27)			
18							21.5	(8.6)	138	(31)	128	(31)			
19							23.4	(12.4)	154	(33)	158	(271)			
20															
21	66.4	(20.2)	1960	(795)	1770	(457)									
22	49.8	(16.4)	1460	(415)	1330	(284)									
23	29.0	(15.3)	1070	(194)	1110	(224)									
24	34.9	(19.4)	1010	(342)	1050	(264)									
25	41.1	(18.3)	1400	(293)	1520	(304)									
26	54.6	(23.8)													
27	51.9	(24.7)													
28	65.6	(36.7)													
29	31.2	(14.6)													
30	30.8	(11.1)													
31	27.9	(11.2)													
Avg	37.9		1250		1230		23.4		128		120				
n	15		9		8		14		12		14		0	0	0
SD	15.6		295		263		6.8		13		16				
Min	17.8		1010		1010		9.9		104		97				
Max	66.4		1960		1770		33.3		154		158				

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for February, 2009.

Day	PM_{10} Concentration, $\mu g\ dsm^{-3}$			$PM_{2.5}$ Concentration, $\mu g\ dsm^{-3}$			TSP Concentration, $\mu g\ dsm^{-3}$		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	29.6 (14.1)								
2	29.6 (12.7)								
3	43.8 (24.8)								
4	59.1 (23.8)								
5	27.7 (21.9)								
6	7.0 (6.3)	29 (109)	27 (7)						
7	9.8 (4.7)	44 (55)	48 (27)						
8	6.9 (6.8)	38 (15)	45 (16)						
9	7.2 (5.0)	177 (258)	176 (231)						
10	9.1 (5.5)	251 (98)	204 (52)						
11	7.2 (6.2)	285 (65)	226 (205)						
12	6.1 (5.9)	319 (37)	251 (27)						
13	4.9 (8.2)	284 (56)	230 (43)						
14	5.7 (5.0)	235 (32)	244 (35)						
15	7.9 (5.1)	274 (69)	299 (547)						
16	7.4 (7.3)	273 (52)	295 (48)						
17	4.6 (4.9)	367 (206)	385 (189)						
18	9.7 (6.4)	539 (291)	581 (324)						
19	12.4 (8.1)	1720 (1210)	1560 (1070)						
20	22.2 (13.7)		2200 (1510)						
21	24.5 (11.1)		2020 (1110)						
22	4.3 (12.6)		1750 (955)						
23	7.0 (7.2)		1460 (844)						
24	16.8 (10.1)		1590 (1560)						
25	17.4 (8.9)		1900 (1630)						
26	16.1 (8.7)		1610 (546)						
27	18.0 (10.9)		1390 (575)						
28	27.6 (17.6)		1370 (366)						
Avg	16.1	346	863						
n	28	14	23	0	0	0	0	0	0
SD	12.9	404	749						
Min	4.3	29	27						
Max	59.1	1720	2200						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for March, 2009.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	21.9 (18.2)		1110 (422)						
2	7.6 (10.2)		1320 (631)						
3	9.2 (7.4)		1500 (720)						
4	11.7 (11.4)		1540 (709)						
5	16.7 (8.9)		1550 (805)						
6	19.4 (8.3)		1530 (796)						
7	19.6 (10.1)		1610 (1580)						
8	22.2 (13.4)		1470 (1350)						
9	27.3 (13.6)		1520 (818)						
10	32.9 (11.2)		1780 (2140)						
11	34.7 (20.5)		1300 (774)						
12	52.1 (20.1)								
13	43.2 (27.5)		1500 (849)						
14	37.6 (14.0)		1400 (655)						
15	34.9 (66.5)		1090 (586)						
16	35.1 (18.0)		953 (387)						
17	52.0 (13.8)		929 (432)						
18	61.4 (30.7)		1060 (450)						
19	68.1 (27.8)		1100 (466)						
20	56.4 (37.0)		1190 (501)						
21	33.3 (17.0)		1340 (349)						
22	42.0 (18.3)		1550 (315)						
23	56.7 (20.7)		1850 (839)						
24	59.1 (40.3)		1630 (444)						
25	59.4 (23.9)		1490 (465)						
26	68.8 (18.1)								
27	88.9 (61.4)								
28	56.5 (33.4)								
29	56.1 (44.7)								
30	62.4 (114.0)								
31	27.0 (10.9)								
Avg	41.1		1390						
n	31	0	24	0	0	0	0	0	0
SD	20.0		245						
Min	7.6		929						
Max	88.9		1850						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for April, 2009.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	44.7 (42.9)								
2	23.4 (13.3)								
3	96.2 (138.0)								
4	24.2 (12.2)								
5	24.1 (8.1)								
6	57.8 (58.4)								
7	74.6 (112.0)								
8	8.4 (6.9)								
9									
10									100 (151)
11							13.2 (4.8)		69 (16)
12							13.2 (6.7)		56 (9)
13							16.6 (6.7)		55 (10)
14							27.6 (16.1)		75 (40)
15							16.7 (8.4)		89 (18)
16							23.4 (6.9)		88 (29)
17							31.1 (12.1)		98 (52)
18							46.0 (29.4)		312 (258)
19							45.1 (22.0)		904 (681)
20									
21	47.0 (21.7)		254 (148)						
22	51.1 (34.5)		229 (142)						
23	38.9 (14.6)		331 (205)						
24	34.1 (11.4)		397 (249)						
25	36.9 (14.0)		358 (226)						
26	37.9 (18.7)		339 (252)						
27	45.2 (29.4)		318 (211)						
28	41.7 (19.9)		271 (120)						
29	32.8 (14.3)		239 (111)						
30	51.0 (51.6)		224 (95)						
Avg	42.8		296				25.9		184
n	18	0	10	0	0	0	9	0	10
SD	19.4		57				12.0		250
Min	8.4		224				13.2		55
Max	96.2		397				46.0		904

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for May, 2009.

Day	PM_{10} Concentration, µg dsm^{-3}			$PM_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	28.1 (18.0)								
2	11.7 (6.6)								
3	18.1 (20.2)								
4	13.3 (7.4)								
5	15.1 (10.7)		244 (96)						
6	23.0 (11.9)		256 (124)						
7	32.9 (16.7)		345 (375)						
8	41.6 (19.4)		398 (421)						
9	48.1 (23.5)		396 (259)						
10	57.6 (22.3)		399 (263)						
11	64.2 (34.3)		644 (415)						
12	62.9 (22.8)	739 (450)	858 (502)						
13	67.9 (26.1)	734 (391)	776 (446)						
14	61.0 (28.4)	693 (393)	814 (478)						
15	66.6 (33.4)	536 (222)	654 (273)						
16	89.1 (47.6)	516 (213)	535 (236)						
17	96.6 (46.4)	492 (250)	518 (253)						
18	114.0 (58.0)	565 (251)	582 (268)						
19	99.9 (50.9)	770 (339)	700 (296)						
20	96.6 (34.1)	942 (295)	959 (335)						
21	111.0 (26.5)	823 (342)	906 (403)						
22	116.0 (37.6)	917 (233)							
23	91.5 (13.7)	1080 (261)							
24	88.3 (19.4)								
25	96.5 (23.4)	1050 (332)							
26	119.0 (42.6)								
27	170.0 (68.0)								
28	180.0 (117.0)								
29	57.5 (30.5)								
30	53.6 (27.9)								
31	32.7 (25.5)								
Avg	71.8	759	587						
n	31	13	17	0	0	0	0	0	0
SD	42.3	191	220						
Min	11.7	492	244						
Max	180.0	1080	959						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for June, 2009.

Day	**PM$_{10}$ Concentration, μg dsm^{-3}**						**PM$_{2.5}$ Concentration, μg dsm^{-3}**						**TSP Concentration, μg dsm^{-3}**					
	Ambient		**House 10**		**House 12**		**Ambient**		**House 10**		**House 12**		**Ambient**		**House 10**		**House 12**	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
1	63.5	(90.3)																
2																		
3																		
4																		
5	14.5	(8.4)	179	(68)														
6	15.2	(6.5)	323	(67)	345	(68)												
7	20.3	(10.9)	269	(56)	379	(75)												
8	29.5	(14.6)	301	(73)	368	(118)												
9	21.5	(9.6)	368	(74)	313	(59)												
10	19.6	(9.9)	387	(68)	325	(75)												
11	21.9	(10.0)	348	(54)	391	(113)												
12	20.8	(9.6)	357	(162)	409	(102)												
13	14.2	(7.4)	366	(172)	500	(251)												
14	23.3	(11.8)	1430	(1100)	1320	(1020)												
15	35.3	(19.1)	1640	(1090)	1890	(1130)												
16	55.5	(62.7)	987	(758)	1130	(862)												
17	49.8	(26.5)	930	(641)	1010	(718)												
18	58.3	(29.8)	681	(532)	734	(592)												
19	58.2	(30.0)	744	(762)	757	(763)												
20	51.7	(26.1)	976	(806)	930	(767)												
21	41.6	(16.9)	650	(463)	783	(528)												
22	53.6	(29.0)	494	(514)	580	(559)												
23	62.2	(36.8)	465	(457)	594	(546)												
24	64.4	(27.2)	465	(409)	515	(469)												
25																		
26													79.7	(29.5)	1440	(1070)	1810	(1270)
27													92.7	(43.3)	970	(648)	1050	(687)
28													88.5	(38.0)	782	(425)	822	(426)
29													78.1	(33.2)	824	(460)	857	(461)
30													76.2	(27.8)	1040	(598)	1070	(547)
Avg	37.8		618		698								83.1		1010		1120	
n	21		20		19		0		0		0		5		5		5	
SD	18.3		386		401								6.4		234		358	
Min	14.2		179		313								76.2		782		822	
Max	64.4		1640		1890								92.7		1440		1810	

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for July, 2009.

Day	PM$_{10}$ Concentration, μg dsm^{-3}						PM$_{2.5}$ Concentration, μg dsm^{-3}						TSP Concentration, μg dsm^{-3}					
	Ambient		**House 10**		**House 12**		**Ambient**		**House 10**		**House 12**		**Ambient**		**House 10**		**House 12**	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
1													74.1	(30.5)	938	(563)	967	(518)
2													86.3	(35.8)	885	(598)	969	(521)
3													77.9	(27.1)	897	(509)	1000	(518)
4													69.7	(29.0)			1010	(384)
5													61.4	(18.3)			1140	(470)
6													62.4	(26.2)	1110	(1130)	1270	(670)
7													81.1	(33.5)	1160	(768)	1490	(1060)
8																		
9	74.4	(29.2)	523	(239)	604	(311)												
10	82.5	(39.4)	541	(249)	612	(294)												
11	97.1	(55.3)	506	(251)	518	(253)												
12	83.6	(32.1)	403	(170)	458	(193)												
13	99.1	(35.0)	414	(187)														
14	101.0	(55.2)	394	(153)														
15			457	(125)														
16	123.0	(33.0)	475	(125)														
17	112.0	(66.2)	460	(131)														
18	139.0	(51.3)	510	(149)														
19	126.0	(43.8)	397	(115)														
20	138.0	(49.5)																
21	154.0	(69.7)																
22	110.0	(130.0)																
23	60.6	(46.5)																
24																		
25																		
26																		
27																		
28	43.8	(21.0)	55	(28)														
29	41.2	(20.8)	47	(11)														
30	38.3	(20.0)	161	(191)														
31	37.0	(20.1)	148	(30)														
Avg	92.3		366		548								73.3		999		1120	
n	18		15		4		0		0		0		7		5		7	
SD	36.1		167		64								8.7		116		183	
Min	37.0		47		458								61.4		885		967	
Max	154.0		541		612								86.3		1160		1490	

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for August, 2009.

Day	PM$_{10}$ Concentration, μg dsm^{-3}			PM$_{2.5}$ Concentration, μg dsm^{-3}			TSP Concentration, μg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	41.5 (15.6)	209 (47)							
2	24.7 (12.0)	182 (46)							
3	29.0 (17.7)	179 (43)							
4	30.7 (17.4)								
5	53.9 (46.7)								
6	29.0 (42.4)								
7	31.6 (17.1)								
8	52.6 (25.9)								
9	78.6 (50.4)								
10	114.0 (74.9)								
11	113.0 (63.1)								
12	108.0 (69.0)								
13	81.9 (61.7)								
14	79.2 (51.1)								
15	97.1 (70.1)								
16	90.3 (60.8)								
17	98.5 (61.9)	1190 (1030)	1250 (1100)						
18	94.3 (56.6)	990 (913)	969 (842)						
19	74.2 (40.0)	707 (601)	723 (594)						
20	58.2 (29.6)	715 (564)	744 (582)						
21	68.0 (46.1)	514 (429)	537 (429)						
22	80.2 (34.3)	352 (316)	382 (299)						
23	57.7 (26.9)	395 (279)	432 (260)						
24	63.0 (28.5)	510 (380)	598 (412)						
25	72.9 (33.0)	516 (380)	559 (383)						
26	78.6 (35.7)	502 (318)	605 (368)						
27	124.0 (52.0)	495 (247)	550 (280)						
28	117.0 (68.8)	428 (217)	476 (263)						
29	84.8 (33.4)	372 (195)	411 (240)						
30	62.9 (40.2)	325 (156)	367 (191)						
31	67.1 (30.0)	365 (186)	411 (230)						
Avg	72.8	497	601						
n	31	18	15	0	0	0	0	0	0
SD	27.6	258	235						
Min	24.7	179	367						
Max	124.0	1190	1250						

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for September, 2009.

Day	PM$_{10}$ Concentration, µg dsm^{-3}			PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1	78.1 (40.4)	317 (168)	367 (199)						
2	87.6 (31.6)	329 (173)	351 (194)						
3	98.1 (56.8)	342 (181)	368 (208)						
4	89.0 (44.9)	426 (171)	510 (242)						
5	91.0 (75.1)	464 (225)	497 (285)						
6	71.1 (49.5)	496 (268)	516 (291)						
7	88.9 (44.9)	479 (285)	572 (373)						
8	111.0 (61.6)	514 (220)	596 (263)						
9	97.9 (49.1)	492 (191)	608 (213)						
10	128.0 (61.9)	516 (157)							
11	124.0 (45.5)	485 (111)							
12	93.4 (45.7)	463 (133)							
13	82.2 (76.0)								
14	56.7 (93.8)								
15	30.8 (32.4)								
16	66.9 (107.0)								
17	77.4 (88.0)								
18	62.0 (39.4)								
19	37.5 (22.6)								
20	29.3 (17.0)								
21	53.9 (23.4)								
22	98.7 (72.0)								
23	71.6 (42.0)								
24	52.6 (38.5)								
25	58.4 (25.7)								
26									
27				22.7 (13.2)	40 (14)				
28				10.7 (11.6)	46 (10)				
29				7.0 (7.1)	43 (13)				
30				10.7 (22.3)	37 (10)				
Avg	77.4	444	487	12.8	42				
n	25	12	9	4	4	0	0	0	0
SD	25.6	70	95	5.9	3				
Min	29.3	317	351	7.0	37				
Max	128.0	516	608	22.7	46				

Table E4. Daily means (SD) of particulate matter concentrations at Site CA1B for October, 2009.

Day	PM$_{10}$ Concentration, µg dsm^{-3}			PM$_{2.5}$ Concentration, µg dsm^{-3}			TSP Concentration, µg dsm^{-3}		
	Ambient	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**	**Ambient**	**House 10**	**House 12**
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
1				9.2 (7.5)	36 (14)				
2				12.9 (9.4)	37 (10)				
3				8.0 (8.1)	36 (8)				
4				5.9 (5.3)	51 (24)				
5				7.9 (5.6)	55 (21)				
6				11.0 (5.8)	67 (29)				
7									
8							78.9 (55.6)	4530 (3450)	
9							74.7 (41.6)	4110 (3500)	
10							86.5 (57.8)	3860 (3170)	
11							59.5 (27.8)	3430 (2430)	
12							75.4 (71.2)	2980 (2050)	
13							103.0 (200.0)	2590 (1470)	
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
Avg				9.2	47		79.6	3580	
n	0	0	0	6	6	0	6	6	0
SD				2.3	12		13.0	661	
Min				5.9	36		59.5	2590	
Max				12.9	67		103.0	4530	

Table E5. PM10 emissions

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for September, 2007.

Day	**House 10**				**House 12**			
	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$mg\ d^{-1}hd^{-1}$	$g\ d^{-1}AU^{-1}$	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$mg\ d^{-1}hd^{-1}$	$g\ d^{-1}AU^{-1}$
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29					53 (73)	35 (48)	2.5 (3.5)	8.7 (12.0)
30					425 (496)	279 (325)	20.2 (23.6)	56.2 (65.3)
Avg					239	157	11.4	32.5
n	0	0	0	0	2	2	2	2
SD					186	122	8.8	23.7
Min					53	35	2.5	8.7
Max					425	279	20.2	56.2

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for October, 2007.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1					559 (637)	366 (418)	26.6 (30.3)	62.2 (70.7)
2					715 (729)	469 (478)	34.0 (34.7)	67.0 (68.2)
3					781 (727)	512 (477)	37.2 (34.6)	62.6 (58.5)
4					631 (688)	414 (451)	30.1 (32.8)	43.8 (47.8)
5					678 (715)	444 (469)	32.3 (34.1)	41.0 (43.1)
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
Avg					673	441	32.0	55.3
n	0	0	0	0	5	5	5	5
SD					75	49	3.6	10.7
Min					559	366	26.6	41.0
Max					781	512	37.2	67.0

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for November, 2007.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6																
7																
8	0	(0)	0	(0)												
9	0	(1)	0	(1)												
10	31	(88)	20	(58)												
11																
12	6	(14)	4	(9)												
13	2	(5)	1	(3)												
14																
15	15	(48)	10	(31)												
16	10	(15)	6	(10)	0.5	(0.7)	3.4	(5.3)								
17	11	(16)	7	(10)	0.5	(0.7)	4.4	(6.3)								
18	13	(17)	8	(11)	0.6	(0.8)	5.4	(7.4)								
19	13	(22)	8	(15)	0.6	(1.1)	5.3	(9.2)								
20	25	(48)	17	(31)	1.2	(2.3)	9.1	(17.2)								
21	38	(76)	25	(50)	1.8	(3.7)	11.6	(23.0)	59	(99)	39	(65)	2.8	(4.7)	18.0	(30.1)
22																
23																
24	66	(92)	43	(60)	3.2	(4.4)	10.7	(14.8)	90	(129)	59	(85)	4.3	(6.2)	14.6	(21.0)
25	325	(611)	213	(401)	15.6	(29.3)	42.8	(79.6)	320	(655)	210	(429)	15.3	(31.2)	42.3	(85.7)
26	551	(920)	361	(603)	26.4	(44.1)	61.7	(104.0)	691	(1120)	453	(735)	32.9	(53.4)	77.2	(126.0)
27	526	(811)	345	(532)	25.3	(38.9)	49.5	(76.7)	587	(904)	385	(593)	28.0	(43.1)	55.3	(86.0)
28	442	(671)	290	(440)	21.2	(32.2)	35.5	(54.2)	520	(740)	341	(485)	24.8	(35.3)	41.8	(59.8)
29	418	(592)	274	(388)	20.1	(28.4)	29.0	(41.3)	486	(661)	319	(433)	23.2	(31.6)	33.8	(46.1)
30	366	(525)	240	(344)	17.6	(25.2)	22.2	(32.1)	404	(570)	265	(374)	19.3	(27.2)	24.4	(34.8)
Avg	150		99		10.3		22.4		395		259		18.8		38.4	
n	19		19		13		13		8		8		8		8	
SD	201		132		10.3		18.8		212		139		10.1		19.4	
Min	0		0		0.5		3.4		59		39		2.8		14.6	
Max	551		361		26.4		61.7		691		453		32.9		77.2	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for December, 2007.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2	453	(542)	297	(355)	21.8	(26.1)	21.4	(25.7)	535	(615)	351	(403)	25.6	(29.4)	25.3	(29.1)
3	497	(499)	326	(327)	23.9	(24.0)	21.0	(21.2)	633	(627)	415	(411)	30.3	(30.0)	26.7	(26.5)
4	475	(493)	311	(324)	22.9	(23.8)	18.1	(18.9)	549	(586)	360	(384)	26.3	(28.0)	20.9	(22.4)
5	478	(505)	313	(331)	23.0	(24.3)	16.4	(17.4)	633	(683)	415	(448)	30.3	(32.7)	21.7	(23.4)
6	453	(544)	297	(357)	21.8	(26.2)	14.3	(17.2)	539	(652)	353	(428)	25.8	(31.2)	16.9	(20.6)
7	536	(574)	351	(377)	25.8	(27.7)	15.4	(16.6)	592	(619)	388	(406)	28.3	(29.6)	17.0	(17.8)
8	714	(670)	468	(440)	34.4	(32.3)	18.9	(17.8)	811	(794)	532	(521)	38.9	(38.0)	21.4	(21.0)
9	714	(733)	468	(481)	34.4	(35.4)	17.5	(18.1)	909	(898)	596	(589)	43.6	(43.0)	22.2	(22.0)
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20	1350	(941)	885	(617)	65.3	(45.6)	17.5	(12.2)	1720	(1210)	1130	(792)	82.6	(58.1)	22.2	(15.7)
21	1590	(1200)	1040	(790)	77.1	(58.3)	19.8	(15.0)	2060	(1540)	1350	(1010)	98.9	(74.3)	25.5	(19.2)
22	1480	(1100)	973	(722)	71.9	(53.4)	17.8	(13.2)	1990	(1610)	1310	(1050)	95.8	(77.3)	23.7	(19.2)
23	1300	(1010)	851	(660)	62.9	(48.8)	14.9	(11.6)	1710	(1330)	1120	(873)	82.5	(64.1)	19.6	(15.3)
24	1240	(833)	816	(546)	60.3	(40.4)	13.8	(9.3)	1500	(986)	987	(647)	72.5	(47.5)	16.6	(10.9)
25	1250	(812)	817	(532)	60.5	(39.4)	13.4	(8.7)	1550	(1090)	1020	(716)	74.6	(52.6)	16.5	(11.7)
26	1470	(876)	967	(574)	71.6	(42.5)	15.3	(9.1)	1400	(823)	918	(540)	67.4	(39.7)	14.4	(8.5)
27	1540	(659)	1010	(432)	74.7	(32.0)	15.5	(6.7)	1060	(593)	693	(389)	51.0	(28.6)	10.6	(6.0)
28	1420	(725)	931	(476)	69.0	(35.2)	13.9	(7.0)	1360	(1110)	889	(727)	65.4	(53.5)	13.1	(10.7)
29	1780	(647)	1160	(424)	86.4	(31.5)	16.9	(6.1)	2080	(683)	1360	(448)	100.0	(33.0)	19.6	(6.5)
30																
31																
Avg	1040		683		50.4		16.8		1200		788		57.8		19.7	
n	18		18		18		18		18		18		18		18	
SD	469		307		22.8		2.4		553		363		26.7		4.3	
Min	453		297		21.8		13.4		535		351		25.6		10.6	
Max	1780		1160		86.4		21.4		2080		1360		100.0		26.7	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for January, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6	9	(16)	6	(11)	1.0	(1.8)	7.2	(13.0)	3	(6)	2	(4)				
7	16	(27)	11	(18)	1.2	(2.0)	10.2	(16.7)	12	(31)	8	(21)				
8	15	(20)	10	(13)	0.7	(1.0)	6.4	(8.6)	12	(16)	8	(11)	0.6	(0.8)	4.1	(5.4)
9									16	(27)	10	(18)	0.7	(1.3)	6.2	(10.7)
10	12	(18)	8	(12)	0.6	(0.8)	4.5	(6.5)	19	(28)	13	(18)	0.9	(1.3)	8.2	(11.8)
11	16	(22)	11	(15)	0.8	(1.1)	5.0	(6.8)	23	(32)	15	(21)	1.1	(1.5)	9.6	(13.1)
12	21	(34)	14	(22)	1.0	(1.6)	5.3	(8.5)	24	(40)	16	(26)	1.2	(1.9)	9.1	(14.6)
13	23	(39)	15	(26)	1.1	(1.9)	4.6	(8.0)	31	(55)	21	(36)	1.5	(2.6)	9.8	(16.9)
14	41	(54)	27	(35)	2.0	(2.6)	6.9	(8.9)	52	(66)	34	(44)	2.5	(3.2)	13.3	(17.1)
15	50	(70)	33	(46)	2.4	(3.3)	6.9	(9.7)	47	(65)	31	(42)	2.2	(3.1)	10.0	(13.7)
16	75	(113)	49	(74)	3.6	(5.4)	8.7	(13.0)	59	(94)	39	(62)	2.8	(4.5)	10.1	(16.1)
17	133	(207)	87	(136)	6.4	(9.9)	12.9	(20.0)	147	(289)	97	(190)	7.0	(13.8)	20.4	(39.8)
18	175	(266)	115	(175)	8.4	(12.8)	14.5	(22.1)	293	(489)	192	(321)	14.0	(23.3)	34.0	(57.3)
19	205	(277)	135	(182)	9.9	(13.3)	14.6	(19.8)	356	(480)	233	(315)	16.9	(22.9)	34.7	(47.0)
20	218	(318)	143	(208)	10.5	(15.3)	13.5	(19.8)	360	(533)	236	(350)	17.2	(25.4)	30.1	(44.7)
21	237	(361)	156	(237)	11.4	(17.3)	12.9	(19.8)	343	(533)	225	(350)	16.4	(25.5)	24.6	(38.4)
22	234	(364)	154	(239)	11.3	(17.5)	11.3	(17.6)	326	(555)	214	(364)	15.6	(26.5)	20.3	(34.8)
23	305	(460)	200	(301)	14.7	(22.1)	13.1	(19.9)	379	(596)	248	(391)	18.1	(28.5)	20.7	(32.6)
24	326	(510)	214	(334)	15.7	(24.6)	12.6	(19.8)	392	(639)	257	(419)	18.8	(30.6)	19.0	(31.1)
25	364	(465)	239	(305)	17.6	(22.4)	12.8	(16.4)	434	(563)	285	(369)	20.8	(27.0)	18.7	(24.3)
26	454	(520)	298	(341)	21.9	(25.1)	14.5	(16.7)	555	(636)	364	(417)	26.6	(30.5)	21.5	(24.8)
27	452	(514)	297	(337)	21.8	(24.8)	13.2	(15.1)	553	(626)	363	(411)	26.5	(30.0)	19.5	(22.1)
28																
29	660	(879)	433	(576)	31.9	(42.4)	16.4	(21.9)	761	(1100)	499	(721)	36.5	(52.9)	22.3	(32.3)
30	757	(936)	496	(614)	36.6	(45.2)	17.5	(21.7)	1010	(1300)	664	(854)	48.7	(62.6)	27.3	(35.0)
31	652	(860)	428	(564)	31.5	(41.5)	14.0	(18.5)	739	(979)	484	(642)	35.5	(47.1)	18.4	(24.5)
Avg	227		149		11.0		10.8		278		182		14.4		17.9	
n	24		24		24		24		25		25		23		23	
SD	224		147		10.8		3.9		277		182		13.3		8.5	
Min	9		6		0.6		4.5		3		2		0.6		4.1	
Max	757		496		36.6		17.5		1010		664		48.7		34.7	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for March, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	25	(32)	17	(21)	1.2	(1.5)	10.0	(12.9)	20	(41)	13	(27)	0.9	(1.9)	8.0	(16.3)
2	53	(72)	35	(47)	2.5	(3.4)	22.4	(30.5)	50	(78)	33	(51)	2.4	(3.7)	21.3	(33.2)
3	75	(83)	49	(55)	3.5	(3.9)	30.8	(34.4)	81	(85)	53	(56)	3.8	(4.0)	33.3	(35.1)
4	59	(66)	39	(43)	2.8	(3.1)	21.3	(23.6)	65	(72)	43	(47)	3.1	(3.4)	23.6	(25.8)
5	57	(68)	37	(45)	2.7	(3.2)	17.4	(20.8)	58	(66)	38	(43)	2.7	(3.1)	17.5	(20.0)
6	59	(67)	39	(44)	2.8	(3.2)	14.7	(16.8)	59	(63)	38	(41)	2.8	(3.0)	14.6	(15.7)
7	81	(103)	53	(68)	3.8	(4.9)	16.2	(20.4)	86	(108)	56	(71)	4.1	(5.1)	17.3	(21.6)
8	74	(119)	48	(78)	3.5	(5.6)	12.0	(19.5)	84	(145)	55	(95)	4.0	(6.9)	13.7	(23.7)
9	216	(263)	142	(173)	10.2	(12.5)	28.7	(34.6)	180	(229)	118	(150)	8.6	(10.9)	23.9	(30.2)
10	285	(292)	187	(192)	13.5	(13.9)	31.7	(32.5)	288	(307)	189	(201)	13.7	(14.6)	31.9	(33.9)
11	249	(312)	163	(205)	11.8	(14.8)	23.4	(29.2)	296	(376)	194	(247)	14.1	(17.9)	27.8	(35.4)
12	331	(419)	217	(275)	15.7	(19.9)	26.5	(33.6)	345	(442)	226	(290)	16.4	(21.1)	27.7	(35.5)
13	309	(339)	202	(222)	14.7	(16.1)	21.4	(23.5)	324	(362)	212	(237)	15.4	(17.2)	22.4	(24.9)
14	386	(465)	253	(305)	18.4	(22.1)	23.1	(27.7)	406	(510)	266	(335)	19.4	(24.3)	24.4	(30.6)
15	468	(571)	307	(375)	22.3	(27.2)	24.7	(30.1)	457	(574)	300	(377)	21.8	(27.4)	24.2	(30.3)
16	622	(799)	408	(524)	29.7	(38.1)	29.0	(37.0)	679	(855)	446	(561)	32.5	(40.8)	31.8	(39.7)
17	566	(598)	371	(392)	27.0	(28.5)	23.8	(25.4)	639	(690)	419	(452)	30.6	(33.0)	27.0	(29.3)
18	511	(390)	335	(255)	24.4	(18.6)	19.4	(14.8)	620	(497)	407	(326)	29.7	(23.8)	23.6	(18.9)
19	472	(450)	309	(295)	22.5	(21.5)	16.2	(15.3)	494	(429)	324	(281)	23.7	(20.5)	17.0	(14.7)
20	500	(610)	328	(400)	23.9	(29.2)	15.7	(19.1)	429	(457)	281	(299)	20.6	(21.9)	13.5	(14.4)
21	666	(864)	437	(567)	31.9	(41.4)	19.2	(25.0)	537	(600)	352	(394)	25.7	(28.8)	15.5	(17.3)
22	777	(911)	510	(597)	37.2	(43.6)	20.6	(24.4)	649	(658)	426	(431)	31.2	(31.6)	17.3	(17.6)
23	811	(838)	532	(549)	38.9	(40.2)	20.0	(20.9)								
24																
25																
26	998	(864)	655	(567)	48.0	(41.5)	19.9	(17.2)	963	(850)	631	(558)	46.5	(41.1)	19.3	(17.1)
27																
28	1080	(823)	711	(540)	52.2	(39.6)	19.1	(14.6)	1140	(854)	748	(560)	55.2	(41.3)	20.2	(15.2)
29	1010	(676)	659	(443)	48.4	(32.6)	16.7	(11.3)	986	(674)	647	(442)	47.7	(32.6)	16.5	(11.3)
30	1140	(816)	749	(535)	55.0	(39.3)	18.0	(13.0)	1140	(807)	745	(529)	55.0	(39.1)	18.0	(12.9)
31	1140	(877)	749	(575)	55.1	(42.3)	17.1	(13.2)	1160	(870)	763	(570)	56.4	(42.1)	17.5	(13.2)
Avg	465		305		22.3		20.7		453		297		21.8		21.1	
n	28		28		28		28		27		27		27		27	
SD	362		238		17.5		5.3		362		237		17.5		6.1	
Min	25		17		1.2		10.0		20		13		0.9		8.0	
Max	1140		749		55.1		31.7		1160		763		56.4		33.3	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for April, 2008.

Day	House 10								House 12							
	$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$		$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$	
1	1290	(906)	845	(594)	62.2	(43.7)	18.4	(13.0)	1170	(843)	765	(553)	56.6	(40.9)	16.7	(12.1)
2	1370	(847)	896	(555)	66.0	(40.9)	18.6	(11.6)	1300	(811)	855	(532)	63.3	(39.4)	17.8	(11.1)
3	1350	(700)	886	(459)	65.3	(33.8)	17.6	(9.1)	1300	(742)	852	(487)	63.1	(36.0)	17.0	(9.7)
4	1820	(1090)	1190	(715)	88.1	(52.8)	22.7	(13.5)	1650	(962)	1080	(631)	80.3	(46.8)	20.7	(12.0)
5	2810	(1550)	1840	(1010)	136.0	(74.8)	33.8	(18.6)	1960	(618)	1280	(405)	95.2	(30.0)	23.6	(7.4)
6																
7																
8																
9																
10																
11																
12	3330	(855)	2180	(561)	162.0	(41.6)	31.8	(8.1)	3460	(973)	2270	(638)	169.0	(47.6)	33.2	(9.3)
13																
14																
15																
16																
17																
18																
19	27	(184)	18	(121)					7	(92)	4	(60)				
20	17	(56)	11	(37)					1	(7)	1	(5)				
21	4	(81)	2	(53)					19	(63)	13	(41)				
22	24	(70)	15	(46)					31	(94)	20	(62)	1.7	(4.9)	10.8	(29.6)
23	29	(50)	19	(33)	1.4	(2.3)	10.1	(17.1)	26	(45)	17	(30)	1.2	(2.1)	9.1	(15.8)
24	32	(43)	21	(28)	1.5	(2.0)	12.6	(17.1)	33	(45)	22	(30)	1.6	(2.1)	13.4	(18.2)
25	48	(71)	32	(47)	2.3	(3.3)	20.3	(30.1)	63	(87)	41	(57)	3.0	(4.1)	26.7	(36.7)
26	83	(85)	54	(56)	3.9	(4.0)	33.5	(34.3)	92	(96)	60	(63)	4.3	(4.5)	36.8	(38.6)
27	105	(101)	69	(66)	4.9	(4.8)	37.5	(35.9)	132	(119)	86	(78)	6.2	(5.6)	46.0	(41.5)
28	115	(118)	75	(78)	5.4	(5.6)	34.5	(35.3)	152	(130)	99	(85)	7.2	(6.1)	44.2	(37.7)
29	73	(95)	48	(63)	3.5	(4.5)	18.0	(23.5)	96	(114)	63	(75)	4.5	(5.4)	22.9	(27.2)
30	78	(113)	51	(74)	3.7	(5.3)	15.7	(22.7)	90	(130)	59	(85)	4.3	(6.1)	17.5	(25.3)
Avg	700		459		43.3		23.2		644		422		37.5		23.8	
n	18		18		14		14		18		18		15		15	
SD	1020		672		52.7		8.8		941		617		48.0		11.1	
Min	4		2		1.4		10.1		1		1		1.2		9.1	
Max	3330		2180		162.0		37.5		3460		2270		169.0		46.0	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for May, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	98	(149)	65	(98)	4.7	(7.1)	16.1	(24.5)	143	(217)	94	(142)	6.8	(10.2)	22.6	(34.5)
2	508	(752)	333	(493)	24.0	(35.5)	67.9	(100.0)	585	(861)	384	(565)	27.7	(40.7)	75.8	(112.0)
3	620	(826)	406	(542)	29.3	(39.1)	68.8	(92.0)	617	(866)	405	(568)	29.2	(41.0)	66.7	(94.1)
4	603	(663)	395	(435)	28.5	(31.4)	56.4	(62.0)	663	(764)	435	(501)	31.4	(36.2)	60.4	(69.4)
5	674	(720)	442	(472)	31.9	(34.1)	53.5	(56.4)	633	(679)	415	(445)	30.0	(32.2)	49.3	(52.9)
6	569	(613)	373	(402)	27.0	(29.0)	39.3	(42.6)	584	(618)	383	(405)	27.7	(29.3)	39.3	(41.5)
7	491	(581)	322	(381)	23.3	(27.5)	29.6	(35.0)	509	(615)	334	(403)	24.1	(29.1)	30.0	(36.4)
8	736	(596)	482	(391)	34.9	(28.3)	38.8	(31.2)	765	(616)	501	(404)	36.3	(29.2)	39.5	(31.6)
9	650	(592)	426	(388)	30.9	(28.1)	30.5	(27.6)	717	(664)	470	(435)	34.0	(31.5)	32.9	(30.2)
10	954	(752)	626	(493)	45.3	(35.7)	39.9	(31.2)	1020	(815)	671	(535)	48.5	(38.7)	42.0	(33.3)
11	871	(854)	571	(560)	41.4	(40.6)	32.8	(32.1)	904	(938)	593	(615)	42.9	(44.5)	33.5	(34.7)
12	796	(675)	522	(442)	37.8	(32.1)	27.2	(23.0)	829	(721)	543	(473)	39.4	(34.3)	27.9	(24.2)
13	1040	(962)	680	(631)	49.3	(45.8)	32.2	(29.7)	1230	(1150)	804	(754)	58.3	(54.7)	37.5	(34.8)
14	1180	(933)	772	(612)	56.1	(44.4)	33.7	(26.7)	1210	(975)	795	(639)	57.7	(46.4)	34.1	(27.5)
15																
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28																
29	2470	(862)	1620	(565)	119.0	(41.5)	29.4	(10.2)	2520	(963)	1650	(632)	121.0	(46.3)	29.8	(11.3)
30	2680	(737)	1760	(484)	129.0	(35.5)	30.7	(8.3)	2830	(877)	1860	(575)	136.0	(42.2)	32.2	(9.8)
31	2700	(863)	1770	(566)	130.0	(41.6)	29.9	(9.5)	2920	(819)	1910	(537)	140.0	(39.4)	32.0	(8.8)
Avg	1040		680		49.6		38.6		1100		721		52.5		40.3	
n	17		17		17		17		17		17		17		17	
SD	769		504		37.2		14.2		810		531		39.1		14.2	
Min	98		65		4.7		16.1		143		94		6.8		22.6	
Max	2700		1770		130.0		68.8		2920		1910		140.0		75.8	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for June, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	2900	(818)	1900	(537)	140.0	(39.5)	31.0	(8.7)	3260	(916)	2140	(601)	157.0	(44.2)	34.6	(9.6)
2	2950	(1650)	1940	(1080)	143.0	(80.0)	30.6	(17.1)	3460	(2460)	2270	(1610)	167.0	(119.0)	35.6	(25.2)
3	3080	(1020)	2020	(670)	149.0	(49.5)	31.0	(10.3)	3270	(901)	2140	(591)	158.0	(43.5)	32.6	(8.9)
4	3330	(1470)	2180	(963)	162.0	(71.2)	32.5	(14.3)								
5																
6																
7																
8																
9																
10																
11																
12																
13	12	(34)	8	(22)					9	(33)	6	(22)				
14	42	(69)	27	(45)					71	(175)	47	(115)				
15	59	(72)	38	(47)	2.8	(3.4)	20.7	(25.5)	59	(69)	39	(45)	2.8	(3.3)	20.6	(24.1)
16	82	(82)	54	(54)	3.9	(3.8)	33.1	(33.1)	95	(96)	62	(63)	4.5	(4.6)	38.0	(38.9)
17	82	(88)	54	(58)	3.9	(4.2)	34.8	(37.5)	88	(93)	58	(61)	4.2	(4.4)	37.3	(39.6)
18	90	(117)	59	(77)	4.2	(5.5)	36.4	(47.1)	104	(152)	68	(100)	4.9	(7.2)	42.5	(62.6)
19	127	(154)	84	(101)	6.0	(7.3)	45.1	(54.7)	121	(149)	80	(98)	5.8	(7.0)	43.4	(53.0)
20	200	(263)	131	(172)	9.5	(12.4)	59.0	(76.6)	205	(253)	135	(166)	9.7	(12.0)	61.3	(74.6)
21	151	(335)	99	(220)	7.2	(15.8)	36.9	(80.8)	170	(301)	111	(198)	8.0	(14.3)	41.9	(73.5)
22	310	(328)	204	(215)	14.7	(15.5)	61.2	(65.2)	276	(299)	181	(196)	13.1	(14.2)	55.3	(60.6)
23	1410	(1460)	926	(955)	66.8	(68.9)	223.0	(227.0)	1500	(1690)	982	(1110)	71.1	(80.0)	238.0	(263.0)
24	2350	(2850)	1540	(1870)	111.0	(135.0)	309.0	(376.0)	2400	(2900)	1570	(1900)	114.0	(138.0)	319.0	(388.0)
25	2300	(2490)	1510	(1630)	109.0	(118.0)	253.0	(276.0)	2150	(2620)	1410	(1720)	102.0	(124.0)	238.0	(291.0)
26	2030	(1940)	1330	(1270)	96.3	(91.8)	188.0	(179.0)	2010	(2090)	1320	(1370)	95.5	(99.2)	188.0	(196.0)
27	1770	(1580)	1160	(1040)	84.0	(74.9)	139.0	(123.0)	1920	(1690)	1260	(1110)	91.1	(80.2)	152.0	(133.0)
28	1690	(1620)	1110	(1060)	80.3	(76.9)	115.0	(110.0)	1860	(1730)	1220	(1140)	88.4	(82.4)	127.0	(119.0)
29	1690	(1520)	1110	(999)	80.4	(72.2)	100.0	(89.5)	1940	(1680)	1270	(1100)	92.4	(80.0)	116.0	(99.9)
30	1770	(1440)	1160	(943)	83.8	(68.2)	92.0	(74.2)	1910	(1520)	1250	(996)	90.8	(72.3)	100.0	(79.3)
Avg	1290		848		67.9		93.6		1280		839		67.4		101.0	
n	22		22		20		20		21		21		19		19	
SD	1170		767		55.5		83.4		1200		788		57.2		85.2	
Min	12		8		2.8		20.7		9		6		2.8		20.6	
Max	3330		2180		162.0		309.0		3460		2270		167.0		319.0	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for July, 2008.

Day	House 10								House 12							
	$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$		$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$	
1	1730	(1390)	1140	(912)	82.3	(66.0)	80.3	(64.5)	1940	(1620)	1270	(1060)	92.2	(77.3)	90.1	(75.6)
2	1590	(1100)	1040	(720)	75.3	(52.2)	65.8	(45.6)	1920	(1400)	1260	(915)	91.5	(66.5)	80.3	(58.2)
3	1080	(888)	709	(583)	51.4	(42.2)	40.7	(33.8)	1270	(1100)	831	(720)	60.4	(52.3)	48.1	(42.1)
4	1040	(813)	682	(533)	49.4	(38.7)	35.4	(27.8)	1160	(942)	759	(618)	55.3	(44.9)	39.7	(32.4)
5	925	(679)	607	(445)	44.0	(32.3)	28.7	(21.2)	1030	(746)	673	(489)	49.0	(35.6)	32.1	(23.5)
6	909	(650)	596	(426)	43.3	(31.0)	25.9	(18.7)	1010	(721)	662	(473)	48.2	(34.5)	28.9	(20.8)
7	944	(859)	619	(563)	45.0	(41.0)	24.8	(22.5)	1100	(909)	722	(596)	52.7	(43.5)	29.1	(24.0)
8	870	(865)	571	(567)	41.5	(41.3)	21.2	(21.0)	999	(1050)	655	(685)	47.9	(50.1)	24.5	(25.5)
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																
25																
26	2990	(977)	1960	(641)	146.0	(47.5)	30.2	(10.0)	2980	(882)	1950	(578)	146.0	(43.3)	30.4	(9.2)
27	3040	(809)	2000	(530)	148.0	(39.4)	29.9	(7.9)	2820	(814)	1850	(534)	139.0	(40.1)	28.0	(8.1)
28	3150	(858)	2060	(562)	154.0	(41.9)	30.1	(8.2)	2930	(712)	1920	(467)	145.0	(35.2)	28.4	(6.9)
29																
30																
31																
Avg	1660		1090		80.0		37.5		1740		1140		84.3		41.8	
n	11		11		11		11		11		11		11		11	
SD	898		589		44.2		17.7		782		513		39.2		21.5	
Min	870		571		41.5		21.2		999		655		47.9		24.5	
Max	3150		2060		154.0		80.3		2980		1950		146.0		90.1	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for August, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12	86	(104)	56	(68)	4.0	(4.8)	29.5	(35.8)	61	(66)	40	(43)	2.8	(3.1)	20.8	(22.7)
13	116	(115)	76	(76)	5.4	(5.4)	46.1	(45.7)	117	(109)	77	(72)	5.5	(5.1)	46.5	(43.5)
14	116	(131)	76	(86)	5.5	(6.1)	49.0	(55.1)	147	(134)	96	(88)	6.9	(6.3)	61.7	(56.5)
15	177	(232)	116	(152)	8.3	(10.9)	71.9	(94.3)	181	(147)	118	(97)	8.5	(6.9)	73.3	(59.7)
16	172	(149)	113	(98)	8.1	(7.0)	62.1	(53.3)	180	(135)	118	(89)	8.4	(6.3)	64.9	(48.6)
17	171	(151)	112	(99)	8.0	(7.1)	51.7	(45.1)	186	(151)	122	(99)	8.7	(7.1)	56.3	(45.4)
18	156	(164)	103	(108)	7.3	(7.7)	38.9	(41.1)	158	(148)	103	(97)	7.4	(7.0)	39.4	(37.3)
19	248	(262)	162	(172)	11.6	(12.3)	49.3	(52.2)	233	(238)	153	(156)	10.9	(11.2)	46.5	(47.7)
20	512	(540)	336	(354)	24.0	(25.3)	82.8	(87.8)	411	(424)	269	(278)	19.3	(19.9)	66.5	(68.3)
21	1510	(1580)	989	(1040)	70.8	(74.1)	201.0	(211.0)	1400	(1340)	917	(881)	65.8	(63.2)	186.0	(177.0)
22	1380	(1200)	908	(790)	65.0	(56.6)	154.0	(135.0)	1200	(1020)	785	(666)	56.3	(47.8)	133.0	(114.0)
23	1370	(1250)	896	(818)	64.2	(58.6)	128.0	(118.0)	1280	(1180)	837	(777)	60.1	(55.7)	119.0	(110.0)
24	1490	(1230)	979	(805)	70.1	(57.6)	119.0	(97.1)	1290	(1100)	845	(724)	60.7	(52.0)	102.0	(87.0)
25	1690	(1460)	1110	(960)	79.2	(68.8)	116.0	(99.7)	1400	(1210)	920	(791)	66.0	(56.8)	96.2	(82.1)
26	1580	(1270)	1040	(833)	74.4	(59.7)	94.7	(76.2)	1320	(1100)	869	(718)	62.4	(51.6)	79.3	(65.4)
27	1420	(1170)	930	(765)	66.7	(54.8)	74.4	(61.2)	1360	(1170)	892	(764)	64.1	(54.9)	71.4	(60.8)
28	1360	(1230)	895	(804)	64.2	(57.7)	63.8	(57.4)	1310	(1090)	859	(714)	61.8	(51.4)	61.4	(51.2)
29	1450	(1080)	950	(710)	68.2	(50.9)	60.3	(45.1)	1040	(862)	685	(566)	49.3	(40.7)	43.7	(36.2)
30	1060	(711)	693	(466)	49.8	(33.5)	39.9	(27.2)	1090	(739)	714	(485)	51.3	(34.9)	41.0	(28.0)
31	1180	(923)	777	(605)	55.8	(43.5)	40.4	(31.6)	1260	(1020)	828	(669)	59.6	(48.2)	43.1	(35.0)
Avg	862		566		40.5		78.6		781		512		36.8		72.6	
n	20		20		20		20		20		20		20		20	
SD	621		407		29.2		43.5		548		360		25.8		37.8	
Min	86		56		4.0		29.5		61		40		2.8		20.8	
Max	1690		1110		79.2		201.0		1400		920		66.0		186.0	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for September, 2008.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1	1110	(766)	731	(502)	52.5	(36.1)	34.6	(23.9)	1140	(793)	745	(520)	53.7	(37.5)	35.3	(24.7)
2	1140	(761)	750	(499)	53.9	(35.9)	32.5	(21.7)	1300	(1090)	851	(712)	61.3	(51.3)	36.9	(31.0)
3	1390	(1040)	910	(684)	65.5	(49.2)	36.3	(27.2)	1290	(946)	843	(621)	60.8	(44.7)	33.7	(24.7)
4	1580	(1200)	1040	(785)	74.5	(56.5)	38.2	(29.1)	1430	(1060)	939	(694)	67.8	(50.1)	34.7	(25.7)
5	1520	(1060)	999	(696)	71.9	(50.1)	34.3	(24.0)	1600	(993)	1050	(651)	75.6	(47.0)	36.0	(22.4)
6	1420	(1090)	934	(714)	67.3	(51.4)	29.9	(22.8)	1510	(1010)	989	(664)	71.4	(47.9)	31.7	(21.3)
7	1370	(1010)	897	(661)	64.6	(47.6)	26.8	(19.8)	1430	(989)	939	(649)	67.8	(46.9)	28.2	(19.5)
8	1790	(1150)	1170	(751)	84.8	(54.2)	33.0	(21.1)	1500	(911)	985	(597)	71.2	(43.2)	27.7	(16.8)
9	1690	(1050)	1110	(690)	79.8	(49.8)	29.2	(18.3)	1450	(895)	952	(587)	68.8	(42.5)	25.2	(15.5)
10	1630	(1220)	1070	(799)	77.4	(57.7)	26.7	(19.9)	1590	(1030)	1040	(678)	75.4	(49.0)	26.0	(16.9)
11	2160	(1430)	1420	(937)	102.0	(67.7)	33.4	(22.0)	2350	(1600)	1540	(1050)	111.0	(75.9)	36.3	(24.6)
12	2290	(1320)	1500	(866)	108.0	(62.6)	33.6	(19.4)	2580	(1490)	1690	(978)	122.0	(70.8)	38.0	(21.9)
13	2280	(1270)	1500	(834)	108.0	(60.3)	32.0	(17.8)	2580	(1460)	1690	(957)	122.0	(69.3)	36.2	(20.4)
14	2060	(983)	1350	(644)	97.7	(46.6)	27.5	(13.1)	2230	(1090)	1460	(712)	106.0	(51.6)	29.8	(14.5)
15	1920	(743)	1260	(487)	91.2	(35.3)	24.6	(9.4)	2040	(749)	1340	(491)	97.1	(35.6)	26.1	(9.4)
16	2070	(843)	1360	(553)	98.4	(40.0)	25.4	(10.2)	2220	(828)	1460	(543)	106.0	(39.4)	27.3	(10.0)
17	2010	(649)	1320	(425)	95.7	(30.9)	23.7	(7.6)	2130	(625)	1400	(410)	102.0	(29.8)	25.3	(7.3)
18	2050	(684)	1350	(448)	97.8	(32.6)	23.3	(7.7)	2080	(590)	1360	(387)	99.4	(28.2)	23.7	(6.6)
19	2250	(798)	1470	(523)	107.0	(38.1)	24.7	(8.7)	2360	(819)	1550	(537)	113.0	(39.2)	26.0	(8.9)
20	1770	(549)	1160	(360)	84.4	(26.2)	18.7	(5.8)	2200	(551)	1440	(361)	105.0	(26.4)	23.4	(5.7)
21	1930	(798)	1270	(523)	92.3	(38.1)	19.8	(8.1)	1970	(478)	1290	(314)	94.2	(22.9)	20.2	(4.9)
22	3560	(1670)	2330	(1100)	170.0	(80.0)	35.3	(16.4)								
23	3120	(1370)	2050	(898)	150.0	(65.5)	30.2	(13.2)								
24	3300	(842)	2170	(552)	158.0	(40.4)	31.1	(8.0)								
25																
26																
27																
28																
29																
30																
Avg	1980		1300		93.9		29.4		1850		1220		88.2		29.9	
n	24		24		24		24		21		21		21		21	
SD	613		402		29.6		5.1		445		291		21.4		5.3	
Min	1110		731		52.5		18.7		1140		745		53.7		20.2	
Max	3560		2330		170.0		38.2		2580		1690		122.0		38.0	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for October, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17	-2	(8)	-1	(5)					36	(387)	24	(253)				
18	0	(8)	0	(5)					-2	(4)	-1	(3)				
19	1	(7)	0	(4)					1	(7)	1	(5)				
20	26	(122)	17	(80)					16	(46)	11	(30)				
21	22	(37)	14	(24)	1.0	(1.8)	7.5	(12.6)	21	(43)	14	(28)	1.0	(2.0)	7.5	(15.3)
22	43	(63)	28	(41)	2.0	(3.0)	17.0	(25.4)	92	(618)	60	(405)	4.3	(29.2)	37.2	(251.0)
23	139	(152)	91	(100)	6.6	(7.2)	59.0	(64.6)	135	(408)	88	(267)	6.4	(19.2)	57.2	(173.0)
24	157	(161)	103	(105)	7.4	(7.6)	64.4	(65.9)	131	(216)	86	(141)	6.2	(10.2)	52.8	(86.5)
25	190	(185)	124	(121)	9.0	(8.7)	69.1	(67.1)	196	(417)	128	(273)	9.3	(19.7)	69.0	(149.0)
26	181	(179)	119	(117)	8.6	(8.4)	55.4	(54.3)	176	(199)	115	(130)	8.3	(9.4)	51.6	(58.3)
27	105	(125)	69	(82)	4.9	(5.9)	26.6	(32.1)	117	(332)	77	(218)	5.6	(15.7)	28.5	(81.4)
28	182	(211)	119	(138)	8.6	(10.0)	37.1	(43.3)	132	(145)	87	(95)	6.2	(6.9)	25.8	(28.6)
29	434	(702)	284	(460)	20.5	(33.2)	70.6	(112.0)	402	(643)	264	(422)	19.0	(30.4)	62.5	(98.5)
30	844	(1350)	553	(886)	39.9	(63.9)	116.0	(187.0)	844	(1310)	553	(857)	39.9	(61.8)	111.0	(174.0)
31	746	(1060)	489	(694)	35.3	(50.1)	84.7	(121.0)	733	(1210)	481	(795)	34.7	(57.4)	80.3	(134.0)
Avg	204		134		13.1		55.2		202		132		12.8		53.0	
n	15		15		11		11		15		15		11		11	
SD	257		168		12.6		30.1		251		165		12.4		27.2	
Min	-2		-1		1.0		7.5		-2		-1		1.0		7.5	
Max	844		553		39.9		116.0		844		553		39.9		111.0	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for November, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	623	(891)	409	(584)	29.5	(42.2)	59.4	(85.0)	622	(904)	408	(593)	29.4	(42.8)	57.1	(83.0)
2	600	(713)	394	(468)	28.4	(33.8)	48.7	(58.1)	615	(742)	403	(486)	29.1	(35.1)	48.3	(58.4)
3	513	(740)	337	(485)	24.3	(35.0)	35.8	(51.8)	532	(804)	349	(527)	25.2	(38.1)	36.1	(54.7)
4	600	(728)	394	(477)	28.4	(34.5)	36.3	(43.8)	606	(700)	397	(459)	28.7	(33.2)	35.6	(41.1)
5	610	(774)	400	(508)	28.9	(36.7)	32.5	(41.5)	616	(711)	404	(466)	29.2	(33.7)	32.0	(37.0)
6	554	(600)	363	(394)	26.3	(28.5)	26.2	(28.7)	513	(572)	336	(375)	24.3	(27.1)	23.7	(26.6)
7																
8																
9																
10																
11	564	(537)	370	(352)	26.8	(25.5)	16.2	(15.5)	593	(570)	389	(374)	28.2	(27.0)	16.7	(16.1)
12	723	(632)	474	(415)	34.4	(30.1)	19.1	(16.7)	625	(543)	410	(356)	29.7	(25.8)	16.2	(14.1)
13	859	(728)	563	(477)	40.9	(34.7)	21.0	(17.9)	806	(687)	528	(450)	38.3	(32.6)	19.3	(16.5)
14	902	(705)	591	(462)	42.9	(33.6)	20.5	(16.1)	903	(686)	592	(450)	42.9	(32.6)	20.1	(15.4)
15	977	(715)	641	(469)	46.6	(34.1)	20.7	(15.1)	944	(707)	619	(463)	44.9	(33.6)	19.6	(14.8)
16	1260	(882)	826	(578)	60.0	(42.0)	24.9	(17.5)	1030	(741)	678	(486)	49.1	(35.2)	20.1	(14.5)
17																
18																
19																
20																
21																
22																
23																
24																
25	1550	(715)	1020	(469)	74.2	(34.2)	19.2	(8.9)	1750	(781)	1140	(512)	83.2	(37.2)	21.3	(9.6)
26	1480	(468)	968	(307)	70.7	(22.4)	17.6	(5.6)	1560	(431)	1020	(283)	74.1	(20.5)	18.2	(5.1)
27	1570	(350)	1030	(230)	75.1	(16.8)	17.9	(4.0)	1700	(350)	1120	(230)	81.2	(16.7)	19.3	(3.9)
28	1770	(376)	1160	(247)	84.8	(18.0)	19.5	(4.1)	2200	(661)	1440	(434)	105.0	(31.5)	24.0	(7.2)
29	1890	(495)	1240	(325)	90.6	(23.8)	20.1	(5.3)	2030	(704)	1330	(461)	97.0	(33.6)	21.4	(7.4)
30	1880	(603)	1230	(395)	90.1	(28.9)	19.4	(6.3)	2050	(593)	1350	(389)	97.9	(28.3)	20.9	(6.1)
Avg	1050		689		50.2		26.4		1090		718		52.1		26.1	
n	18		18		18		18		18		18		18		18	
SD	493		323		23.7		11.6		588		386		28.1		11.1	
Min	513		337		24.3		16.2		513		336		24.3		16.2	
Max	1890		1240		90.6		59.4		2200		1440		105.0		57.1	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for December, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	1890	(426)	1240	(279)	90.6	(20.5)	18.9	(4.3)	1900	(417)	1240	(274)	90.5	(19.9)	18.7	(4.2)
2	2110	(551)	1380	(361)	101.0	(26.5)	20.5	(5.3)	2060	(624)	1350	(409)	98.5	(29.8)	19.8	(5.9)
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13	24	(66)	16	(43)	1.2	(3.1)	8.5	(22.2)	17	(31)	11	(20)	0.8	(1.5)	5.8	(10.6)
14	32	(54)	21	(35)	1.5	(2.5)	12.8	(21.4)	29	(58)	19	(38)	1.3	(2.7)	11.2	(22.2)
15	36	(54)	24	(35)	1.7	(2.6)	15.3	(22.9)	35	(50)	23	(33)	1.7	(2.3)	14.8	(21.0)
16	37	(49)	24	(32)	1.7	(2.3)	15.0	(20.0)	39	(54)	25	(36)	1.8	(2.6)	15.9	(22.4)
17	43	(65)	28	(43)	2.0	(3.1)	15.7	(24.0)	38	(61)	25	(40)	1.8	(2.9)	14.2	(22.8)
18	43	(54)	28	(36)	2.1	(2.6)	13.3	(16.7)	40	(67)	26	(44)	1.9	(3.2)	12.5	(21.0)
19	41	(53)	27	(35)	1.9	(2.5)	10.2	(13.1)	39	(64)	25	(42)	1.8	(3.1)	9.9	(16.5)
20	50	(75)	33	(49)	2.4	(3.5)	10.1	(15.2)	41	(77)	27	(50)	1.9	(3.6)	8.5	(16.0)
21	136	(272)	89	(178)	6.4	(12.9)	22.2	(45.4)	117	(185)	77	(121)	5.6	(8.8)	19.5	(30.6)
22	342	(529)	224	(347)	16.2	(25.1)	45.1	(69.7)	292	(462)	191	(303)	13.9	(21.9)	40.2	(63.2)
23	398	(628)	261	(412)	18.9	(29.8)	44.3	(69.8)	341	(538)	223	(353)	16.2	(25.5)	38.8	(61.3)
24	410	(617)	269	(405)	19.5	(29.3)	38.6	(58.1)	367	(550)	240	(361)	17.4	(26.1)	35.2	(52.8)
25	418	(647)	274	(424)	19.9	(30.7)	33.3	(51.3)	385	(582)	252	(381)	18.3	(27.6)	31.3	(47.2)
26	458	(652)	300	(428)	21.7	(31.0)	31.6	(45.2)	469	(640)	307	(420)	22.3	(30.4)	33.0	(45.1)
27	656	(806)	430	(529)	31.1	(38.3)	39.4	(48.2)	653	(807)	428	(529)	31.1	(38.4)	39.9	(49.0)
28	645	(764)	423	(501)	30.7	(36.3)	34.2	(40.3)	662	(769)	434	(504)	31.5	(36.6)	35.6	(41.3)
29	620	(687)	406	(451)	29.5	(32.7)	29.1	(32.5)	652	(754)	427	(494)	31.0	(35.9)	31.1	(36.0)
30	532	(602)	349	(395)	25.3	(28.7)	22.4	(25.4)	563	(695)	369	(456)	26.8	(33.1)	24.0	(29.7)
31	481	(609)	315	(399)	22.9	(29.0)	18.2	(23.2)	488	(617)	320	(405)	23.3	(29.4)	18.8	(23.8)
Avg	448		294		21.4		23.7		439		288		20.9		22.8	
n	21		21		21		21		21		21		21		21	
SD	553		363		26.5		11.4		551		361		26.3		11.0	
Min	24		16		1.2		8.5		17		11		0.8		5.8	
Max	2110		1380		101.0		45.1		2060		1350		98.5		40.2	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for January, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	459	(489)	301	(320)	21.8	(23.2)	15.7	(16.8)	428	(465)	281	(305)	20.4	(22.2)	14.9	(16.2)
2	475	(477)	312	(313)	22.6	(22.7)	14.9	(14.9)	448	(449)	294	(294)	21.4	(21.4)	14.2	(14.2)
3	517	(479)	339	(314)	24.6	(22.8)	14.8	(13.7)	496	(466)	325	(306)	23.6	(22.2)	14.3	(13.5)
4	599	(579)	393	(380)	28.5	(27.6)	15.8	(15.3)								
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																
21	2600	(1080)	1710	(708)	125.0	(51.7)	27.7	(11.5)	2280	(491)	1490	(322)	110.0	(23.7)	24.5	(5.4)
22	2280	(601)	1500	(394)	109.0	(28.8)	23.4	(6.3)	1910	(368)	1250	(241)	92.3	(17.7)	19.9	(3.9)
23	1710	(300)	1120	(197)	82.1	(14.4)	17.1	(3.0)	1740	(330)	1140	(216)	83.9	(15.9)	17.5	(3.4)
24	1690	(592)	1110	(388)	81.0	(28.4)	16.3	(5.7)	1750	(439)	1150	(288)	84.4	(21.2)	17.1	(4.3)
25	2050	(455)	1350	(298)	98.6	(21.8)	19.3	(4.3)	2230	(459)	1460	(301)	108.0	(22.2)	21.2	(4.4)
26																
27																
28																
29																
30																
31																
Avg	1380		903		65.9		18.3		1410		924		68.0		18.0	
n	9		9		9		9		8		8		8		8	
SD	816		535		39.2		4.2		760		498		36.8		3.4	
Min	459		301		21.8		14.8		428		281		20.4		14.2	
Max	2600		1710		125.0		27.7		2280		1490		110.0		24.5	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for February, 2009.

Day	**House 10**								**House 12**							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6	1	(8)	1	(6)					2	(3)	1	(2)				
7	2	(8)	2	(5)					3	(7)	2	(5)				
8	2	(5)	2	(3)					3	(6)	2	(4)				
9									12	(42)	8	(28)				
10	18	(43)	12	(28)	0.9	(2.0)	6.2	(14.8)	15	(25)	10	(16)	0.7	(1.2)	4.9	(8.3)
11	20	(42)	13	(28)	0.9	(2.0)	7.9	(16.8)	19	(57)	12	(38)	0.9	(2.7)	7.3	(22.7)
12									22	(29)	15	(19)	1.0	(1.4)	9.3	(12.2)
13	29	(52)	19	(34)	1.4	(2.5)	11.8	(21.5)	23	(39)	15	(25)	1.1	(1.8)	9.6	(15.7)
14	23	(30)	15	(20)	1.1	(1.4)	8.6	(11.2)	24	(32)	16	(21)	1.1	(1.5)	9.0	(11.8)
15	34	(45)	22	(29)	1.6	(2.1)	10.3	(13.4)	36	(78)	23	(51)	1.7	(3.7)	10.9	(23.7)
16	38	(48)	25	(32)	1.8	(2.3)	9.6	(12.1)	41	(53)	27	(35)	1.9	(2.5)	10.4	(13.2)
17	55	(89)	36	(58)	2.6	(4.2)	11.2	(18.1)	57	(88)	37	(58)	2.7	(4.1)	11.6	(17.9)
18	95	(149)	62	(97)	4.5	(7.1)	15.8	(24.7)	104	(164)	68	(107)	4.9	(7.7)	17.2	(27.2)
19	485	(703)	318	(461)	23.1	(33.4)	65.8	(95.4)	435	(648)	286	(425)	20.5	(30.5)	58.8	(86.9)
20									501	(871)	328	(571)	23.6	(41.0)	56.6	(98.2)
21									513	(751)	336	(492)	24.1	(35.3)	48.9	(71.9)
22									455	(670)	298	(439)	21.4	(31.6)	36.9	(54.4)
23									468	(630)	307	(413)	22.1	(29.7)	32.7	(43.9)
24									629	(982)	412	(644)	29.7	(46.4)	38.2	(59.3)
25									773	(1180)	507	(771)	36.5	(55.6)	41.3	(62.8)
26									651	(555)	427	(364)	30.8	(26.3)	30.9	(26.4)
27									611	(572)	401	(375)	28.9	(27.1)	25.8	(24.0)
28									651	(514)	427	(337)	30.9	(24.4)	24.9	(19.5)
Avg	67		44		4.2		16.3		263		172		15.0		25.5	
n	12		12		9		9		23		23		19		19	
SD	128		84		6.8		17.7		278		182		13.1		17.0	
Min	1		1		0.9		6.2		2		1		0.7		4.9	
Max	485		318		23.1		65.8		773		507		36.5		58.8	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for March, 2009.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1					559 (447)	367 (293)	26.5 (21.2)	19.4 (15.5)
2					862 (595)	566 (390)	41.0 (28.3)	27.3 (19.0)
3					898 (796)	589 (522)	42.7 (37.8)	26.0 (23.0)
4					996 (966)	653 (633)	47.4 (45.9)	26.5 (25.8)
5					1040 (985)	681 (646)	49.4 (46.9)	25.6 (24.3)
6					1070 (1010)	700 (659)	50.8 (47.9)	24.4 (23.0)
7					1120 (1530)	735 (1000)	53.4 (72.9)	23.9 (33.1)
8					1160 (1320)	763 (868)	55.5 (63.1)	23.2 (26.6)
9					1130 (1050)	740 (690)	53.9 (50.3)	21.1 (19.7)
10					1260 (1830)	824 (1200)	60.1 (87.6)	22.2 (32.9)
11					1030 (921)	677 (604)	49.4 (44.1)	17.2 (15.3)
12								
13					1480 (1010)	973 (661)	71.1 (48.3)	22.2 (15.2)
14					1280 (890)	842 (584)	61.6 (42.7)	18.3 (12.6)
15					1300 (776)	853 (509)	62.4 (37.2)	17.7 (10.6)
16					1280 (574)	837 (377)	61.3 (27.6)	16.6 (7.5)
17					1350 (593)	883 (389)	64.8 (28.5)	16.8 (7.4)
18					1720 (775)	1130 (508)	83.0 (37.3)	20.7 (9.2)
19					1960 (986)	1290 (646)	94.6 (47.5)	22.6 (11.3)
20					2100 (1150)	1370 (755)	101.0 (55.6)	23.3 (12.8)
21					2100 (673)	1380 (442)	102.0 (32.5)	22.7 (7.3)
22					2070 (826)	1350 (542)	100.0 (40.0)	21.5 (8.6)
23					2610 (1520)	1710 (995)	126.0 (73.6)	26.4 (15.4)
24					2410 (987)	1580 (647)	117.0 (47.9)	23.7 (9.7)
25					2510 (1070)	1650 (702)	122.0 (52.1)	24.0 (10.2)
26								
27								
28								
29								
30								
31								
Avg					1470	964	70.7	22.2
n	0	0	0	0	24	24	24	24
SD					559	367	27.4	3.1
Min					559	367	26.5	16.6
Max					2610	1710	126.0	27.3

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for April, 2009.

Day	House 10				House 12							
	g d^{-1}	mg $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$	g d^{-1}		mg $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21					142	(130)	93	(85)	6.8	(6.2)	16.2	(14.8)
22					142	(129)	93	(85)	6.7	(6.1)	13.6	(12.4)
23					127	(139)	83	(91)	6.1	(6.6)	10.4	(11.5)
24					124	(167)	82	(110)	5.9	(8.0)	8.7	(11.6)
25					148	(177)	97	(116)	7.1	(8.4)	9.1	(10.8)
26					182	(243)	119	(159)	8.7	(11.6)	9.8	(13.0)
27					149	(167)	98	(109)	7.1	(8.0)	7.1	(8.0)
28					93	(109)	61	(71)	4.4	(5.2)	4.0	(4.7)
29					104	(96)	68	(63)	5.0	(4.6)	4.0	(3.7)
30					108	(98)	71	(65)	5.2	(4.7)	3.8	(3.5)
Avg					132		87		6.3		8.7	
n	0	0	0	0	10		10		10		10	
SD					25		16		1.2		3.9	
Min					93		61		4.4		3.8	
Max					182		119		8.7		16.2	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for May, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5									360	(256)	236	(168)	17.3	(12.3)	8.3	(5.8)
6									372	(261)	244	(171)	17.9	(12.5)	7.9	(5.6)
7									436	(418)	286	(274)	20.9	(20.1)	8.7	(8.5)
8									529	(501)	347	(328)	25.4	(24.0)	9.9	(9.5)
9									677	(592)	444	(388)	32.5	(28.4)	11.9	(10.4)
10									681	(444)	446	(291)	32.7	(21.3)	11.3	(7.4)
11									1090	(888)	713	(582)	52.3	(42.7)	17.1	(13.8)
12	1250	(633)	820	(415)	60.3	(30.5)	18.8	(9.5)	1460	(769)	960	(504)	70.5	(37.0)	22.0	(11.5)
13	1600	(931)	1050	(611)	77.2	(44.9)	22.9	(13.2)	1610	(936)	1050	(614)	77.6	(45.2)	23.0	(13.2)
14	1550	(780)	1010	(512)	74.6	(37.6)	21.1	(10.6)	1800	(983)	1180	(645)	87.0	(47.4)	24.6	(13.3)
15	1280	(478)	840	(313)	61.9	(23.1)	16.8	(6.2)	1520	(554)	996	(363)	73.4	(26.8)	19.9	(7.2)
16	1490	(806)	978	(529)	72.1	(39.0)	18.7	(10.1)	1450	(732)	952	(480)	70.2	(35.4)	18.2	(9.2)
17	1570	(923)	1030	(605)	75.9	(44.7)	18.9	(11.2)	1690	(922)	1110	(605)	82.0	(44.7)	20.5	(11.2)
18	1850	(948)	1210	(622)	89.3	(45.9)	21.4	(11.0)	1910	(932)	1250	(611)	92.6	(45.2)	22.2	(10.9)
19	2340	(1050)	1540	(686)	114.0	(50.7)	26.2	(11.8)	2060	(927)	1350	(608)	100.0	(45.1)	23.1	(10.5)
20	2550	(843)	1670	(553)	124.0	(40.9)	27.5	(9.1)	2460	(903)	1620	(592)	120.0	(43.9)	26.7	(9.7)
21	2220	(1200)	1460	(789)	108.0	(58.4)	23.2	(12.5)	2370	(1320)	1550	(867)	116.0	(64.6)	24.9	(13.9)
22	2620	(870)	1720	(571)	127.0	(42.3)	26.5	(8.7)								
23	2770	(703)	1820	(461)	135.0	(34.2)	27.3	(6.9)								
24																
25	2760	(689)	1810	(452)	134.0	(33.6)	25.7	(6.4)								
26																
27																
28																
29																
30																
31																
Avg	1990		1300		96.4		22.7		1320		867		64.0		17.7	
n	13		13		13		13		17		17		17		17	
SD	550		360		27.0		3.6		683		448		33.3		6.4	
Min	1250		820		60.3		16.8		360		236		17.3		7.9	
Max	2770		1820		135.0		27.5		2460		1620		120.0		26.7	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for June, 2009.

Day	House 10								House 12							
	$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$		$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$	
1																
2																
3																
4																
5																
6	35	(64)	23	(42)	1.6	(3.0)	13.9	(25.8)	34	(48)	22	(31)	1.6	(2.3)	11.8	(16.7)
7	46	(65)	30	(42)	2.2	(3.1)	19.3	(27.5)	56	(81)	37	(53)	2.7	(3.8)	22.7	(32.9)
8	57	(71)	37	(46)	2.7	(3.4)	23.3	(29.0)	57	(80)	38	(52)	2.7	(3.8)	24.3	(33.8)
9	67	(84)	44	(55)	3.2	(4.0)	24.2	(30.3)	52	(63)	34	(42)	2.5	(3.0)	21.4	(26.0)
10	83	(95)	54	(63)	3.9	(4.5)	25.1	(28.7)	67	(77)	44	(50)	3.2	(3.6)	24.1	(27.6)
11	80	(85)	52	(56)	3.8	(4.0)	19.5	(20.7)	93	(98)	61	(64)	4.4	(4.6)	27.7	(29.0)
12	105	(114)	69	(75)	5.0	(5.4)	20.8	(22.5)	110	(117)	72	(77)	5.2	(5.5)	26.9	(28.4)
13	119	(122)	78	(80)	5.6	(5.8)	19.3	(19.8)	148	(165)	97	(108)	7.0	(7.8)	29.5	(32.8)
14	576	(719)	378	(471)	27.3	(34.1)	76.3	(95.2)	429	(612)	281	(401)	20.4	(29.1)	69.2	(98.8)
15	562	(717)	368	(470)	26.7	(34.1)	62.4	(79.4)	565	(821)	370	(539)	26.8	(39.0)	75.7	(110.0)
16	556	(533)	365	(349)	26.4	(25.3)	52.0	(49.8)	592	(612)	388	(402)	28.2	(29.1)	65.7	(68.0)
17	635	(526)	416	(345)	30.2	(25.0)	50.6	(42.0)	630	(588)	413	(386)	30.0	(28.0)	59.1	(55.6)
18	680	(612)	446	(402)	32.4	(29.1)	46.6	(41.5)	664	(637)	436	(418)	31.6	(30.3)	52.9	(50.4)
19	681	(774)	447	(507)	32.4	(36.8)	40.8	(45.8)	654	(792)	429	(520)	31.2	(37.7)	45.0	(53.8)
20	701	(634)	460	(416)	33.4	(30.2)	37.1	(33.3)	652	(646)	427	(424)	31.0	(30.8)	39.2	(38.8)
21	606	(488)	397	(320)	28.9	(23.2)	28.3	(22.7)	655	(576)	430	(378)	31.2	(27.4)	34.6	(30.3)
22	422	(570)	277	(374)	20.1	(27.2)	17.6	(23.7)	539	(683)	353	(448)	25.7	(32.6)	25.2	(31.9)
23	587	(695)	385	(456)	28.0	(33.2)	22.1	(26.2)	834	(912)	547	(598)	39.8	(43.5)	34.9	(37.9)
24	670	(909)	439	(596)	32.0	(43.4)	23.0	(31.0)	697	(840)	457	(551)	33.3	(40.1)	26.4	(31.6)
25																
26																
27																
28																
29																
30																
Avg	382		251		18.2		32.7		396		260		18.9		37.7	
n	19		19		19		19		19		19		19		19	
SD	270		177		12.9		17.0		283		185		13.5		17.9	
Min	35		23		1.6		13.9		34		22		1.6		11.8	
Max	701		460		33.4		76.3		834		547		39.8		75.7	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for July, 2009.

Day	House 10								House 12							
	$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$		$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$	
1																
2																
3																
4																
5																
6																
7																
8																
9	1530	(718)	1000	(471)	74.3	(34.8)	20.0	(9.4)	1690	(822)	1110	(539)	82.0	(39.9)	23.1	(11.2)
10	1650	(859)	1080	(563)	80.3	(41.8)	20.7	(10.6)	1850	(942)	1210	(618)	90.0	(45.8)	24.2	(12.2)
11	1830	(865)	1200	(567)	88.9	(42.1)	22.0	(10.5)	1830	(888)	1200	(582)	89.2	(43.2)	23.0	(11.2)
12	1480	(720)	970	(472)	72.0	(35.1)	17.2	(8.4)	1660	(738)	1090	(484)	81.1	(36.0)	20.1	(8.9)
13	1360	(707)	891	(464)	66.3	(34.5)	15.2	(7.9)								
14	1420	(714)	933	(468)	69.6	(34.9)	15.4	(7.8)								
15																
16	1710	(588)	1120	(386)	83.6	(28.8)	17.4	(6.1)								
17	1710	(649)	1120	(426)	83.9	(31.9)	16.9	(6.5)								
18	1800	(680)	1180	(446)	88.4	(33.5)	17.4	(6.7)								
19	1310	(489)	862	(320)	64.8	(24.1)	12.4	(4.6)								
20																
21																
22																
23																
24																
25																
26																
27																
28	-1	(12)	-1	(8)												
29	0	(5)	0	(3)												
30	26	(55)	17	(36)												
31	33	(41)	22	(27)	1.7	(2.1)	12.9	(16.2)								
Avg	1130		742		70.3		17.0		1760		1150		85.6		22.6	
n	14		14		11		11		4		4		4		4	
SD	722		474		23.2		2.9		84		55		4.0		1.5	
Min	-1		-1		1.7		12.4		1660		1090		81.1		20.1	
Max	1830		1200		88.9		22.0		1850		1210		90.0		24.2	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for August, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	54	(60)	35	(39)	2.8	(3.1)	24.1	(26.6)								
2	53	(56)	35	(37)	2.8	(2.9)	24.9	(26.4)								
3	45	(51)	29	(34)	2.3	(2.7)	19.8	(22.7)								
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17	1470	(1300)	966	(850)	77.3	(68.0)	67.2	(58.9)	1260	(1140)	826	(751)	66.2	(60.2)	59.2	(53.9)
18	1100	(977)	721	(641)	57.6	(51.2)	45.4	(40.4)	1050	(866)	686	(568)	55.0	(45.6)	44.3	(36.9)
19	894	(755)	586	(495)	46.9	(39.6)	33.4	(28.2)	870	(676)	571	(443)	45.8	(35.6)	33.3	(26.0)
20	818	(626)	537	(410)	43.0	(32.9)	27.9	(21.2)	828	(622)	543	(408)	43.6	(32.7)	28.8	(21.6)
21	732	(669)	480	(438)	38.4	(35.1)	22.9	(20.8)	713	(573)	468	(376)	37.6	(30.2)	22.8	(18.3)
22	644	(812)	422	(532)	33.8	(42.7)	18.5	(23.1)	721	(762)	473	(500)	38.0	(40.2)	21.1	(22.1)
23	647	(554)	424	(363)	34.0	(29.1)	17.2	(14.7)	720	(537)	472	(352)	37.9	(28.3)	19.5	(14.5)
24	756	(691)	496	(453)	39.8	(36.3)	18.7	(17.0)	893	(734)	586	(481)	47.1	(38.7)	22.5	(18.4)
25	812	(749)	532	(491)	42.7	(39.4)	18.7	(17.3)	892	(734)	585	(481)	47.1	(38.7)	20.9	(17.2)
26	892	(638)	585	(419)	47.0	(33.6)	19.2	(13.8)	1110	(942)	729	(618)	58.6	(49.7)	24.3	(20.6)
27	889	(561)	583	(368)	46.8	(29.6)	18.0	(11.4)	1000	(661)	657	(433)	52.9	(34.9)	20.6	(13.6)
28	977	(604)	641	(396)	51.5	(31.8)	18.6	(11.5)	1140	(726)	751	(476)	60.5	(38.4)	22.2	(14.0)
29	1010	(647)	665	(424)	53.5	(34.1)	18.3	(11.6)	1120	(704)	734	(462)	59.2	(37.2)	20.5	(12.9)
30	1040	(597)	683	(391)	55.0	(31.5)	17.8	(10.3)	1160	(690)	761	(452)	61.4	(36.5)	20.1	(12.0)
31	1010	(506)	661	(332)	53.3	(26.7)	16.4	(8.2)	1130	(608)	741	(399)	59.8	(32.2)	18.6	(10.0)
Avg	769		505		40.5		24.8		974		639		51.4		26.6	
n	18		18		18		18		15		15		15		15	
SD	370		243		19.5		12.4		175		115		9.3		10.9	
Min	45		29		2.3		16.4		713		468		37.6		18.6	
Max	1470		966		77.3		67.2		1260		826		66.2		59.2	

Table E5. Daily means (SD) of PM10 emissions at Site CA1B for September, 2009.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1	862 (544)	565 (357)	45.5 (28.8)	13.4 (8.4)	1030 (634)	675 (416)	54.5 (33.6)	16.1 (9.9)
2	1110 (731)	729 (479)	58.8 (38.6)	16.5 (10.8)	1170 (782)	770 (513)	62.2 (41.4)	17.6 (11.7)
3	1180 (825)	775 (541)	62.5 (43.7)	16.8 (11.8)	1280 (932)	842 (611)	68.1 (49.4)	18.4 (13.3)
4	1420 (652)	929 (428)	75.0 (34.5)	19.2 (8.8)	1730 (927)	1130 (608)	91.6 (49.2)	23.7 (12.6)
5	1520 (831)	994 (545)	80.3 (44.0)	19.8 (10.8)	1550 (813)	1020 (533)	82.3 (43.2)	20.4 (10.7)
6	1740 (884)	1140 (580)	92.3 (46.9)	21.9 (11.1)	1800 (1020)	1180 (668)	95.5 (54.1)	22.8 (12.8)
7	1520 (811)	997 (532)	80.7 (43.0)	18.5 (9.9)	1830 (1000)	1200 (656)	97.5 (53.2)	22.5 (12.3)
8	1580 (657)	1030 (431)	83.7 (34.9)	18.5 (7.8)	1840 (693)	1210 (454)	98.1 (36.9)	21.9 (8.3)
9	1730 (672)	1140 (441)	92.1 (35.7)	19.7 (7.7)	2140 (626)	1400 (411)	114.0 (33.4)	24.6 (7.2)
10	1870 (552)	1230 (362)	99.6 (29.4)	20.6 (6.1)				
11	1880 (656)	1240 (430)	100.0 (35.0)	20.2 (7.2)				
12	1890 (677)	1240 (444)	101.0 (36.2)	19.7 (7.1)				
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
Avg	1530	1000	81.0	18.7	1600	1050	84.9	20.9
n	12	12	12	12	9	9	9	9
SD	318	209	17.1	2.2	345	226	18.5	2.8
Min	862	565	45.5	13.4	1030	675	54.5	16.1
Max	1890	1240	101.0	21.9	2140	1400	114.0	24.6

Table E6. PM2.5 emissions

Table E6. Daily means (SD) of PM2.5 emissions at Site CA1B for February, 2008.

Day	House 10								House 12							
	$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$		$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$	
1																
2																
3																
4																
5	81	(99)	53	(65)	4.0	(4.8)	1.3	(1.6)	100	(110)	66	(72)	4.8	(5.3)	1.8	(2.0)
6	79	(62)	52	(40)	3.8	(3.0)	1.2	(0.9)	77	(58)	50	(38)	3.7	(2.8)	1.3	(1.0)
7	84	(68)	55	(45)	4.1	(3.3)	1.2	(1.0)	89	(69)	59	(45)	4.3	(3.3)	1.4	(1.1)
8	92	(72)	60	(47)	4.5	(3.5)	1.3	(1.0)	95	(75)	62	(49)	4.6	(3.6)	1.4	(1.2)
9	92	(82)	61	(54)	4.5	(4.0)	1.2	(1.1)	84	(68)	55	(45)	4.1	(3.3)	1.2	(1.0)
10	98	(77)	64	(50)	4.8	(3.7)	1.2	(1.0)	98	(74)	64	(48)	4.7	(3.6)	1.4	(1.0)
11	100	(76)	66	(50)	4.9	(3.7)	1.2	(0.9)	103	(73)	68	(48)	5.0	(3.5)	1.4	(1.0)
12	105	(81)	69	(53)	5.1	(3.9)	1.2	(0.9)	98	(71)	64	(47)	4.8	(3.4)	1.2	(0.9)
13	115	(95)	75	(63)	5.6	(4.7)	1.3	(1.1)	107	(75)	70	(49)	5.2	(3.7)	1.3	(0.9)
14	160	(105)	105	(69)	7.8	(5.1)	1.7	(1.1)	133	(91)	87	(60)	6.4	(4.4)	1.5	(1.1)
15	148	(108)	97	(71)	7.2	(5.3)	1.6	(1.1)	141	(101)	92	(66)	6.8	(4.9)	1.6	(1.1)
16	184	(88)	121	(58)	9.0	(4.3)	1.9	(0.9)	138	(73)	90	(48)	6.7	(3.6)	1.5	(0.8)
17	138	(88)	90	(58)	6.7	(4.3)	1.4	(0.9)	132	(78)	87	(51)	6.4	(3.8)	1.4	(0.8)
18	84	(71)	55	(46)	4.1	(3.5)	0.8	(0.7)	136	(68)	89	(45)	6.6	(3.3)	1.4	(0.7)
19																
20																
21																
22																
23																
24																
25																
26																
27																
28																
29																
Avg	111		73		5.4		1.3		109		72		5.3		1.4	
n	14		14		14		14		14		14		14		14	
SD	32		21		1.6		0.2		21		14		1.0		0.1	
Min	79		52		3.8		0.8		77		50		3.7		1.2	
Max	184		121		9.0		1.9		141		92		6.8		1.8	

Table E6. Daily means (SD) of PM2.5 emissions at Site CA1B for July, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6																
7																
8																
9																
10	46	(153)	30	(100)	2.2	(7.3)	0.9	(3.2)	146	(85)	96	(56)	7.0	(4.1)	3.1	(1.8)
11	65	(129)	43	(85)	3.1	(6.2)	1.3	(2.5)	114	(42)	74	(28)	5.5	(2.0)	2.3	(0.8)
12	79	(104)	52	(68)	3.8	(5.0)	1.5	(1.9)	102	(42)	67	(27)	4.9	(2.0)	1.9	(0.8)
13	74	(92)	49	(61)	3.5	(4.4)	1.3	(1.6)	111	(46)	73	(30)	5.4	(2.2)	2.0	(0.8)
14	113	(95)	74	(62)	5.4	(4.5)	1.9	(1.6)	126	(55)	82	(36)	6.1	(2.6)	2.1	(0.9)
15	125	(80)	82	(53)	6.0	(3.9)	2.0	(1.2)	128	(52)	84	(34)	6.2	(2.5)	2.0	(0.8)
16	108	(81)	71	(53)	5.2	(3.9)	1.6	(1.2)	140	(64)	92	(42)	6.8	(3.1)	2.1	(0.9)
17	145	(110)	95	(72)	7.0	(5.3)	2.0	(1.6)	179	(103)	118	(68)	8.7	(5.0)	2.6	(1.5)
18	164	(68)	107	(45)	7.9	(3.3)	2.2	(0.9)	205	(92)	134	(61)	9.9	(4.5)	2.8	(1.2)
19	174	(50)	114	(33)	8.4	(2.4)	2.2	(0.6)	192	(60)	126	(40)	9.3	(2.9)	2.5	(0.8)
20	177	(51)	116	(34)	8.6	(2.5)	2.2	(0.6)	179	(54)	118	(35)	8.7	(2.6)	2.2	(0.7)
21	195	(54)	128	(35)	9.4	(2.6)	2.3	(0.6)	216	(74)	141	(48)	10.5	(3.6)	2.6	(0.9)
22	207	(69)	136	(45)	10.0	(3.3)	2.4	(0.8)	194	(66)	127	(43)	9.5	(3.2)	2.2	(0.7)
23	228	(66)	149	(43)	11.0	(3.2)	2.5	(0.7)	216	(62)	142	(41)	10.5	(3.1)	2.4	(0.7)
24	243	(67)	160	(44)	11.8	(3.2)	2.6	(0.7)	235	(61)	154	(40)	11.5	(3.0)	2.6	(0.7)
25																
26																
27																
28																
29																
30																
31																
Avg	143		94		6.9		1.9		166		109		8.0		2.4	
n	15		15		15		15		15		15		15		15	
SD	60		39		2.9		0.5		42		28		2.1		0.3	
Min	46		30		2.2		0.9		102		67		4.9		1.9	
Max	243		160		11.8		2.6		235		154		11.5		3.1	

Table E6. Daily means (SD) of PM2.5 emissions at Site CA1B for January, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6	48	(49)	32	(32)	2.3	(2.3)	1.1	(1.1)	45	(43)	30	(29)	2.2	(2.1)	1.0	(1.0)
7	49	(58)	32	(38)	2.3	(2.8)	1.0	(1.2)	47	(55)	31	(36)	2.3	(2.6)	1.0	(1.2)
8	61	(60)	40	(39)	2.9	(2.8)	1.2	(1.2)	62	(63)	40	(41)	3.0	(3.0)	1.2	(1.3)
9	79	(57)	52	(37)	3.7	(2.7)	1.5	(1.1)	74	(52)	48	(34)	3.5	(2.5)	1.4	(1.0)
10	74	(62)	49	(40)	3.5	(2.9)	1.3	(1.1)	71	(57)	47	(37)	3.4	(2.7)	1.3	(1.0)
11	81	(60)	53	(39)	3.9	(2.9)	1.3	(1.0)	74	(55)	49	(36)	3.6	(2.6)	1.2	(0.9)
12	88	(60)	58	(40)	4.2	(2.9)	1.4	(0.9)	79	(54)	52	(36)	3.8	(2.6)	1.3	(0.9)
13	122	(163)	80	(107)	5.9	(7.8)	1.8	(2.4)	77	(55)	50	(36)	3.7	(2.7)	1.2	(0.8)
14	123	(77)	81	(51)	5.9	(3.7)	1.7	(1.1)	94	(59)	62	(38)	4.5	(2.8)	1.3	(0.8)
15	125	(77)	82	(50)	6.0	(3.7)	1.7	(1.0)	148	(121)	97	(79)	7.1	(5.8)	2.0	(1.6)
16	132	(48)	87	(31)	6.3	(2.3)	1.7	(0.6)	124	(45)	81	(30)	6.0	(2.2)	1.6	(0.6)
17	133	(52)	87	(34)	6.3	(2.5)	1.6	(0.6)	118	(48)	77	(32)	5.7	(2.3)	1.5	(0.6)
18	161	(53)	105	(35)	7.7	(2.5)	1.9	(0.6)	143	(47)	94	(31)	6.9	(2.3)	1.7	(0.6)
19	185	(52)	122	(34)	8.9	(2.5)	2.1	(0.6)	180	(241)	118	(158)	8.7	(11.6)	2.1	(2.8)
20																
21																
22																
23																
24																
25																
26																
27																
28																
29																
30																
31																
Avg	104		68		5.0		1.5		95		63		4.6		1.4	
n	14		14		14		14		14		14		14		14	
SD	41		27		1.9		0.3		39		26		1.9		0.3	
Min	48		32		2.3		1.0		45		30		2.2		1.0	
Max	185		122		8.9		2.1		180		118		8.7		2.1	

Table E6. Daily means (SD) of PM2.5 emissions at Site CA1B for September, 2009.

Day	House 10				House 12			
	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$mg\ d^{-1}hd^{-1}$	$g\ d^{-1}AU^{-1}$	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$mg\ d^{-1}hd^{-1}$	$g\ d^{-1}AU^{-1}$
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27	1 (9)	1 (6)	0.1 (0.4)	0.5 (3.3)				
28	6 (8)	4 (5)	0.3 (0.4)	2.7 (3.4)				
29	5 (7)	3 (5)	0.3 (0.4)	2.4 (3.4)				
30	4 (8)	3 (5)	0.2 (0.4)	1.8 (3.4)				
Avg	4	3	0.2	1.9				
n	4	4	4	4	0	0	0	0
SD	2	1	0.1	0.9				
Min	1	1	0.1	0.5				
Max	6	4	0.3	2.7				

Table E6. Daily means (SD) of PM2.5 emissions at Site CA1B for October, 2009.

Day	House 10								House 12			
	g d^{-1}		mg $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		g d^{-1}	mg $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$
1	5	(7)	3	(5)	0.3	(0.4)	1.9	(2.8)				
2	5	(8)	3	(5)	0.3	(0.4)	1.7	(2.5)				
3	6	(7)	4	(5)	0.3	(0.4)	1.7	(2.0)				
4	10	(12)	7	(8)	0.5	(0.6)	2.2	(2.7)				
5	11	(15)	7	(10)	0.6	(0.8)	2.0	(2.6)				
6	20	(24)	13	(16)	1.0	(1.3)	2.9	(3.5)				
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Avg	10		6		0.5		2.1					
n	6		6		6		6		0	0	0	0
SD	5		3		0.3		0.4					
Min	5		3		0.3		1.7					
Max	20		13		1.0		2.9					

Table E7. TSP emissions

Table E7. Daily means (SD) of TSP emissions at Site CA1B for December, 2007.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12	1840 (1960)	1210 (1290)	88.8 (94.7)	36.5 (39.0)	2150 (2250)	1410 (1480)	103.0 (108.0)	42.5 (45.0)
13	1980 (1860)	1300 (1220)	95.7 (89.7)	37.0 (34.8)	1940 (1870)	1270 (1230)	93.1 (89.7)	36.1 (35.0)
14	2030 (1830)	1330 (1200)	98.0 (88.4)	35.7 (32.2)	1600 (1430)	1050 (940)	76.7 (68.8)	28.0 (25.2)
15	2080 (1730)	1360 (1130)	100.0 (83.6)	34.5 (28.9)	1530 (1270)	1010 (830)	73.7 (60.7)	25.4 (21.1)
16	2130 (1550)	1390 (1010)	103.0 (74.8)	33.4 (24.4)	1470 (1130)	962 (744)	70.5 (54.5)	23.0 (17.8)
17	1960 (1520)	1290 (994)	94.8 (73.3)	29.3 (22.8)	1750 (2170)	1150 (1420)	84.1 (104.0)	26.1 (32.6)
18	2060 (1650)	1350 (1080)	99.5 (79.9)	29.3 (23.5)	2320 (2010)	1520 (1320)	111.0 (96.6)	32.8 (28.4)
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
Avg	2010	1320	97.1	33.7	1820	1200	87.5	30.6
n	7	7	7	7	7	7	7	7
SD	87	57	4.2	3.0	300	196	14.4	6.4
Min	1840	1210	88.8	29.3	1470	962	70.5	23.0
Max	2130	1390	103.0	37.0	2320	1520	111.0	42.5

Table E7. Daily means (SD) of TSP emissions at Site CA1B for May, 2008.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20	3610 (2330)	2370 (1530)	173.0 (111.0)	66.9 (43.1)	4310 (2810)	2830 (1840)	206.0 (134.0)	79.0 (51.4)
21	3750 (2490)	2460 (1630)	180.0 (119.0)	65.6 (43.6)	4890 (3320)	3200 (2170)	233.0 (158.0)	84.3 (56.9)
22	4030 (2630)	2640 (1720)	193.0 (126.0)	66.5 (43.5)	6220 (4150)	4080 (2720)	297.0 (198.0)	101.0 (67.6)
23	4360 (2870)	2860 (1880)	209.0 (137.0)	68.2 (44.9)	5450 (3350)	3580 (2200)	261.0 (160.0)	84.5 (52.0)
24	3590 (2260)	2350 (1480)	172.0 (108.0)	53.5 (33.9)	3890 (2310)	2550 (1520)	186.0 (111.0)	57.4 (34.3)
25	3250 (1920)	2130 (1260)	156.0 (92.1)	46.1 (27.3)	3570 (2260)	2340 (1480)	171.0 (108.0)	50.1 (31.8)
26	4450 (2650)	2920 (1740)	214.0 (127.0)	60.0 (35.6)				
27	4760 (1770)	3120 (1160)	229.0 (85.1)	61.5 (22.6)				
28								
29								
30								
31								
Avg	3980	2610	191.0	61.0	4720	3100	226.0	76.1
n	8	8	8	8	6	6	6	6
SD	481	315	23.2	7.2	911	597	43.5	17.4
Min	3250	2130	156.0	46.1	3570	2340	171.0	50.1
Max	4760	3120	229.0	68.2	6220	4080	297.0	101.0

Table E7. Daily means (SD) of TSP emissions at Site CA1B for November, 2008.

Day	House 10								House 12							
	$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$		$g\ d^{-1}$		$mg\ d^{-1}m^{-2}$		$mg\ d^{-1}hd^{-1}$		$g\ d^{-1}AU^{-1}$	
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18	3250	(2120)	2130	(1390)	155.0	(101.0)	56.9	(37.3)								
19	3250	(2260)	2130	(1480)	155.0	(108.0)	53.7	(37.5)	3220	(2500)	2110	(1640)	153.0	(119.0)	52.5	(40.8)
20	3620	(3200)	2370	(2100)	173.0	(153.0)	56.7	(50.1)	2790	(2390)	1830	(1570)	133.0	(114.0)	43.0	(36.9)
21	2950	(2350)	1930	(1540)	141.0	(112.0)	43.9	(35.1)	3500	(3030)	2290	(1990)	166.0	(144.0)	51.2	(44.6)
22	2670	(2020)	1750	(1330)	128.0	(96.7)	37.8	(28.7)	3410	(2710)	2240	(1780)	162.0	(129.0)	47.6	(37.9)
23	3150	(2230)	2070	(1460)	151.0	(107.0)	42.5	(30.1)	3890	(2790)	2550	(1830)	185.0	(133.0)	51.7	(37.3)
24																
25																
26																
27																
28																
29																
30																
Avg	3150		2060		150.0		48.6		3360		2200		160.0		49.2	
n	6		6		6		6		5		5		5		5	
SD	291		191		13.8		7.5		358		235		17.1		3.5	
Min	2670		1750		128.0		37.8		2790		1830		133.0		43.0	
Max	3620		2370		173.0		56.9		3890		2550		185.0		52.5	

Table E7. Daily means (SD) of TSP emissions at Site CA1B for April, 2009.

Day	House 10				House 12			
	g d^{-1}	mg $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$	g d^{-1}	mg $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11					4 (8)	3 (6)	0.2 (0.4)	1.3 (2.8)
12					4 (8)	3 (5)	0.2 (0.4)	1.6 (3.1)
13					3 (7)	2 (5)	0.2 (0.3)	1.5 (3.0)
14					5 (12)	3 (8)	0.2 (0.6)	1.9 (4.8)
15					8 (15)	5 (10)	0.4 (0.7)	2.9 (5.6)
16					9 (15)	6 (10)	0.4 (0.7)	2.7 (4.6)
17					13 (20)	8 (13)	0.6 (1.0)	3.2 (5.2)
18					104 (135)	68 (89)	5.0 (6.4)	21.1 (27.0)
19					482 (464)	316 (305)	22.9 (22.1)	80.4 (77.7)
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
Avg					70	46	3.3	12.9
n	0	0	0	0	9	9	9	9
SD					149	98	7.1	24.6
Min					3	2	0.2	1.3
Max					482	316	22.9	80.4

Table E7. Daily means (SD) of TSP emissions at Site CA1B for June, 2009.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26	1980 (1280)	1300 (839)	94.7 (61.3)	56.7 (36.5)	2490 (1760)	1630 (1150)	119.0 (84.1)	77.8 (54.6)
27	1940 (1070)	1270 (704)	93.0 (51.5)	51.3 (28.2)	2120 (1200)	1390 (789)	101.0 (57.7)	60.8 (34.4)
28	2060 (1230)	1350 (805)	99.1 (58.9)	50.5 (29.8)	2050 (1160)	1350 (760)	98.6 (55.7)	54.4 (30.6)
29	2220 (1310)	1460 (861)	107.0 (63.1)	50.6 (29.6)	2210 (1250)	1450 (819)	106.0 (60.1)	54.2 (30.6)
30	2290 (1270)	1500 (831)	110.0 (61.0)	48.6 (26.9)	2330 (1300)	1520 (853)	112.0 (62.6)	53.0 (29.4)
Avg	2100	1380	101.0	51.5	2240	1470	107.0	60.0
n	5	5	5	5	5	5	5	5
SD	137	90	6.7	2.7	155	102	7.4	9.3
Min	1940	1270	93.0	48.6	2050	1350	98.6	53.0
Max	2290	1500	110.0	56.7	2490	1630	119.0	77.8

Table E7. Daily means (SD) of TSP emissions at Site CA1B for July, 2009.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1	2080	(1340)	1370	(878)	100.0	(64.5)	41.4	(26.4)	2170	(1280)	1420	(841)	105.0	(61.8)	46.2	(27.2)
2	2120	(1870)	1390	(1220)	102.0	(89.9)	39.7	(34.9)	2380	(1470)	1560	(962)	115.0	(70.8)	47.3	(29.1)
3	2230	(1410)	1470	(925)	108.0	(68.1)	39.3	(24.9)	2450	(1310)	1610	(858)	119.0	(63.2)	45.9	(24.3)
4									2390	(1160)	1570	(764)	116.0	(56.3)	42.1	(20.4)
5									2540	(1180)	1670	(772)	123.0	(56.9)	42.4	(19.4)
6	2930	(5470)	1920	(3590)	142.0	(265.0)	43.9	(82.0)	3090	(2190)	2030	(1440)	150.0	(106.0)	48.8	(34.3)
7	3010	(1940)	1980	(1280)	146.0	(94.3)	43.0	(27.7)	3770	(2530)	2470	(1660)	183.0	(123.0)	56.7	(37.9)
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																
25																
26																
27																
28																
29																
30																
31																
Avg	2480		1620		120.0		41.5		2690		1760		130.0		47.0	
n	5		5		5		5		7		7		7		7	
SD	408		267		20.0		1.8		517		339		25.3		4.6	
Min	2080		1370		100.0		39.3		2170		1420		105.0		42.1	
Max	3010		1980		146.0		43.9		3770		2470		183.0		56.7	

Table E7. Daily means (SD) of TSP emissions at Site CA1B for October, 2009.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1								
2								
3								
4								
5								
6								
7								
8	2000 (2350)	1310 (1540)	105.0 (123.0)	207.0 (242.0)				
9	1810 (2290)	1190 (1500)	94.5 (119.0)	159.0 (200.0)				
10	1840 (2210)	1210 (1450)	96.3 (116.0)	140.0 (167.0)				
11	1780 (2250)	1170 (1480)	93.1 (118.0)	118.0 (149.0)				
12	1770 (2140)	1160 (1400)	92.8 (112.0)	103.0 (124.0)				
13	1300 (1760)	852 (1160)	68.0 (92.3)	67.4 (92.0)				
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31								
Avg	1750	1150	91.6	132.0				
n	6	6	6	6	0	0	0	0
SD	216	142	11.3	43.8				
Min	1300	852	68.0	67.4				
Max	2000	1310	105.0	207.0				

Table E8. H2S concentrations

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for November, 2007.

Day	Ambient				House 10						House 12			
	ppb		µg dsm^{-3}		ppb		µg dsm^{-3}		ppb	µg/dsm	ppb		µg dsm^{-3}	
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14	3.3	(6.1)												
15	3.4	(5.4)	4.8	(7.7)	5.7	(1.7)	8.2	(2.5)	10.5	15.0	4.7	(1.4)	6.7	(2.0)
16	0.2	(0.9)	0.3	(1.3)	4.8	(0.4)	6.9	(0.5)	5.7	8.1	3.9	(0.4)	5.6	(0.6)
17	0.9	(2.6)	1.3	(3.7)	6.7	(1.4)	9.7	(2.0)	10.8	15.5	5.9	(1.6)	8.4	(2.2)
18	3.4	(5.1)	4.9	(7.2)	10.5	(1.1)	15.1	(1.6)	13.2	19.0	10.7	(1.4)	15.5	(2.0)
19	0.2	(0.6)	0.3	(0.9)	13.0	(1.8)	18.7	(2.6)	16.8	24.2	15.2	(2.9)	21.8	(4.2)
20	0.5	(0.8)	0.7	(1.1)							17.6	(1.8)	25.3	(2.6)
21	2.0	(3.7)	2.9	(5.3)							18.5	(3.0)	26.6	(4.4)
22	4.4	(2.0)												
23	3.0	(5.3)												
24	6.6	(6.2)	9.4	(8.9)	26.0	(6.9)	37.4	(10.0)	39.1	56.3	26.7	(6.7)	38.4	(9.7)
25	4.6	(3.3)	6.5	(4.7)	40.1	(7.6)	57.7	(10.9)	55.6	79.9	39.5	(6.2)	56.8	(8.9)
26	4.9	(4.6)	6.9	(6.5)	52.8	(8.1)	75.8	(11.7)	64.7	93.0	45.8	(6.7)	65.8	(9.6)
27	2.1	(1.9)	3.0	(2.7)	47.7	(7.1)	68.5	(10.2)	61.3	88.0	40.5	(6.5)	58.2	(9.3)
28	3.7	(3.2)	5.3	(4.5)	41.5	(4.9)	59.6	(7.0)	49.0	70.2	39.0	(4.9)	56.0	(7.0)
29	7.4	(6.7)	10.6	(9.5)	39.4	(5.4)	56.6	(7.7)	47.9	68.8	40.3	(5.9)	57.9	(8.5)
30	1.4	(1.8)	2.0	(2.5)	40.2	(5.3)	57.7	(7.5)	51.2	73.4	42.2	(5.2)	60.5	(7.4)
Avg	3.1		4.2		27.4		39.3		35.5	51.0	25		36	
n	17		14		12		12		12	12	14		14	
SD	2.1		3.2		17.4		25		21.4	30.7	15.2		21.8	
Min	0.2		0.3		4.8		6.9		5.7	8.1	3.9		5.6	
Max	7.4		10.6		52.8		75.8		64.7	93.0	45.8		65.8	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for December, 2007.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	1.6	(3.2)	2.1	(4.7)	41.1	(5.6)	59.2	(8.4)	51.7	74.0	42.9	(6.3)	62.6	(9.1)
2	0.8	(2.7)	1.1	(3.8)	52.6	(7.0)	75.4	(10.1)	70.5	101.0	55.0	(7.8)	78.9	(11.2)
3	1.9	(2.0)	2.7	(2.8)	65.9	(8.8)	94.4	(12.6)	85.4	122.0	67.9	(10.8)	97.3	(15.5)
4	1.1	(1.0)	1.6	(1.4)	85.3	(11.3)	123.0	(16.3)	117.0	168.0	89.9	(11.1)	129.0	(16.0)
5	4.8	(5.8)	6.8	(8.3)	118.0	(18.9)	170.0	(27.2)	158.0	227.0	114.0	(19.6)	163.0	(28.2)
6	3.5	(4.4)	5.0	(6.3)	135.0	(11.1)	194.0	(15.9)	154.0	221.0	130.0	(10.9)	186.0	(15.5)
7	2.3	(0.5)	3.3	(0.8)	135.0	(15.5)	194.0	(22.2)	160.0	230.0	126.0	(14.7)	181.0	(21.1)
8	2.3	(1.6)	3.3	(2.2)	113.0	(23.2)	162.0	(33.3)	155.0	222.0	112.0	(21.0)	161.0	(30.1)
9	1.7	(1.6)	2.5	(2.3)	97.4	(18.9)	140.0	(27.2)	131.0	188.0	96.3	(17.9)	138.0	(25.6)
10	3.7	(2.0)	4.5	(2.9)	91.9	(21.3)	132.0	(30.6)	127.0	182.0	88.0	(20.9)	126.0	(30.0)
11	8.9	(2.8)												
12	3.5	(3.3)	4.9	(4.7)	105.0	(19.7)	151.0	(28.3)	139.0	199.0	108.0	(21.9)	155.0	(31.4)
13	5.8	(5.1)	8.6	(7.2)	99.0	(18.7)	143.0	(27.1)	135.0	194.0	114.0	(18.3)	165.0	(26.3)
14	2.9	(2.6)	4.1	(3.7)	92.7	(16.1)	133.0	(23.1)	118.0	170.0	102.0	(15.1)	146.0	(21.6)
15	4.2	(2.2)	6.0	(3.1)	95.3	(18.7)	137.0	(26.8)	127.0	182.0	95.6	(17.2)	137.0	(24.6)
16	3.1	(3.4)	4.9	(5.1)	88.7	(17.4)	129.0	(25.9)	115.0	164.0	86.4	(16.8)	126.0	(24.7)
17	0.9	(0.5)	1.3	(0.8)	96.6	(9.1)	139.0	(13.0)	114.0	164.0	95.9	(8.9)	138.0	(12.7)
18	1.4	(0.8)	1.9	(1.2)	89.9	(12.1)	129.0	(17.4)	112.0	162.0	89.6	(9.6)	129.0	(13.7)
19	1.3	(1.2)	1.9	(1.7)	79.3	(12.8)	114.0	(18.5)	102.0	147.0	78.9	(12.4)	113.0	(17.8)
20	2.5	(1.7)	3.5	(2.5)	82.2	(10.0)	118.0	(14.4)	103.0	148.0	77.0	(9.2)	111.0	(13.3)
21	2.3	(2.8)	3.3	(3.9)	72.7	(11.1)	104.0	(15.8)	90.9	130.0	68.3	(12.2)	97.8	(17.4)
22	3.6	(2.4)	5.1	(3.5)	72.0	(16.2)	104.0	(23.3)	99.5	143.0	71.0	(15.9)	103.0	(22.9)
23	1.9	(1.4)	2.6	(2.1)										
24	2.9	(1.9)	4.2	(2.7)	85.1	(14.3)	122.0	(20.4)	118.0	168.0	81.5	(13.9)	117.0	(19.9)
25	2.1	(1.5)	3.0	(2.2)	80.8	(14.0)	117.0	(20.3)	108.0	154.0	73.1	(14.6)	106.0	(21.2)
26	1.7	(1.3)	2.5	(1.8)	70.2	(15.1)	101.0	(21.6)	106.0	152.0	71.9	(14.6)	103.0	(21.0)
27	0.5	(0.9)	0.5	(1.2)	61.2	(9.7)	90.8	(13.6)	80.6	115.0	59.1	(10.9)	87.1	(16.5)
28	1.6	(2.8)	2.2	(4.1)	66.7	(5.3)	95.7	(7.6)	79.2	113.0	71.9	(3.6)	103.0	(5.1)
29	1.5	(1.5)	2.1	(2.2)	67.4	(3.5)	96.6	(5.0)	73.7	106.0	72.6	(4.0)	104.0	(5.7)
30	1.9	(0.7)	2.8	(1.0)	51.3	(10.7)	73.6	(15.4)	72.2	104.0	54.1	(12.9)	77.5	(18.6)
31	3.4	(3.5)	4.8	(5.0)	43.6	(11.2)	62.4	(16.1)	66.3	95.0	58.0	(30.7)	65.3	(33.5)
Avg	2.6		3.4		84		121		109.0	157.0	84.5		121	
n	31		30		29		29		29	29	29		29	
SD	1.7		1.8		23.5		33.7		28.9	41.5	21.8		32.2	
Min	0.5		0.5		41.1		59.2		51.7	74.0	42.9		62.6	
Max	8.9		8.6		135.0		194.0		160.0	230.0	130.0		186.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for January, 2008.

Day	Ambient				House 10						House 12			
	ppb		µg dsm^{-3}		ppb		µg dsm^{-3}		ppb	µg/dsm	ppb		µg dsm^{-3}	
1	4.3	(3.4)	6.1	(4.9)	49.7	(12.5)	71.1	(17.9)	74.9	107.0	52.2	(32.1)		
2	3.5	(2.6)	5.0	(3.7)	28.7	(11.1)	40.8	(15.8)	62.4	88.9	73.1	(67.8)		
3	10.0	(9.5)	14.2	(13.5)	69.2	(22.0)	99.3	(31.7)	160.0	230.0	97.3	(57.3)		
4	-2.3	(2.4)	-3.3	(3.5)	93.0	(11.0)	134.0	(15.8)	113.0	162.0	69.1	(10.7)	97.3	(14.4)
5	-1.7	(1.0)	-2.5	(1.4)	92.0	(13.3)	132.0	(19.1)	114.0	164.0	60.2	(11.9)	86.4	(17.1)
6	0.5	(1.0)	0.7	(1.5)	83.3	(7.1)	120.0	(10.2)	96.9	139.0	55.4	(3.5)	79.5	(5.0)
7	1.4	(1.2)	2.1	(1.7)	53.6	(11.2)	77.0	(16.1)	76.7	110.0	41.9	(5.7)	60.1	(8.1)
8	0.1	(0.6)	0.2	(0.9)	33.4	(3.9)	48.0	(5.6)	47.5	68.2	28.3	(3.4)	40.6	(4.9)
9	1.4	(2.5)	1.9	(3.8)	18.7	(7.0)	27.0	(10.6)	29.0	41.7	17.1	(6.2)	24.6	(8.9)
10	2.7	(3.4)	3.8	(4.9)	19.1	(2.4)	27.4	(3.4)	24.3	35.0	16.3	(1.1)		
11	1.9	(3.2)	2.7	(4.6)	14.5	(3.2)	20.8	(4.6)	20.7	29.8	12.4	(2.1)	16.6	(1.8)
12	1.4	(2.5)	1.9	(3.6)	14.6	(3.4)	21.0	(4.9)	22.0	31.6	11.9	(2.2)	17.1	(3.1)
13	3.2	(5.7)	4.5	(8.1)	15.8	(4.4)	22.7	(6.3)	24.4	35.1	12.9	(3.6)	18.6	(5.2)
14	5.7	(9.1)	8.2	(13.0)	8.0	(4.0)	11.4	(5.7)	15.7	22.6	7.6	(3.5)	11.0	(5.0)
15	2.3	(1.4)	3.3	(2.0)	1.8	(1.0)	2.6	(1.5)	4.5	6.6	2.3	(0.9)	3.3	(1.3)
16	0.6	(0.8)	0.9	(1.1)	5.3	(5.2)	7.7	(7.5)	14.5	20.9	3.1	(3.2)	4.4	(4.6)
17	2.3	(1.8)	3.2	(2.6)	17.3	(12.9)	24.9	(18.6)	38.0	54.7	10.4	(8.5)	15.0	(12.1)
18	6.6	(6.5)	9.4	(9.3)	20.3	(14.3)	29.1	(20.6)	43.4	62.6	16.0	(7.9)	23.0	(11.3)
19	3.5	(2.1)	4.9	(3.0)	26.7	(16.3)	38.4	(23.5)	56.3	81.0	19.9	(7.5)	28.6	(10.8)
20	1.4	(1.6)	1.9	(2.3)	25.9	(9.9)	37.3	(14.2)	48.5	69.7	20.9	(4.7)	30.0	(6.7)
21	5.2	(4.2)	7.4	(6.0)	30.7	(11.9)	44.1	(17.1)	62.8	90.3	25.1	(5.8)	36.2	(8.4)
22	2.4	(1.8)	3.4	(2.5)	41.8	(9.8)	60.1	(14.1)	64.9	93.3	31.4	(5.7)	45.2	(8.2)
23	2.2	(0.6)	3.1	(0.9)	41.6	(8.4)	59.9	(12.0)	62.5	90.0	36.5	(4.3)	52.5	(6.2)
24	-0.3	(0.3)	-0.4	(0.4)	33.8	(12.2)	48.6	(17.6)	64.6	93.0	36.3	(8.4)	52.1	(12.1)
25	8.4	(5.3)	11.9	(7.6)	50.1	(9.0)	72.0	(13.1)	72.4	104.0	51.5	(8.4)	74.1	(12.1)
26	19.9	(4.7)	28.4	(6.8)	73.9	(13.4)	106.0	(19.3)	106.0	152.0	71.3	(10.6)	103.0	(15.2)
27	24.1	(3.8)	34.2	(5.3)	74.6	(12.7)	107.0	(18.2)	104.0	150.0	73.5	(9.2)	106.0	(13.2)
28	12.3	(7.0)			70.8	(12.5)	102.0	(18.0)	90.8	130.0	73.5	(11.6)	106.0	(16.7)
29	1.5	(0.9)	2.2	(1.3)	57.9	(14.2)	83.2	(20.4)	84.4	121.0	62.4	(13.3)	89.6	(19.0)
30	2.3	(1.3)	3.2	(1.8)	61.9	(13.8)	88.9	(19.8)	84.3	121.0	62.6	(11.7)	89.9	(16.7)
31	1.6	(0.8)	2.3	(1.1)	72.0	(11.4)	103.0	(16.3)	95.5	137.0	71.2	(8.6)	102.0	(12.4)
Avg	4.1		5.5		41.9		60.3		63.9	91.7	39.5		52.3	
n	31		30		31		31		31	31	31		27	
SD	5.6		7.9		26.4		38		35.7	51.2	26.2		34.7	
Min	-2.3		-3.3		1.8		2.6		4.5	6.6	2.3		3.3	
Max	24.1		34.2		93.0		134.0		160.0	230.0	97.3		106.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for February, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1					77.8	(17.7)	112.0	(25.4)	106.0	153.0	72.5	(14.5)	104.0	(20.8)
2														
3														
4														
5	5.2	(0.9)	7.3	(1.3)	82.0	(24.4)	118.0	(35.0)	126.0	180.0	72.7	(19.0)	104.0	(27.3)
6	2.6	(1.0)	3.6	(1.5)	85.3	(21.5)	122.0	(30.9)	120.0	172.0	81.4	(19.5)	117.0	(28.0)
7	1.3	(0.7)	1.9	(1.0)	88.4	(22.7)	127.0	(32.6)	125.0	179.0	84.6	(21.9)	121.0	(31.5)
8	4.6	(0.7)	6.6	(1.0)	86.1	(21.5)	123.0	(30.8)	120.0	172.0	80.7	(20.7)	116.0	(29.6)
9	5.3	(3.8)	7.6	(5.5)	99.3	(31.9)	142.0	(45.8)	163.0	233.0	89.4	(27.4)	128.0	(39.3)
10	10.2	(6.7)	14.5	(9.5)	107.0	(33.2)	154.0	(47.6)	158.0	227.0	103.0	(28.8)	148.0	(41.3)
11	6.0	(3.1)	8.6	(4.4)	88.1	(28.7)	127.0	(41.3)	141.0	202.0	84.9	(30.1)	122.0	(43.3)
12	2.1	(1.8)	3.0	(2.6)	74.4	(28.6)	107.0	(41.1)	118.0	170.0	67.6	(26.3)	97.0	(37.7)
13	3.5	(3.5)	5.0	(5.0)	76.2	(20.2)	109.0	(28.9)	109.0	157.0	71.2	(16.3)	102.0	(23.3)
14	11.1	(7.5)	15.6	(10.9)	61.3	(12.4)	88.6	(17.2)	79.1	113.0	57.5	(10.8)	83.0	(15.1)
15	9.7	(10.5)	13.8	(14.9)	67.6	(21.8)	96.6	(31.2)	104.0	149.0	63.5	(18.3)	90.9	(26.2)
16	1.2	(0.8)	1.7	(1.1)	68.9	(22.9)	98.6	(32.8)	114.0	163.0	67.5	(23.2)	96.6	(33.2)
17	0.9	(1.2)	1.2	(1.7)	72.4	(24.9)	104.0	(35.6)	112.0	161.0	75.3	(26.0)	108.0	(37.2)
18	0.6	(0.4)	0.9	(0.5)	68.9	(18.4)	98.7	(26.4)	95.3	136.0	65.2	(20.3)	93.5	(29.1)
19	2.2	(1.7)	3.2	(2.5)	62.3	(14.6)	89.3	(20.9)	88.9	127.0	61.0	(12.4)	87.4	(17.8)
20	3.1	(2.0)	4.5	(2.8)	51.3	(12.1)	73.5	(17.4)	68.3	97.8	60.5	(12.8)	86.7	(18.4)
21	2.3	(1.4)	3.3	(2.0)	22.6	(21.2)	32.7	(30.8)	67.6	96.7	55.2	(17.7)	79.3	(25.7)
22	1.2	(1.4)	1.9	(2.0)	44.0	(36.4)	66.0	(54.9)	210.0	301.0	60.8	(69.2)	92.4	(105.0)
23	0.0	(0.3)	0.0	(0.4)	24.3	(9.4)	34.6	(13.5)	35.8	51.1	22.6	(12.1)	32.2	(17.3)
24	1.2	(1.1)	1.7	(1.6)	27.5	(2.8)	39.3	(4.0)	33.3	47.5	18.7	(3.9)	26.8	(5.5)
25	4.4	(3.3)	6.1	(4.6)	31.2	(11.6)	44.5	(16.7)	65.4	93.6	26.9	(8.9)	38.4	(12.8)
26	7.1	(0.7)	10.1	(1.1)	228.0	(163.0)	321.0	(241.0)	415.0	595.0	156.0	(112.0)	219.0	(164.0)
27	3.4	(1.8)	4.9	(2.5)	300.0	(70.5)	432.0	(102.0)	374.0	538.0	212.0	(52.9)	305.0	(76.2)
28	4.6	(1.8)	6.5	(2.6)	224.0	(71.6)	322.0	(103.0)	350.0	504.0	155.0	(55.9)	223.0	(80.2)
29	1.3	(1.6)	1.9	(2.2)	139.0	(55.0)	203.0	(78.1)	229.0	330.0	97.8	(40.2)	142.0	(57.4)
Avg	3.8		5.4		90.7		130		143.0	206.0	79.4		114	
n	25		25		26		26		26	26	26		26	
SD	3		4.3		64.4		92.2		96.2	138	40.7		58.1	
Min	0.0		0.0		22.6		32.7		33.3	47.5	18.7		26.8	
Max	11.1		15.6		300.0		432.0		415.0	595.0	212.0		305.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for March, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	1.9	(1.2)	2.7	(1.7)	105.0	(21.0)	151.0	(30.2)	144.0	208.0	75.1	(13.6)	108.0	(19.6)
2	4.3	(3.4)	6.2	(4.9)	63.1	(8.0)	90.6	(11.4)	87.0	125.0	46.6	(5.1)	66.9	(7.3)
3	4.3	(2.3)	6.1	(3.3)	59.5	(20.6)	85.3	(29.5)	103.0	147.0	44.9	(15.5)	64.4	(22.3)
4	5.0	(2.6)	7.1	(3.7)	56.0	(19.6)	80.4	(28.1)	87.0	125.0	40.7	(15.3)	58.4	(22.0)
5	0.0	(0.5)	0.0	(0.7)	49.3	(11.2)	70.9	(16.1)	73.7	106.0	36.9	(10.2)	53.0	(14.7)
6	1.3	(0.7)	1.9	(1.0)	40.4	(9.2)	58.2	(13.3)	57.0	82.0	31.6	(8.2)	45.5	(11.7)
7	0.5	(0.9)	0.6	(1.3)	39.1	(11.3)	56.2	(16.3)	59.7	85.9	28.6	(8.7)	41.2	(12.5)
8	0.2	(0.7)	0.4	(1.0)	41.1	(12.3)	59.2	(17.7)	60.0	86.2	27.0	(9.0)	38.9	(12.9)
9	1.8	(2.0)	2.6	(2.8)	50.9	(14.9)	72.7	(21.7)	76.0	109.0	30.2	(10.5)	43.2	(15.4)
10	2.5	(2.1)	3.6	(3.0)	56.6	(20.4)	81.4	(29.4)	86.2	124.0	29.9	(12.4)	42.9	(17.9)
11	0.9	(0.6)	1.3	(0.9)	81.2	(13.1)	117.0	(18.9)	103.0	148.0	33.9	(5.3)	48.8	(7.6)
12	1.5	(0.9)	2.2	(1.3)	98.2	(19.5)	141.0	(28.1)	139.0	201.0	36.6	(7.1)	52.7	(10.2)
13	2.1	(1.4)	3.0	(2.0)	105.0	(28.6)	152.0	(41.2)	150.0	217.0	47.2	(9.8)	67.8	(14.1)
14	0.2	(0.3)	0.3	(0.4)	101.0	(19.3)	145.0	(27.8)	132.0	190.0	52.0	(10.1)	74.7	(14.6)
15	1.3	(1.2)	1.8	(1.7)	105.0	(14.1)	151.0	(20.3)	127.0	183.0	49.8	(6.0)	71.5	(8.7)
16	0.7	(0.7)	1.0	(1.1)	87.0	(18.5)	125.0	(26.6)	121.0	174.0	47.1	(7.9)	67.6	(11.4)
17	0.9	(0.9)	1.2	(1.2)	82.9	(20.9)	119.0	(30.1)	105.0	151.0	44.5	(12.4)	63.8	(17.8)
18	0.8	(0.6)	1.2	(0.9)	83.5	(33.7)	120.0	(48.5)	153.0	220.0	43.3	(16.2)	62.1	(23.2)
19	1.0	(0.3)	1.5	(0.5)	123.0	(42.9)	177.0	(61.8)	177.0	255.0	67.9	(20.9)	97.6	(30.1)
20	0.8	(0.4)	1.1	(0.6)	148.0	(35.3)	213.0	(50.9)	208.0	298.0	97.3	(22.7)	140.0	(32.7)
21	1.5	(1.1)	2.1	(1.5)	141.0	(35.2)	202.0	(50.7)	196.0	281.0	107.0	(25.1)	154.0	(36.0)
22	3.0	(1.6)	4.3	(2.3)	120.0	(45.9)	172.0	(65.9)	187.0	268.0	107.0	(33.7)	154.0	(48.4)
23	2.7	(1.6)	3.8	(2.2)	115.0	(55.5)	165.0	(79.7)	191.0	273.0	104.0	(46.8)	150.0	(67.2)
24	1.2	(0.9)												
25	0.8	(0.2)	1.2	(0.3)	132.0	(52.7)	197.0	(71.8)	214.0	308.0	112.0	(42.5)	167.0	(58.0)
26	1.2	(0.2)	1.7	(0.2)	136.0	(41.5)	196.0	(59.6)	194.0	278.0	116.0	(33.1)	167.0	(47.6)
27	1.1	(0.5)												
28	0.8	(0.6)	1.2	(0.8)	108.0	(41.7)	155.0	(59.9)	168.0	242.0	111.0	(39.9)	160.0	(57.3)
29	1.6	(0.6)	2.3	(0.8)	117.0	(30.9)	168.0	(44.5)	177.0	254.0	121.0	(29.4)	174.0	(42.2)
30	2.0	(0.2)	2.9	(0.2)	99.8	(33.3)	143.0	(47.8)	158.0	227.0	108.0	(32.2)	154.0	(46.2)
31	3.7	(1.5)	5.2	(2.1)	92.1	(33.6)	132.0	(48.2)	155.0	222.0	98.0	(38.3)	140.0	(54.8)
Avg	1.7		2.4		90.9		131		134.0	193.0	65.4		94.1	
n	31		29		29		29		29	29	29		29	
SD	1.2		1.8		31.7		45.9		47.6	68.3	32.9		47.5	
Min	0.0		0.0		39.1		56.2		57.0	82.0	27.0		38.9	
Max	5.0		7.1		148.0		213.0		214.0	308.0	121.0		174.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for April, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	5.3	(0.5)	7.6	(0.7)	85.9	(37.5)	123.0	(53.7)	150.0	214.0	90.0	(40.8)	129.0	(58.5)
2	2.2	(0.7)	3.2	(1.1)	81.3	(31.4)	116.0	(45.0)	138.0	198.0	80.4	(33.8)	115.0	(48.5)
3	1.7	(0.2)	2.4	(0.3)	80.1	(31.5)	115.0	(45.2)	123.0	177.0	73.9	(27.2)	106.0	(39.0)
4	1.2	(0.2)	1.7	(0.2)	73.9	(31.5)	106.0	(45.2)	128.0	183.0	81.8	(28.0)	117.0	(40.1)
5					56.4	(23.9)	80.6	(34.3)	95.2	136.0	70.9	(23.2)	102.0	(33.2)
6														
7														
8														
9														
10														
11														
12	2.2	(1.5)	3.1	(2.1)	41.8	(19.8)	59.9	(28.3)	82.2	118.0	35.3	(18.0)	50.6	(25.7)
13	0.7	(0.4)	1.0	(0.6)	31.3	(16.7)	44.9	(23.8)	67.7	96.9	25.2	(14.7)	36.1	(21.0)
14	1.4	(0.3)	1.9	(0.4)	36.0	(10.5)	51.5	(15.1)	52.7	75.2	25.8	(7.8)	36.8	(11.2)
15	1.2	(0.2)	1.7	(0.3)	69.4	(49.1)	99.1	(70.2)	152.0	217.0	35.9	(25.5)	51.3	(36.4)
16	0.6	(0.2)	0.9	(0.2)	35.0	(60.1)	55.0	(88.7)	167.0	238.0	18.1	(28.1)		
17	0.7	(0.3)	1.0	(0.5)	3.7	(2.7)	5.3	(3.9)	10.0	14.3	7.4	(7.1)		
18	0.3	(0.5)	0.4	(0.7)	1.1	(1.5)	1.6	(2.1)	10.8	15.3	0.9	(0.5)		
19	0.1	(0.1)	0.1	(0.1)	0.5	(0.5)	0.7	(0.7)	1.9	2.8	0.6	(0.3)		
20	-0.3	(0.4)	-0.4	(0.6)	1.1	(1.3)	1.6	(1.8)	5.6	8.0	1.8	(1.0)	2.6	(1.5)
21	-0.2	(0.2)	-0.2	(0.3)	0.7	(0.5)	1.0	(0.7)	2.4	3.4	1.0	(0.7)	1.4	(1.0)
22	0.6	(0.6)	0.8	(0.8)	1.9	(0.9)	2.7	(1.3)	5.1	7.3	2.0	(1.0)	2.9	(1.4)
23	1.0	(1.0)	1.5	(1.4)	2.8	(1.6)	4.0	(2.2)	7.3	10.4	3.0	(1.6)	4.3	(2.4)
24	0.2	(0.1)	0.3	(0.2)	2.8	(0.7)	4.0	(1.0)	4.6	6.6	3.2	(1.1)	4.5	(1.5)
25	0.2	(0.2)	0.3	(0.2)	4.5	(1.4)	6.4	(2.0)	7.4	10.6	4.9	(1.7)	7.0	(2.4)
26	0.3	(0.5)	0.5	(0.7)	5.1	(2.3)	7.3	(3.3)	8.5	12.2	4.1	(2.1)	5.8	(3.0)
27	0.2	(0.5)	0.3	(0.7)	5.0	(3.2)	7.2	(4.6)	11.4	16.4	3.6	(2.6)	5.2	(3.7)
28	-0.3	(0.4)	-0.4	(0.6)	4.5	(2.5)	6.5	(3.6)	8.5	12.2	3.1	(1.7)	4.4	(2.4)
29	-0.7	(0.1)	-0.9	(0.2)	5.7	(1.4)	8.1	(2.0)	7.8	11.2	3.8	(1.2)	5.4	(1.7)
30	-0.2	(0.3)	-0.3	(0.4)	7.1	(1.2)	10.2	(1.7)	11.6	16.7	4.6	(1.0)	6.5	(1.4)
Avg	0.8		1.2		26.6		38.2		52.5	75.1	24.2		39.7	
n	23		23		24		24		24	24	24		20	
SD	1.2		1.7		30.5		43.8		58.5	83.7	30.3		45.7	
Min	-0.7		-0.9		0.5		0.7		1.9	2.8	0.6		1.4	
Max	5.3		7.6		85.9		123.0		167.0	238.0	90.0		129.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for May, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	0.0	(0.2)	0.0	(0.2)	7.0	(2.3)	10.1	(3.3)	12.7	18.3	4.8	(1.5)	6.9	(2.2)
2	0.1	(0.3)	0.2	(0.5)	9.9	(6.0)	14.2	(8.6)	29.8	42.7	6.8	(4.2)	9.7	(6.1)
3	-0.1	(0.3)	-0.2	(0.4)	12.1	(5.1)	17.4	(7.3)	18.6	26.8	6.3	(2.7)	9.1	(3.9)
4	0.3	(0.4)	0.4	(0.6)	12.5	(5.5)	18.0	(7.9)	20.7	29.8	6.1	(2.7)	8.8	(3.8)
5	-0.2	(0.3)	-0.3	(0.4)	11.2	(5.7)	16.1	(8.1)	18.2	26.2	7.1	(3.6)	10.2	(5.1)
6	-0.2	(0.4)	-0.3	(0.6)	11.5	(5.6)	16.5	(8.1)	18.1	26.0	9.2	(4.3)	13.2	(6.2)
7	-0.3	(0.1)	-0.4	(0.2)	15.5	(2.7)	22.3	(3.8)	19.6	28.2	12.5	(1.8)	17.9	(2.7)
8	-0.2	(0.4)	-0.2	(0.6)	12.3	(6.3)	17.6	(9.0)	22.8	32.8	10.0	(5.1)	14.3	(7.4)
9	-0.5	(0.3)	-0.7	(0.5)	14.6	(5.8)	21.0	(8.3)	21.2	30.4	11.4	(4.0)	16.3	(5.8)
10	-0.4	(0.1)	-0.6	(0.1)	14.5	(7.8)	20.9	(11.2)	25.1	36.1	11.1	(5.7)	15.9	(8.2)
11	0.0	(0.3)	0.1	(0.4)	18.3	(8.5)	26.2	(12.2)	28.4	40.8	14.1	(6.1)	20.3	(8.7)
12	0.2	(0.6)	0.3	(0.9)	23.8	(7.9)	34.1	(11.3)	35.9	51.5	18.9	(4.9)	27.1	(7.0)
13	2.3	(1.6)	3.3	(2.2)	20.7	(13.2)	29.6	(19.0)	40.3	58.0	15.7	(9.8)	22.4	(14.1)
14	3.3	(2.7)	4.7	(3.9)	19.6	(12.9)	28.1	(18.5)	40.9	58.7	17.0	(12.1)	24.4	(17.3)
15	7.5	(5.8)	10.9	(8.2)	23.3	(16.5)	33.6	(23.7)	57.8	83.1	20.1	(13.8)	29.1	(19.8)
16														
17														
18														
19														
20	1.1	(0.1)	1.6	(0.2)	43.3	(22.1)	62.1	(31.7)	89.9	129.0	29.4	(14.3)	42.2	(20.5)
21	0.8	(0.2)	1.1	(0.3)	44.4	(19.7)	63.6	(28.3)	81.1	116.0	33.4	(12.3)	47.8	(17.7)
22	0.5	(0.2)	0.7	(0.3)	41.2	(18.2)	59.0	(26.0)	73.1	105.0	27.4	(11.1)	39.3	(15.9)
23	0.8	(0.3)	1.1	(0.4)	46.7	(19.5)	67.0	(27.9)	85.4	122.0	29.5	(11.5)	42.3	(16.5)
24	1.5	(0.6)	2.1	(0.8)	71.6	(11.2)	103.0	(16.0)	96.8	139.0	55.7	(11.6)	79.9	(16.7)
25	2.7	(0.8)	3.8	(1.2)	73.5	(23.0)	105.0	(33.0)	113.0	162.0	69.5	(21.0)	99.7	(30.2)
26	1.2	(0.4)	1.8	(0.6)	60.9	(27.3)	87.3	(39.2)	120.0	172.0	60.9	(26.1)	87.4	(37.5)
27	1.0	(0.4)	1.4	(0.6)	50.9	(18.8)	72.9	(27.0)	78.2	112.0	59.5	(21.6)	85.3	(31.0)
28	2.3	(0.1)	3.3	(0.1)	44.4	(20.3)	63.7	(29.1)	76.2	109.0	54.7	(24.8)	78.5	(35.6)
29	1.7	(0.3)	2.4	(0.5)	38.1	(17.5)	54.5	(25.1)	65.1	93.3	44.6	(22.1)	64.0	(31.7)
30	1.1	(0.3)	1.5	(0.5)	31.7	(14.6)	45.5	(21.0)	54.8	78.5	36.0	(17.5)	51.7	(25.1)
31	1.1	(0.1)	1.5	(0.1)	32.0	(12.9)	45.8	(18.5)	51.9	74.4	33.9	(14.0)	48.6	(20.1)
Avg	1		1.5		29.8		42.8		51.7	74.1	26.1		37.5	
n	27		27		27		27		27	27	27		27	
SD	1.6		2.3		19		27.2		31.5	45.1	19.3		27.7	
Min	-0.5		-0.7		7.0		10.1		12.7	18.3	4.8		6.9	
Max	7.5		10.9		73.5		105.0		120.0	172.0	69.5		99.7	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for June, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	0.5	(0.2)	0.8	(0.2)	31.3	(14.8)	44.8	(21.2)	56.4	80.8	31.0	(14.6)	44.4	(21.0)
2	1.0	(0.2)	1.4	(0.3)	29.9	(13.8)	42.8	(19.8)	53.3	76.3	30.1	(14.0)	43.1	(20.0)
3	0.7	(0.2)	1.0	(0.3)	28.1	(11.5)	40.3	(16.4)	51.1	73.2	29.2	(11.8)	41.9	(16.9)
4	0.4	(0.5)	0.6	(0.7)	27.6	(12.8)	39.5	(18.3)	49.8	71.3	27.5	(12.9)	39.4	(18.5)
5	0.6	(0.3)	0.9	(0.5)	23.4	(13.1)	33.5	(18.8)	46.0	65.8	22.1	(11.8)	31.7	(16.9)
6	1.1	(0.2)	1.6	(0.4)	20.0	(10.2)	28.6	(14.6)	38.1	54.5	19.2	(10.7)	27.5	(15.3)
7	0.8	(0.5)	1.1	(0.8)	30.5	(35.9)	43.8	(51.5)	106.0	151.0	32.8	(46.4)	47.1	(66.5)
8	3.8	(1.3)	5.4	(1.9)	129.0	(34.5)	185.0	(49.4)	196.0	280.0	160.0	(53.5)	230.0	(76.5)
9	4.0	(0.8)	5.7	(1.1)	117.0	(49.2)	168.0	(70.4)	199.0	285.0	119.0	(63.3)	171.0	(90.6)
10	0.5	(0.7)	0.7	(1.0)	26.0	(39.4)	37.3	(56.5)	135.0	193.0	22.1	(37.0)	31.7	(53.1)
11	0.0	(0.4)	0.1	(0.6)	4.6	(3.4)	6.6	(4.9)	13.4	19.2	3.2	(1.6)	4.6	(2.2)
12	0.9	(0.2)	1.3	(0.3)	24.0	(26.0)	34.4	(37.2)	101.0	145.0	18.1	(12.3)	25.8	(17.6)
13	0.9	(0.1)	1.2	(0.2)	22.5	(15.0)	32.2	(21.5)	43.9	62.9	22.3	(15.6)	31.9	(22.3)
14	0.6	(0.1)	0.8	(0.2)	26.2	(15.6)	37.6	(22.3)	45.1	64.6	27.2	(16.1)	39.0	(23.1)
15	0.6	(0.3)	0.8	(0.4)	23.1	(15.1)	33.1	(21.6)	43.9	62.9	24.4	(15.6)	35.0	(22.4)
16	0.7	(0.2)	1.0	(0.3)	17.8	(10.1)	25.5	(14.4)	30.6	43.8	18.2	(10.4)	26.1	(14.8)
17	0.5	(0.5)	0.7	(0.7)	15.2	(8.6)	21.8	(12.3)	25.7	36.9	15.5	(9.1)	22.3	(13.1)
18	0.0	(0.2)	0.0	(0.3)	11.8	(7.6)	17.0	(10.8)	22.3	31.9	11.7	(7.7)	16.7	(11.0)
19	0.7	(0.6)	1.1	(0.9)	10.1	(6.5)	14.5	(9.3)	18.2	26.0	9.5	(6.2)	13.7	(8.8)
20	0.9	(0.4)	1.3	(0.6)	8.0	(6.4)	11.5	(9.2)	17.8	25.4	7.6	(6.2)	10.8	(8.9)
21	0.3	(0.3)	0.5	(0.4)	7.5	(6.1)	10.8	(8.8)	19.8	28.4	6.9	(5.6)	9.9	(8.1)
22	0.1	(0.2)	0.2	(0.2)	6.2	(4.3)	8.8	(6.2)	12.9	18.5	5.8	(3.9)	8.3	(5.6)
23	0.2	(0.3)	0.2	(0.4)	6.9	(3.6)	9.9	(5.1)	12.2	17.6	6.5	(3.4)	9.4	(4.9)
24	0.9	(0.3)	1.2	(0.4)	7.1	(3.8)	10.2	(5.5)	13.2	19.0	6.0	(3.5)	8.6	(5.0)
25	0.6	(0.3)	0.8	(0.4)	6.0	(3.2)	8.6	(4.6)	10.4	15.0	5.0	(2.5)	7.1	(3.6)
26	0.5	(0.4)	0.7	(0.6)	6.4	(2.9)	9.2	(4.2)	10.6	15.3	5.1	(2.7)	7.4	(3.8)
27	1.2	(0.7)	1.8	(1.0)	6.4	(4.4)	9.2	(6.4)	15.6	22.4	5.3	(3.4)	7.6	(4.8)
28	0.3	(0.2)	0.4	(0.3)	5.9	(3.3)	8.4	(4.7)	10.1	14.5	4.7	(2.5)	6.7	(3.6)
29	0.4	(0.2)	0.5	(0.3)	5.2	(3.1)	7.5	(4.4)	9.2	13.3	4.0	(2.2)	5.7	(3.1)
30	0.0	(0.3)	-0.1	(0.5)	5.2	(3.0)	7.5	(4.3)	9.4	13.5	3.9	(2.2)	5.5	(3.1)
Avg	0.8		1.1		23		32.9		47.2	67.6	23.5		33.6	
n	30		30		30		30		30	30	30		30	
SD	0.9		1.3		28.3		40.6		50.2	71.9	32.9		47.2	
Min	0.0		-0.1		4.6		6.6		9.2	13.3	3.2		4.6	
Max	4.0		5.7		129.0		185.0		199.0	285.0	160.0		230.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for July, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	0.0	(0.1)	0.0	(0.1)	6.1	(3.2)	8.7	(4.6)	10.6	15.2	4.3	(2.3)	6.1	(3.3)
2	0.2	(0.2)	0.2	(0.2)	6.3	(3.8)	9.1	(5.4)	11.5	16.5	4.5	(2.6)	6.4	(3.7)
3	0.1	(0.2)	0.1	(0.3)	6.4	(4.2)	9.2	(6.1)	12.7	18.2	4.4	(2.7)	6.3	(3.9)
4	0.4	(0.4)	0.6	(0.6)	9.5	(4.6)	13.6	(6.6)	16.1	23.1	6.1	(2.8)	8.8	(4.1)
5	0.6	(0.3)	0.8	(0.4)	10.0	(6.2)	14.4	(8.9)	20.1	28.8	6.0	(3.5)	8.6	(5.0)
6	0.7	(0.6)	1.0	(0.8)	11.8	(6.9)	17.0	(9.9)	26.1	37.6	7.6	(3.8)	10.9	(5.5)
7	1.6	(0.5)	2.3	(0.7)	14.1	(7.8)	20.2	(11.3)	35.2	50.6	10.3	(5.0)	14.9	(7.2)
8	2.5	(0.6)	3.6	(0.8)	13.8	(5.6)	19.8	(8.1)	27.7	39.9	13.0	(6.4)	18.7	(9.1)
9	1.1	(0.5)	1.6	(0.8)	11.2	(3.5)	16.1	(5.0)	19.4	27.9	10.9	(4.5)	15.7	(6.4)
10	1.6	(1.3)	2.3	(1.8)	13.0	(5.1)	18.7	(7.3)	27.1	38.9	13.4	(5.9)	19.2	(8.4)
11	0.8	(0.1)	1.2	(0.2)	18.9	(6.3)	27.2	(9.0)	30.6	43.9	16.2	(5.5)	23.3	(7.9)
12	0.7	(0.2)	1.1	(0.2)	22.9	(7.6)	32.9	(10.8)	38.0	54.6	20.8	(6.6)	29.9	(9.4)
13	0.8	(0.2)	1.1	(0.3)	24.6	(8.9)	35.4	(12.8)	42.3	60.7	23.7	(9.3)	34.1	(13.3)
14	1.0	(0.1)	1.5	(0.2)	23.0	(7.6)	33.1	(10.9)	41.8	60.0	24.6	(8.8)	35.4	(12.6)
15	0.6	(0.3)	0.8	(0.4)	28.2	(10.2)	40.4	(14.7)	45.4	65.1	33.4	(12.4)	48.1	(17.9)
16	1.4	(0.1)	1.9	(0.2)	28.0	(10.7)	40.2	(15.4)	49.0	70.4	32.4	(13.9)	46.5	(20.0)
17	1.0	(0.3)	1.5	(0.4)	23.3	(10.3)	33.4	(14.8)	45.5	65.2	26.9	(12.1)	38.7	(17.3)
18	2.1	(0.9)	3.0	(1.3)	25.8	(11.9)	37.0	(17.0)	49.8	71.4	27.2	(13.5)	39.0	(19.3)
19	2.8	(0.3)	4.1	(0.4)	29.4	(7.8)	42.2	(11.1)	48.0	68.8	26.9	(8.7)	38.6	(12.4)
20	1.9	(0.8)	2.7	(1.1)	34.8	(12.0)	50.0	(17.2)	64.3	92.3	33.3	(12.6)	47.8	(18.0)
21	1.2	(0.2)	1.7	(0.2)	35.5	(14.6)	50.9	(21.0)	59.7	85.7	32.6	(15.9)	46.9	(22.8)
22	1.3	(0.3)	1.8	(0.4)	28.6	(12.3)	41.0	(17.7)	50.0	71.6	26.4	(9.9)	37.9	(14.2)
23	1.5	(0.7)	2.1	(1.0)	20.1	(5.1)	28.9	(7.3)	38.3	54.9	20.2	(5.5)	29.0	(7.8)
24	1.5	(1.0)	2.1	(1.5)	20.3	(2.9)	29.1	(4.1)	25.7	36.8	19.6	(3.4)	28.1	(4.8)
25	0.9	(0.3)	1.2	(0.4)	21.3	(5.7)	30.7	(8.1)	31.4	45.1	19.4	(5.4)	28.0	(7.7)
26	1.6	(0.6)	2.3	(0.9)	21.5	(3.1)	30.8	(4.4)	28.7	41.1	18.9	(2.8)	27.1	(3.9)
27	1.3	(0.6)	1.9	(0.8)	22.4	(4.1)	32.2	(5.9)	33.1	47.5	20.0	(3.4)	28.7	(4.9)
28	0.9	(0.1)	1.3	(0.2)	21.6	(5.5)	31.0	(7.9)	37.6	53.8	22.1	(7.2)	31.8	(10.3)
29	1.4	(0.6)	1.9	(0.8)	19.6	(5.8)	28.1	(8.3)	30.0	42.9	19.4	(6.2)	27.8	(8.8)
30	1.9	(0.3)	2.7	(0.4)	21.2	(6.5)	30.4	(9.2)	35.1	50.3	19.8	(7.7)	28.4	(11.0)
31	2.0	(0.1)	2.8	(0.2)	18.1	(7.2)	25.9	(10.2)	34.6	49.6	16.2	(6.3)	23.3	(9.0)
Avg	1.2		1.7		19.7		28.3		34.4	49.3	18.7		26.9	
n	31		31		31		31		31	31	31		31	
SD	0.7		0.9		7.8		11.2		13.3	19	8.8		12.7	
Min	0.0		0.0		6.1		8.7		10.6	15.2	4.3		6.1	
Max	2.8		4.1		35.5		50.9		64.3	92.3	33.4		48.1	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for August, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	1.6	(0.5)	2.3	(0.7)	71.8	(86.1)	103.0	(124.0)	287.0	414.0	82.9	(98.7)	119.0	(142.0)
2	0.8	(0.5)	1.2	(0.7)	71.9	(106.0)	104.0	(152.0)	299.0	432.0	79.5	(117.0)		
3	0.2	(0.1)	0.3	(0.2)	11.6	(2.8)	16.5	(4.1)	18.7	26.7	13.3	(2.6)		
4	0.2	(0.3)	0.2	(0.5)	4.9	(2.9)	7.0	(4.1)	10.3	14.8	4.1	(3.1)		
5	-0.2	(0.3)	-0.3	(0.4)	2.3	(0.7)	3.3	(1.1)	4.2	6.0	1.6	(0.4)		
6	0.4	(0.2)	0.6	(0.2)	8.4	(12.9)	12.0	(18.4)	37.1	53.2	10.3	(13.7)		
7	0.1	(0.2)	0.2	(0.3)	18.5	(12.4)	26.4	(17.7)	36.1	51.7	18.4	(12.2)		
8	-0.5	(0.2)	-0.7	(0.3)	4.9	(4.6)	7.1	(6.5)	15.4	22.1	5.3	(5.3)		
9	-0.5	(0.3)	-0.7	(0.5)	2.5	(0.8)	3.5	(1.1)	5.2	7.4	2.3	(0.5)		
10	0.1	(0.1)	0.2	(0.2)	7.1	(5.8)	10.2	(8.4)	17.8	25.5	7.0	(6.1)		
11	0.1	(0.4)	0.2	(0.5)	9.9	(7.8)	15.2	(10.9)	20.3	29.1	9.8	(7.7)		
12	0.3	(0.5)	0.5	(0.7)	10.1	(7.8)	14.5	(11.3)	20.3	29.1	9.6	(7.2)	13.8	(10.3)
13	-0.2	(0.3)	-0.3	(0.4)	8.1	(6.6)	11.6	(9.4)	18.9	27.1	8.1	(6.5)	11.7	(9.3)
14	-0.8	(0.4)	-1.1	(0.6)	8.2	(5.9)	12.1	(8.5)	17.6	25.3	7.4	(5.4)	11.0	(7.8)
15	-0.4	(0.1)	-0.5	(0.2)	6.6	(5.3)	9.5	(7.6)	14.6	21.0	6.0	(4.8)	8.6	(6.9)
16	-0.4	(0.2)	-0.5	(0.3)	5.5	(4.0)	7.9	(5.7)	10.9	15.6	4.9	(3.6)	7.0	(5.1)
17	-0.6	(0.2)	-0.8	(0.3)	5.8	(3.4)	8.4	(4.9)	10.0	14.4	4.6	(2.7)	6.6	(3.9)
18	-0.5	(0.3)	-0.7	(0.4)	6.6	(2.8)	9.8	(4.0)	10.1	14.5				
19	-0.6	(0.1)	-0.8	(0.2)	6.6	(2.7)	9.5	(3.9)	11.2	16.2	4.9	(2.1)	7.0	(3.0)
20	-0.4	(0.2)	-0.6	(0.2)	6.7	(3.8)	9.7	(5.5)	13.9	20.1	4.3	(2.6)	6.2	(3.7)
21	-0.6	(0.3)	-0.8	(0.5)	7.9	(5.3)	11.5	(7.7)	15.1	21.7	4.4	(3.2)	6.4	(4.5)
22	-0.4	(0.3)	-0.6	(0.4)	8.9	(6.2)	12.8	(8.9)	18.7	26.9	4.4	(3.2)	6.3	(4.6)
23	0.2	(0.5)	0.3	(0.8)	11.5	(7.1)	16.5	(10.3)	20.7	29.9	5.2	(3.2)	7.4	(4.6)
24	0.0	(0.4)	0.0	(0.6)	11.9	(7.8)	17.1	(11.2)	24.0	34.5	5.5	(3.7)	7.9	(5.3)
25	-0.1	(0.1)	-0.2	(0.2)	12.6	(8.2)	18.0	(11.7)	25.1	36.1	6.3	(4.0)	9.1	(5.7)
26	0.4	(0.1)	0.5	(0.1)	13.1	(8.4)	18.8	(12.0)	24.6	35.3	7.1	(4.3)	10.2	(6.2)
27	0.5	(0.3)	0.7	(0.5)	14.7	(10.7)	21.1	(15.3)	38.6	55.4	8.1	(5.4)	11.6	(7.8)
28	1.7	(0.5)	2.4	(0.7)	18.9	(14.3)	27.2	(20.5)	44.7	64.3	9.7	(6.9)	14.0	(9.9)
29	1.6	(0.9)	2.3	(1.3)	18.7	(13.5)	26.9	(19.5)	45.0	64.7	11.0	(6.3)	15.8	(9.0)
30	0.9	(1.2)	1.4	(1.8)	22.1	(15.1)	31.8	(21.8)	50.4	72.5	16.7	(11.1)	23.9	(16.0)
31	-0.2	(0.3)	-0.2	(0.4)	30.3	(18.3)	43.4	(26.3)	52.4	75.2	20.7	(11.8)	29.7	(16.9)
Avg	0.1		0.1		14.5		20.8		39.9	57.5	12.8		16.7	
n	31		31		31		31		31	31	30		20	
SD	0.7		0.9		16.2		23.3		67.7	97.7	18.8		24.3	
Min	-0.8		-1.1		2.3		3.3		4.2	6.0	1.6		6.2	
Max	1.7		2.4		71.9		104.0		299.0	432.0	82.9		119.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for September, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	0.6	(0.8)	0.9	(1.1)	32.7	(19.6)	46.8	(28.1)	62.5	89.7	22.9	(13.2)	32.8	(18.9)
2	1.6	(0.9)	2.3	(1.2)	37.4	(23.7)	54.3	(34.0)	70.3	101.0	27.1	(16.8)	39.3	(24.0)
3	2.7	(0.5)	3.9	(0.7)	37.9	(28.0)	54.4	(40.3)	85.9	123.0	30.2	(20.4)	43.3	(29.3)
4	3.0	(0.7)	4.3	(1.0)	24.8	(14.0)	35.6	(20.1)	53.0	75.9	25.7	(14.8)	36.9	(21.2)
5	2.7	(0.6)	3.9	(0.9)	21.7	(9.9)	31.1	(14.2)	43.7	62.6	25.0	(13.5)	35.9	(19.4)
6	5.3	(0.7)	7.6	(1.0)	24.7	(10.8)	35.5	(15.5)	51.3	73.6	26.8	(13.8)	38.5	(19.7)
7	4.2	(0.6)	5.9	(0.9)	27.7	(10.8)	39.7	(15.5)	52.6	75.5	28.8	(13.5)	41.3	(19.3)
8	2.4	(0.3)	3.5	(0.4)	35.8	(17.3)	51.4	(24.8)	70.5	101.0	37.9	(18.6)	54.4	(26.7)
9	1.9	(0.3)	2.7	(0.4)	42.6	(17.8)	61.1	(25.6)	71.2	102.0	50.3	(22.8)	72.2	(32.8)
10	1.9	(0.5)	2.8	(0.7)	46.8	(22.3)	67.3	(32.0)	89.0	128.0	50.8	(27.3)	72.9	(39.2)
11	1.9	(0.8)	2.7	(1.2)	47.7	(24.2)	68.5	(34.8)	88.0	126.0	43.9	(25.4)	63.0	(36.5)
12	1.3	(0.3)	1.9	(0.4)	47.9	(24.8)	68.8	(35.7)	98.4	141.0	41.5	(23.0)	59.6	(33.0)
13	1.2	(0.4)	1.8	(0.5)	48.1	(21.0)	69.1	(30.1)	86.6	124.0	41.7	(18.3)	59.8	(26.3)
14	1.5	(0.4)	2.1	(0.5)	48.8	(21.1)	70.0	(30.3)	100.0	144.0	43.8	(21.2)	62.9	(30.4)
15	2.4	(0.5)	3.5	(0.7)	50.1	(19.8)	71.9	(28.4)	91.0	131.0	45.4	(20.2)	65.1	(29.0)
16	2.4	(0.3)	3.4	(0.4)	43.4	(14.1)	62.3	(20.2)	77.0	111.0	40.8	(15.3)	58.5	(22.0)
17	1.4	(0.3)	2.0	(0.4)	43.0	(14.5)	61.6	(20.8)	74.9	107.0	43.0	(15.9)	61.7	(22.8)
18	2.1	(0.3)	3.0	(0.4)	46.9	(17.7)	67.2	(25.4)	77.9	112.0	47.1	(19.6)	67.6	(28.2)
19	0.7	(0.5)	1.1	(0.6)	40.2	(11.9)	57.6	(17.1)	64.0	91.7	41.2	(13.6)	59.1	(19.5)
20	0.8	(0.8)	1.2	(1.2)	40.6	(6.8)	58.3	(9.7)	54.5	78.1	37.2	(7.3)	53.4	(10.4)
21	2.5	(0.2)	3.6	(0.4)	47.0	(13.1)	67.4	(18.8)	79.7	114.0	42.6	(13.0)	61.1	(18.7)
22	1.8	(0.4)	2.6	(0.5)	42.2	(17.0)	60.5	(24.4)	80.0	115.0	40.6	(19.2)	58.2	(27.5)
23	3.6	(2.0)	5.1	(2.9)	31.9	(10.7)	45.7	(15.2)	64.8	92.8	33.8	(13.7)	48.4	(19.7)
24	3.7	(2.2)	5.3	(3.1)	27.2	(8.2)	39.5	(11.5)	52.0	74.3	28.0	(9.5)	40.5	(13.4)
25	0.6	(0.2)	0.9	(0.4)	22.1	(7.0)	31.6	(10.1)	43.8	62.7	21.5	(6.3)	30.8	(8.9)
26	1.6	(0.5)	2.2	(0.7)	18.8	(6.1)	26.9	(8.8)	31.7	45.4	18.7	(6.4)	26.8	(9.1)
27														
28														
29														
30														
Avg	2.2		3.1		37.6		54		69.8	100.0	36		51.7	
n	26		26		26		26		26	26	26		26	
SD	1.1		1.6		9.7		13.9		17.7	25.5	9.2		13.2	
Min	0.6		0.9		18.8		26.9		31.7	45.4	18.7		26.8	
Max	5.3		7.6		50.1		71.9		100.0	144.0	50.8		72.9	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for November, 2008.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20	-1.0	(0.9)	-1.4	(1.3)	45.5	(14.2)	66.3	(20.3)	65.1	93.6	47.7	(15.7)	69.2	(22.5)
21	2.6	(2.2)	3.8	(3.2)	50.4	(10.1)	72.4	(14.6)	68.1	98.0	49.6	(9.2)	71.2	(13.1)
22	4.7	(2.7)			52.9	(15.3)	76.0	(22.0)	76.7	110.0	52.3	(15.7)	75.0	(22.5)
23	8.1	(8.2)			55.1	(16.6)	79.1	(23.8)	85.8	123.0	57.5	(17.0)	82.4	(24.3)
24	4.5	(0.9)			54.0	(9.7)	77.6	(14.0)	69.1	99.2	54.5	(12.2)	78.1	(17.4)
25	5.9	(0.3)			45.9	(11.4)	65.9	(16.1)	63.2	90.5				
26	4.4	(1.0)			45.5	(6.2)	65.4	(9.0)	55.4	79.5	51.0	(9.2)	73.2	(13.3)
27	3.2	(0.6)			41.4	(4.9)			49.8		42.2	(5.0)	60.5	(7.2)
28	4.0	(1.3)			37.6	(4.4)	55.7	(5.8)	45.9	65.9	30.8	(5.8)	44.1	(8.4)
29	2.0	(0.9)			40.1	(7.8)	57.7	(11.2)	52.3	75.1	42.9	(9.4)	61.5	(13.4)
30	2.9	(1.2)			41.7	(10.1)	59.6	(14.8)	60.3	86.5	47.9	(12.0)	68.7	(17.2)
Avg	3.8		1.2		46.4		67.6		62.9	92.2	47.7		68.4	
n	11		2		11		10		11	10	10		10	
SD	2.2		2.6		5.7		8		11.4	16	7.2		10.3	
Min	-1.0		-1.4		37.6		55.7		45.9	65.9	30.8		44.1	
Max	8.1		3.8		55.1		79.1		85.8	123.0	57.5		82.4	

Table E8. Daily means (SD) of H_2S concentrations at Site CA1B for December, 2008.

Day	Ambient				House 10						House 12			
	ppb		µg dsm^{-3}		ppb		µg dsm^{-3}		ppb	µg/dsm	ppb		µg dsm^{-3}	
1	2.4	(0.5)			40.3	(3.0)	57.6	(4.2)	46.4	66.6	44.2	(3.8)	63.3	(5.4)
2	2.3	(1.1)			37.3	(4.6)	53.6	(6.5)	42.5	61.0	40.7	(5.3)	58.4	(7.6)
3	1.9	(0.2)	2.7	(0.3)	38.9	(7.8)	54.9	(11.8)	49.1	70.6	37.4	(10.8)	53.8	(15.7)
4	2.7	(1.9)	3.8	(2.7)	24.6	(42.5)	37.7	(62.5)	153.0	219.0	6.6	(3.0)	9.4	(4.2)
5	2.0	(1.5)	2.8	(2.1)	5.2	(1.3)	7.5	(1.8)	9.0	12.8	8.1	(1.5)	11.6	(2.1)
6	0.7	(0.1)	1.0	(0.2)	3.1	(0.5)	4.4	(0.8)	4.2	6.0	5.1	(0.5)	7.2	(0.8)
7	0.9	(0.2)	1.3	(0.2)	4.6	(1.3)	6.6	(1.9)	7.1	10.1	7.1	(2.1)	10.0	(3.1)
8	1.1	(0.1)	1.6	(0.2)	18.6	(16.1)	26.6	(23.0)	41.0	58.6	26.3	(22.4)	37.5	(32.0)
9	2.6	(1.2)	3.6	(1.8)	37.5	(2.5)	53.6	(3.6)	44.4	63.6	49.9	(8.6)	71.3	(12.2)
10	2.0	(1.4)	2.9	(2.0)	30.8	(2.5)	44.2	(3.6)	36.0	51.5	44.4	(2.7)	63.5	(4.0)
11	1.1	(1.0)	1.6	(1.4)	29.7	(3.6)	42.6	(5.1)	36.2	52.0	41.5	(5.1)	59.6	(7.3)
12	1.7	(1.3)	2.5	(1.8)	26.8	(4.1)	38.4	(5.8)	31.9	45.7	38.4	(5.3)	55.1	(7.6)
13	2.0	(2.3)	2.9	(3.3)	21.7	(4.9)	31.1	(7.1)	31.4	45.0	30.5	(7.2)	43.7	(10.3)
14	2.2	(2.9)	3.2	(4.1)	17.9	(2.5)	25.7	(3.5)	22.6	32.3	24.3	(3.5)	34.8	(5.0)
15	0.5	(0.4)	0.7	(0.5)	19.8	(2.2)	28.4	(3.2)	24.9	35.7	23.6	(2.3)	33.9	(3.3)
16	0.5	(0.2)	0.6	(0.2)	14.8	(2.3)	21.3	(3.3)	20.8	29.8	16.9	(3.4)	24.2	(4.8)
17	0.4	(0.2)	0.6	(0.2)	8.6	(3.2)	12.4	(4.6)	13.4	19.2	9.5	(3.8)	13.6	(5.5)
18	0.2	(0.2)	0.3	(0.3)	8.6	(3.3)	12.3	(4.8)	13.1	18.8	10.8	(3.3)	15.4	(4.7)
19	1.3	(1.0)	1.8	(1.4)	14.1	(2.3)	20.2	(3.3)	21.2	30.4	14.6	(1.6)	21.0	(2.3)
20	2.0	(0.9)	2.9	(1.2)	9.5	(3.0)	13.6	(4.4)	14.3	20.5	9.7	(2.8)	14.0	(4.0)
21	1.8	(0.7)	2.6	(1.0)	6.4	(4.2)	9.2	(6.0)	14.3	20.6	6.0	(3.7)	8.6	(5.3)
22	2.3	(1.7)	3.3	(2.5)	16.8	(6.1)	24.2	(8.8)	28.5	41.0	12.6	(4.0)	18.1	(5.7)
23	0.8	(0.2)	1.1	(0.3)	25.3	(2.4)	36.5	(3.5)	30.4	43.8	17.6	(1.7)	25.3	(2.4)
24	0.7	(0.4)	1.0	(0.5)	27.6	(2.1)	39.8	(3.1)	31.4	45.3	20.0	(1.2)	28.7	(1.7)
25	0.7	(0.2)	0.9	(0.3)	28.2	(3.6)	40.6	(5.1)	33.9	48.8	20.2	(2.1)	29.1	(3.1)
26	1.8	(1.3)	2.5	(1.8)	26.9	(6.1)	38.7	(8.7)	38.6	55.4	19.2	(3.2)	27.6	(4.6)
27	4.7	(2.7)	6.6	(3.8)	35.5	(11.6)	51.1	(16.8)	72.5	104.0	24.1	(5.9)	34.6	(8.5)
28	6.1	(3.8)	8.6	(5.5)	45.8	(7.8)	65.9	(11.2)	63.9	91.9	29.3	(4.6)	42.1	(6.6)
29	25.4	(13.8)	36.3	(19.6)	55.9	(10.1)	80.6	(14.6)	76.8	111.0	35.5	(6.3)	51.0	(9.0)
30	3.9	(0.5)	5.6	(0.7)	68.5	(7.6)	98.7	(10.9)	89.6	129.0	46.7	(4.5)	67.1	(6.5)
31	3.6	(0.5)	5.1	(0.8)	72.4	(15.0)	104.0	(21.5)	97.2	140.0	59.6	(8.0)	85.7	(11.4)
Avg	2.7		3.8		26.5		38.1		40.0	57.4	25.2		36.1	
n	31		29		31		31		31	31	31		31	
SD	4.4		6.4		17.2		24.8		30.8	44.3	14.9		21.4	
Min	0.2		0.3		3.1		4.4		4.2	6.0	5.1		7.2	
Max	25.4		36.3		72.4		104.0		153.0	219.0	59.6		85.7	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for January, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	2.1	(0.3)	2.9	(0.4)	86.9	(8.5)	125.0	(12.2)	104.0	150.0	88.5	(6.8)	127.0	(9.8)
2	2.3	(0.2)	3.3	(0.2)	77.9	(15.1)	112.0	(21.6)	112.0	161.0	92.0	(12.6)	132.0	(18.0)
3	1.8	(0.5)	2.5	(0.7)	49.3	(20.0)	77.3	(24.8)	80.9	116.0	65.2	(20.8)	93.6	(29.8)
4	1.9	(0.4)	2.7	(0.5)	46.5	(26.1)	66.5	(37.5)	78.8	113.0	58.7	(29.3)	84.3	(42.1)
5	1.9	(0.1)	2.8	(0.1)	58.4	(8.7)	84.0	(12.5)	78.0	112.0	69.4	(11.8)	99.6	(16.9)
6	3.0	(2.0)	4.2	(2.9)	61.9	(11.6)	89.0	(16.7)	83.2	120.0	70.3	(12.3)	101.0	(17.7)
7	5.0	(1.0)	7.1	(1.5)	50.5	(19.8)	72.8	(28.4)	84.6	122.0	53.0	(23.8)	76.2	(34.2)
8	2.8	(1.2)	4.0	(1.7)	41.3	(16.4)	62.0	(24.3)	77.1	111.0	43.8	(19.0)	62.9	(27.3)
9	2.3	(1.3)	3.3	(1.8)	50.9	(10.5)			73.8		50.8	(12.5)	72.8	(18.0)
10	5.8	(1.0)	8.3	(1.4)	65.7	(17.5)			96.7		68.3	(17.9)	98.0	(25.7)
11	7.8	(2.0)	11.1	(2.8)	67.8	(18.6)	92.2	(26.2)	97.8	139.0	71.6	(20.6)	103.0	(29.6)
12	3.8	(1.3)	5.4	(1.9)	67.6	(20.2)	97.0	(29.0)	92.8	133.0	72.4	(22.9)	104.0	(32.9)
13	6.7	(2.0)	9.6	(2.8)	69.8	(22.5)	100.0	(32.4)	97.8	140.0	75.9	(25.2)	109.0	(36.2)
14	6.1	(2.7)	8.7	(3.8)	67.8	(24.1)	97.3	(34.6)	101.0	146.0	74.5	(26.6)	107.0	(38.1)
15	10.9	(5.6)	15.5	(8.0)	61.0	(22.1)	87.5	(31.7)	90.6	130.0	67.6	(25.9)	96.9	(37.1)
16	11.1	(9.2)	15.9	(13.1)	62.9	(22.5)	84.4	(32.1)	93.7	134.0	65.8	(28.5)	94.4	(40.9)
17	4.1	(1.5)	5.8	(2.2)	59.0	(20.9)	82.0	(29.8)	87.6	125.0	61.9	(28.8)	88.7	(41.2)
18	5.1	(3.0)	7.3	(4.3)	55.0	(20.0)	78.7	(28.7)	82.6	118.0	58.0	(23.8)	83.1	(34.0)
19	13.7	(9.9)	19.5	(14.1)	56.6	(20.4)	81.1	(29.2)	95.6	137.0	53.9	(22.0)	77.2	(31.6)
20	12.6	(6.0)	18.0	(8.5)	53.2	(17.6)	76.3	(25.2)	84.7	121.0	49.7	(19.1)	71.1	(27.4)
21	4.6	(2.5)	6.6	(3.6)	45.7	(12.0)	65.5	(17.2)	78.7	113.0	54.8	(10.9)	78.6	(15.6)
22	8.4	(1.2)	12.0	(1.8)	47.5	(5.9)	68.1	(8.5)	56.4	80.8	52.4	(8.0)	75.2	(11.5)
23	3.4	(0.9)	4.8	(1.3)	48.8	(5.1)	70.0	(7.3)	56.5	81.0	45.7	(5.6)	65.5	(8.0)
24	3.7	(0.3)	5.2	(0.5)	42.9	(8.0)	61.5	(11.4)	53.5	76.8	40.2	(6.4)	57.7	(9.2)
25	1.6	(0.7)	2.3	(1.0)	44.1	(6.3)	63.1	(9.1)	54.9	78.6	41.9	(6.1)	60.1	(8.7)
26	2.5	(0.9)	3.6	(1.3)	43.2	(7.7)	61.9	(11.0)	55.0	78.7	40.6	(8.1)	58.1	(11.7)
27	2.7	(1.3)	3.8	(1.8)	40.7	(8.0)	58.2	(11.5)	61.6	88.0	37.3	(7.2)	53.3	(10.3)
28	2.1	(1.8)	3.0	(2.6)	23.7	(18.1)	33.8	(25.8)	56.9	81.3	23.8	(17.5)	34.0	(25.0)
29	2.4	(1.1)	3.4	(1.5)	11.4	(9.4)	16.3	(13.4)	31.7	45.4	10.9	(7.8)	15.6	(11.2)
30	7.5	(7.1)	10.6	(10.0)	128.0	(97.0)	183.0	(139.0)	324.0	464.0	111.0	(83.8)	159.0	(120.0)
31	6.1	(5.1)	9.3	(7.7)	227.0	(70.9)	343.0	(96.9)	337.0	482.0	227.0	(66.1)	342.0	(87.8)
Avg	5		7.2		61.7		89.3		95.5	138.0	64.4		92.9	
n	31		31		31		29		31	29	31		31	
SD	3.3		4.8		35.9		55.8		64.3	95	35.4		53.4	
Min	1.6		2.3		11.4		16.3		31.7	45.4	10.9		15.6	
Max	13.7		19.5		227.0		343.0		337.0	482.0	227.0		342.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for February, 2009.

Day	Ambient				House 10						House 12			
	ppb		µg dsm^{-3}		ppb		µg dsm^{-3}		ppb	µg/dsm	ppb		µg dsm^{-3}	
1	2.6	(0.5)	3.7	(0.7)	138.0	(30.2)	197.0	(43.1)	200.0	287.0	156.0	(33.4)	224.0	(47.6)
2	1.9	(0.8)	2.7	(1.1)	88.5	(16.8)	127.0	(24.0)	137.0	197.0	104.0	(20.0)	148.0	(28.6)
3	3.9	(0.6)	5.5	(0.8)	61.2	(9.0)	87.7	(12.7)	79.0	113.0	68.8	(9.5)	98.5	(13.4)
4	1.4	(0.7)	2.1	(0.9)	44.0	(19.8)	63.8	(28.8)	100.0	144.0	52.2	(19.0)	75.9	(27.3)
5	0.7	(0.2)	0.9	(0.2)	32.5	(10.1)	46.6	(14.7)	44.7	63.9	33.7	(11.9)	48.2	(17.4)
6	0.6	(0.4)	0.8	(0.6)	41.5	(3.3)	59.4	(4.7)	47.6	68.2	41.1	(2.4)	58.8	(3.4)
7	4.1	(4.5)	5.9	(6.4)	44.2	(7.7)	63.4	(11.1)	57.3	82.3	42.3	(6.9)	60.7	(10.0)
8	5.4	(5.7)	7.8	(8.1)	46.7	(6.0)	67.0	(8.6)	55.1	78.9	43.6	(5.7)	62.5	(8.2)
9	0.8	(0.3)	1.1	(0.4)	48.0	(3.0)	68.7	(4.3)	52.7	75.5	43.9	(3.5)	62.9	(4.9)
10	1.0	(0.4)	1.4	(0.6)	49.2	(3.1)	70.6	(4.5)	55.2	79.2	46.6	(2.5)	66.8	(3.6)
11	0.9	(0.3)	1.3	(0.4)	44.5	(4.1)	63.9	(5.9)	52.2	74.9	42.0	(4.3)	60.3	(6.1)
12	3.7	(3.1)	5.2	(4.4)	48.1	(4.3)	69.1	(6.1)	56.8	81.6	46.6	(5.4)	66.9	(7.7)
13	2.1	(1.6)	3.1	(2.2)	43.2	(5.6)	62.1	(8.1)	52.1	74.8	41.9	(5.7)	60.2	(8.2)
14	1.1	(0.2)	1.6	(0.2)	42.2	(2.2)	60.6	(3.1)	46.1	66.2	39.3	(2.2)	56.4	(3.1)
15	0.5	(0.2)	0.7	(0.3)	32.1	(4.4)	46.1	(6.3)	42.2	60.6	29.0	(3.9)	41.5	(5.6)
16	1.6	(0.4)	2.3	(0.6)	32.1	(2.6)	46.1	(3.8)	36.8	52.9	26.5	(1.9)	38.0	(2.7)
17	0.8	(0.2)	1.2	(0.3)	23.0	(7.5)	34.0	(10.2)	34.2	49.2	18.3	(5.1)	27.0	(6.8)
18	0.7	(0.4)	1.1	(0.6)	41.1	(7.0)	59.3	(10.0)	56.3	81.2	28.8	(4.4)	41.5	(6.3)
19	1.3	(0.3)	1.8	(0.4)	43.7	(10.9)	62.9	(15.8)	55.2	79.6	29.5	(8.4)	42.4	(12.1)
20	2.6	(1.4)	3.7	(2.0)	46.5	(9.3)	67.4	(13.3)	69.5	100.0	32.0	(6.1)	46.3	(8.8)
21	2.6	(1.9)	3.7	(2.7)	50.1	(3.8)	72.2	(5.5)	61.7	88.9	35.1	(2.8)	50.5	(4.1)
22	1.4	(0.3)	2.0	(0.4)	54.8	(6.1)	79.0	(8.8)	70.3	101.0	40.8	(4.2)	58.7	(6.1)
23	1.6	(0.7)	2.3	(1.0)	67.0	(15.4)	96.7	(22.3)	88.8	128.0	48.5	(9.6)	69.9	(13.9)
24	1.8	(0.4)	2.6	(0.6)	69.5	(20.4)	100.0	(29.5)	101.0	146.0	48.1	(13.9)	69.2	(20.0)
25	5.1	(3.8)	7.3	(5.5)	73.4	(20.3)	106.0	(29.4)	106.0	152.0	52.3	(15.8)	75.2	(22.8)
26	4.9	(2.4)	7.0	(3.5)	93.2	(23.8)	134.0	(34.3)	125.0	181.0	65.8	(17.3)	94.6	(25.0)
27	2.5	(2.2)	3.6	(3.1)	115.0	(24.5)	166.0	(35.3)	163.0	234.0	77.7	(17.7)	112.0	(25.5)
28	7.7	(3.2)	11.0	(4.5)	142.0	(21.6)	204.0	(31.1)	169.0	243.0	101.0	(13.6)	146.0	(19.6)
Avg	2.3		3.3		59.1		85		79.1	114.0	51.3		73.7	
n	28		28		28		28		28	28	28		28	
SD	1.8		2.5		29.8		42.7		42.8	61.5	28.2		40.4	
Min	0.5		0.7		23.0		34.0		34.2	49.2	18.3		27.0	
Max	7.7		11.0		142.0		204.0		200.0	287.0	156.0		224.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for March, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	3.1	(1.4)	4.5	(2.0)	148.0	(10.2)	213.0	(14.7)	182.0	263.0	120.0	(11.7)	173.0	(16.9)
2	1.5	(0.2)	2.1	(0.3)	109.0	(33.6)	157.0	(48.4)	185.0	267.0	110.0	(27.2)	159.0	(39.1)
3	2.9	(0.6)	4.2	(0.8)	97.2	(14.7)	140.0	(21.1)	129.0	185.0	111.0	(21.4)	160.0	(30.8)
4	2.3	(1.2)	3.3	(1.7)	109.0	(16.3)	156.0	(23.5)	137.0	196.0	113.0	(16.5)	162.0	(23.7)
5	2.1	(1.1)	3.0	(1.6)	107.0	(24.0)	154.0	(34.6)	141.0	203.0	114.0	(27.2)	164.0	(39.1)
6	1.7	(0.4)	2.4	(0.5)	104.0	(27.3)	150.0	(39.2)	148.0	212.0	110.0	(27.6)	158.0	(39.7)
7	2.7	(1.3)	3.8	(1.9)	114.0	(24.7)	164.0	(35.5)	151.0	216.0	110.0	(25.1)	158.0	(36.0)
8	2.4	(0.9)	3.4	(1.3)	110.0	(35.3)	158.0	(50.7)	171.0	246.0	108.0	(35.7)	155.0	(51.2)
9	2.6	(1.1)	3.6	(1.6)	125.0	(30.1)	179.0	(43.3)	177.0	254.0	113.0	(27.5)	163.0	(39.6)
10	5.7	(1.4)	8.1	(1.9)	132.0	(43.6)	189.0	(62.7)	229.0	328.0	128.0	(43.3)	183.0	(62.1)
11	9.5	(3.9)	13.5	(5.5)	137.0	(41.5)	196.0	(59.7)	208.0	298.0	138.0	(41.8)	197.0	(60.0)
12	3.1	(0.8)	4.5	(1.1)	119.0	(41.7)	171.0	(59.9)	178.0	255.0	119.0	(41.2)	170.0	(59.1)
13	2.3	(0.3)	3.2	(0.4)	112.0	(42.3)	161.0	(60.8)	173.0	248.0	105.0	(37.6)	151.0	(54.0)
14	2.0	(0.4)	2.8	(0.6)	119.0	(25.5)	171.0	(36.6)	158.0	227.0	130.0	(26.2)	186.0	(37.7)
15	2.0	(1.8)	2.9	(2.6)	92.1	(34.4)	132.0	(49.5)	137.0	196.0	103.0	(41.8)	148.0	(60.0)
16	3.5	(1.9)	5.0	(2.7)	90.2	(35.9)	129.0	(51.7)	152.0	219.0	96.7	(40.0)	139.0	(57.6)
17	3.7	(1.4)	5.2	(1.9)	78.4	(34.5)	113.0	(49.6)	142.0	204.0	79.7	(34.7)	114.0	(49.9)
18	6.2	(3.3)	8.8	(4.8)	58.4	(16.4)	83.7	(23.5)	103.0	147.0	64.2	(18.7)	92.1	(26.8)
19	5.0	(2.3)	7.1	(3.3)	59.8	(27.0)	85.8	(38.8)	102.0	146.0	61.1	(27.6)	87.6	(39.6)
20	2.3	(1.0)	3.2	(1.4)	54.5	(21.2)	78.2	(30.3)	83.1	119.0	56.1	(22.4)	80.4	(32.1)
21	2.7	(0.6)	3.8	(0.8)	59.9	(18.0)	85.9	(25.9)	85.4	122.0	64.6	(19.0)	92.7	(27.2)
22	1.8	(1.1)	2.6	(1.5)	63.1	(15.3)	90.4	(22.1)	93.0	133.0	69.6	(16.0)	99.8	(23.0)
23	1.9	(0.6)	2.7	(0.8)	54.1	(14.0)	77.3	(20.1)	74.2	106.0	55.7	(14.7)	79.8	(21.0)
24	2.0	(0.6)	2.9	(0.9)	60.9	(23.1)	87.3	(33.1)	101.0	145.0	58.6	(21.9)	84.0	(31.4)
25	2.6	(1.1)	3.8	(1.6)	56.5	(22.6)	81.0	(32.4)	93.2	134.0	57.8	(22.5)	83.0	(32.3)
26	2.1	(0.7)	3.0	(1.1)	40.9	(22.4)	58.6	(32.2)	79.5	114.0	44.7	(23.9)	64.1	(34.3)
27	3.3	(2.1)	4.8	(3.0)	76.9	(68.6)	110.0	(98.7)	231.0	332.0	34.6	(17.4)	49.6	(24.9)
28	5.0	(2.3)	7.2	(3.3)	112.0	(108.0)	161.0	(154.0)	294.0	422.0	12.5	(6.8)	17.9	(9.8)
29	0.7	(0.6)	1.0	(0.9)	3.0	(0.9)	4.2	(1.3)	5.6	8.0	3.0	(0.7)	4.3	(1.0)
30	6.2	(6.9)	8.9	(9.8)	8.3	(7.3)	11.9	(10.4)	21.9	31.4	24.0	(34.2)	34.4	(49.0)
31	3.9	(4.2)	5.5	(5.9)	6.6	(7.2)	9.5	(10.3)	20.9	30.0	41.5	(54.1)	59.4	(77.4)
Avg	3.2		4.5		84.4		121		135.0	194.0	82.5		118	
n	31		31		31		31		31	31	31		31	
SD	1.8		2.5		37.9		54.4		62.8	90.3	36.7		52.8	
Min	0.7		1.0		3.0		4.2		5.6	8.0	3.0		4.3	
Max	9.5		13.5		148.0		213.0		294.0	422.0	138.0		197.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for April, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	1.7	(0.3)	2.4	(0.5)	5.4	(5.3)	7.7	(7.6)	18.1	26.0	7.5	(8.6)	10.8	(12.3)
2	0.3	(0.4)	0.4	(0.5)	6.1	(7.7)	8.8	(11.0)	18.0	25.7	10.0	(12.7)	14.3	(18.2)
3	0.9	(0.8)	1.3	(1.2)	0.7	(0.6)	1.0	(0.9)	2.9	4.1	0.5	(0.4)	0.7	(0.6)
4	4.5	(2.8)	6.4	(4.0)	3.1	(7.4)	4.4	(10.6)	34.9	49.7	3.3	(7.0)	4.8	(10.0)
5	10.0	(5.5)	14.2	(7.8)	4.2	(6.9)	6.0	(9.9)	34.4	49.0	4.1	(8.0)	5.8	(11.3)
6	7.5	(8.4)	10.7	(11.9)	3.5	(7.5)	5.0	(10.6)	39.9	56.9	1.5	(1.7)	2.1	(2.4)
7	0.7	(0.1)	1.0	(0.2)	0.7	(0.7)	1.0	(1.0)	3.0	4.2	0.6	(0.7)	0.8	(1.1)
8	0.8	(0.2)	1.2	(0.3)	1.3	(0.6)	1.9	(0.9)	3.4	4.8	1.5	(0.5)	2.2	(0.8)
9	0.7	(0.3)	1.1	(0.4)	2.0	(0.7)	2.9	(1.0)	4.5	6.4	2.4	(0.7)	3.4	(0.9)
10	0.4	(0.0)	0.5	(0.1)	1.1	(0.7)	1.7	(1.1)	2.8	4.0	1.7	(0.5)		
11	0.5	(0.2)	0.7	(0.2)	1.9	(0.4)	2.8	(0.6)	3.1	4.4	2.3	(0.6)	3.3	(0.9)
12	0.4	(0.4)	0.6	(0.6)	2.9	(0.6)	4.1	(0.9)	4.6	6.5	3.2	(0.7)	4.6	(1.1)
13	0.4	(0.3)	0.5	(0.5)	6.0	(1.5)	8.6	(2.2)	9.7	13.9	6.5	(1.6)	9.4	(2.3)
14	0.4	(0.1)	0.6	(0.2)	6.5	(1.4)	9.3	(2.1)	8.9	12.7	6.8	(1.5)	9.8	(2.1)
15	0.2	(0.2)	0.2	(0.3)	9.1	(1.6)	13.0	(2.3)	12.4	17.8	8.7	(1.7)	12.5	(2.5)
16	0.7	(0.3)	1.1	(0.5)	10.8	(1.6)	15.5	(2.3)	14.3	20.6	9.4	(1.5)	13.5	(2.2)
17	1.1	(0.5)	1.5	(0.7)	11.0	(2.6)	15.8	(3.8)	15.3	22.0	9.0	(2.4)	12.9	(3.4)
18	1.1	(0.4)	1.5	(0.5)	9.5	(5.4)	13.7	(7.7)	20.9	30.0	8.4	(4.4)	12.0	(6.3)
19	0.9	(0.2)	1.2	(0.3)	8.8	(6.0)	12.7	(8.6)	19.8	28.5	7.3	(5.0)	10.5	(7.1)
20														
21														
22														
23														
24														
25														
26														
27														
28														
29	0.4	(0.2)	0.5	(0.2)	24.4	(7.8)	35.0	(11.3)	38.0	54.6	13.9	(4.3)	19.9	(6.2)
30	1.0	(0.5)	1.5	(0.7)	33.5	(12.6)	48.1	(18.1)	55.4	79.6	15.8	(5.9)	22.7	(8.4)
Avg	1.6		2.3		7.3		10.4		17.3	24.8	5.9		8.8	
n	21		21		21		21		21	21	21		20	
SD	2.5		3.6		7.9		11.3		14.7	21	4.2		6.1	
Min	0.2		0.2		0.7		1.0		2.8	4.0	0.5		0.7	
Max	10.0		14.2		33.5		48.1		55.4	79.6	15.8		22.7	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for May, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	1.2	(0.3)	1.7	(0.4)	62.1	(18.7)	89.5	(27.0)	107.0	154.0	33.8	(11.1)	48.7	(16.0)
2	3.3	(0.7)	4.7	(0.9)	126.0	(26.6)	181.0	(38.4)	199.0	287.0	75.6	(18.2)	109.0	(26.3)
3	2.6	(0.3)	3.8	(0.5)	148.0	(46.9)	213.0	(67.7)	226.0	325.0	104.0	(32.5)	150.0	(46.8)
4	1.7	(0.6)	2.4	(0.8)	111.0	(51.4)	160.0	(74.0)	200.0	287.0	98.0	(44.6)	141.0	(64.3)
5	2.7	(1.2)	3.9	(1.6)	80.4	(42.3)	116.0	(60.9)	156.0	225.0	89.5	(47.9)	129.0	(69.0)
6	2.0	(0.3)	2.9	(0.5)	68.0	(35.4)	97.9	(51.0)	119.0	171.0	76.4	(41.4)	110.0	(59.6)
7	2.1	(0.3)	3.0	(0.5)	66.6	(33.4)	95.7	(48.1)	116.0	166.0	74.3	(35.6)	107.0	(51.2)
8	1.9	(0.3)	2.7	(0.5)	56.7	(30.7)	81.3	(44.2)	104.0	150.0	64.6	(35.3)	92.7	(50.8)
9	2.2	(0.6)	3.2	(0.8)	51.0	(32.2)	73.1	(46.3)	108.0	155.0	56.8	(35.0)	81.5	(50.3)
10	2.3	(0.3)	3.3	(0.5)	35.3	(21.6)	50.6	(31.0)	74.9	107.0	50.5	(28.3)	72.5	(40.6)
11	1.8	(0.2)	2.6	(0.3)	41.7	(19.6)	59.8	(28.2)	80.7	116.0	51.3	(27.7)	73.6	(39.7)
12	2.6	(0.4)	3.6	(0.5)	57.9	(27.3)	82.9	(39.2)	100.0	144.0	59.4	(28.8)	85.2	(41.3)
13	2.7	(0.2)	3.8	(0.2)	50.2	(30.8)	72.0	(44.2)	111.0	160.0	54.5	(32.8)	78.2	(47.1)
14	2.4	(0.6)	3.4	(0.8)	44.6	(21.0)	64.0	(30.1)	89.0	128.0	48.7	(25.2)	69.9	(36.2)
15	3.9	(1.0)	5.7	(1.4)	46.9	(17.7)	67.4	(25.4)	89.2	128.0	49.8	(22.4)	71.6	(32.2)
16	3.4	(0.7)	4.8	(1.0)	35.0	(6.3)	50.3	(8.9)	51.2	73.4	37.5	(9.5)	53.9	(13.5)
17	2.6	(0.4)	3.8	(0.6)	30.3	(3.9)	43.5	(5.6)	39.4	56.6	31.9	(5.8)	46.0	(8.3)
18	1.9	(0.3)	2.7	(0.5)	25.3	(2.5)	36.4	(3.6)	30.6	44.0	26.9	(3.4)	38.7	(4.9)
19	1.7	(0.3)	2.5	(0.4)	25.0	(2.2)	35.8	(3.1)	30.5	43.6	27.9	(3.8)	40.1	(5.4)
20	1.5	(0.3)	2.2	(0.4)	26.5	(7.6)	37.9	(10.8)	44.8	64.1	31.1	(12.0)	44.6	(17.1)
21	1.8	(0.6)	2.6	(0.9)	29.6	(6.7)	42.3	(9.6)	48.0	68.6	31.3	(11.4)	44.9	(16.3)
22	1.5	(0.3)	2.1	(0.4)	30.7	(6.2)	44.1	(8.9)	50.0	71.6	31.1	(9.0)	44.6	(12.9)
23	1.6	(0.1)	2.3	(0.2)	34.0	(9.7)	48.7	(13.9)	52.4	75.1	34.1	(9.4)	48.9	(13.5)
24	1.7	(0.2)	2.4	(0.2)	33.4	(9.9)	47.9	(14.1)	47.0	67.3	33.9	(10.2)	48.7	(14.7)
25	2.4	(0.4)	3.4	(0.6)	31.9	(8.3)	45.7	(11.8)	45.6	65.3	30.9	(8.1)	44.4	(11.5)
26	2.7	(0.8)	3.9	(1.1)	23.1	(8.9)	33.2	(12.7)	44.9	64.3	26.2	(11.7)	37.6	(16.8)
27	4.9	(0.9)	7.0	(1.4)	23.1	(9.1)	33.3	(13.1)	49.4	70.8	24.7	(14.4)	35.6	(20.7)
28	1.8	(0.4)	2.5	(0.6)	27.4	(13.5)	39.2	(19.3)	46.7	66.9	29.4	(14.1)	42.1	(20.2)
29	1.4	(0.4)	2.0	(0.5)	53.8	(12.7)	77.1	(18.2)	84.3	121.0	61.8	(20.4)	88.5	(29.3)
30	0.7	(0.1)	0.9	(0.2)	21.5	(10.1)	30.8	(14.4)	43.0	61.6	29.8	(8.4)	42.7	(11.9)
31	0.3	(0.2)	0.4	(0.3)	9.0	(2.0)	12.8	(2.8)	13.3	19.1	14.1	(3.5)	20.2	(5.0)
Avg	2.2		3.1		48.6		69.8		83.9	121.0	48.1		69	
n	31		31		31		31		31	31	31		31	
SD	0.9		1.3		30.9		44.5		52.1	75.1	22.8		32.9	
Min	0.3		0.4		9.0		12.8		13.3	19.1	14.1		20.2	
Max	4.9		7.0		148.0		213.0		226.0	325.0	104.0		150.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for June, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	0.4	(0.2)	0.6	(0.4)	5.4	(2.4)	7.7	(3.4)	12.6	18.1	4.6	(4.3)	6.5	(6.1)
2														
3														
4														
5	0.9	(0.3)	1.3	(0.4)	42.3	(15.1)	61.0	(21.5)	60.4	86.8	76.2	(22.1)	110.0	(31.4)
6	0.8	(0.2)	1.1	(0.2)	42.8	(12.2)	61.5	(17.5)	57.2	82.1	74.4	(18.8)	107.0	(26.9)
7	0.6	(0.1)	0.9	(0.1)	35.2	(14.0)	50.6	(20.1)	54.6	78.4	57.4	(23.6)	82.4	(33.9)
8	0.4	(0.3)	0.5	(0.4)	27.3	(10.8)	39.2	(15.5)	39.9	57.3	41.0	(15.9)	58.9	(22.8)
9	0.6	(0.2)	0.9	(0.2)	25.1	(6.5)	36.0	(9.3)	33.1	47.5	36.8	(10.7)	52.8	(15.4)
10	0.8	(0.3)	1.1	(0.5)	24.6	(9.1)	35.4	(13.1)	34.8	49.9	34.9	(13.6)	50.2	(19.5)
11	0.6	(0.4)	0.9	(0.5)	22.9	(10.9)	33.0	(15.7)	38.5	55.3	30.7	(15.9)	44.2	(22.8)
12	0.3	(0.1)	0.4	(0.2)	21.3	(8.0)	30.6	(11.6)	31.0	44.5	28.8	(12.1)	41.4	(17.4)
13	0.5	(0.2)	0.7	(0.2)	20.8	(7.1)	30.0	(10.3)	30.3	43.6	27.6	(9.9)	39.8	(14.3)
14	0.4	(0.2)	0.5	(0.3)	22.0	(8.7)	31.7	(12.6)	34.5	49.8	23.9	(8.9)	34.3	(12.8)
15	0.5	(0.2)	0.7	(0.3)	25.5	(8.6)	36.6	(12.4)	36.4	52.3	24.2	(6.3)	34.8	(9.0)
16	0.8	(0.1)	1.1	(0.1)	19.1	(11.1)	27.5	(16.0)	35.4	50.9	17.9	(10.4)	25.8	(15.0)
17	0.9	(0.2)	1.3	(0.3)	15.8	(8.7)	22.7	(12.4)	26.5	38.1	14.4	(7.7)	20.7	(11.0)
18	0.9	(0.1)	1.3	(0.2)	13.3	(9.6)	19.2	(13.8)	28.7	41.3	12.8	(8.9)	18.4	(12.7)
19	0.4	(0.3)	0.6	(0.4)	12.5	(9.1)	17.9	(13.1)	27.9	40.1	12.0	(8.0)	17.2	(11.5)
20	0.3	(0.1)	0.4	(0.2)	14.9	(8.7)	21.3	(12.5)	29.6	42.6	13.1	(7.0)	18.8	(10.0)
21	0.8	(0.7)	1.1	(0.9)	18.9	(10.6)	27.1	(15.2)	41.9	60.2	15.5	(8.2)	22.2	(11.7)
22	1.8	(1.2)	2.6	(1.7)	24.2	(17.6)	34.7	(25.3)	51.0	73.3	18.2	(12.4)	26.2	(17.8)
23	1.4	(0.6)	2.0	(0.8)	19.2	(17.1)	27.5	(24.6)	51.4	73.9	15.3	(12.9)	21.9	(18.6)
24	1.2	(1.1)	1.7	(1.6)	16.3	(12.4)	23.4	(17.8)	47.2	67.7	14.6	(10.6)	20.9	(15.2)
25	0.6	(0.1)	0.8	(0.2)	16.5	(10.9)	25.2	(15.6)	40.9	58.7	17.8	(11.2)	27.1	(16.0)
26	0.7	(0.1)	1.0	(0.2)	19.5	(12.8)	28.8	(18.4)	43.5	62.5	19.7	(12.4)	29.0	(17.8)
27	0.6	(0.1)	0.8	(0.2)	19.7	(13.2)	28.3	(19.0)	50.9	73.1	18.5	(12.1)	26.6	(17.4)
28	0.7	(0.3)	1.1	(0.5)	17.6	(4.8)	25.4	(6.9)	32.0	46.0	18.4	(6.3)	26.5	(9.0)
29	0.7	(0.2)	1.0	(0.4)	18.5	(4.5)	26.6	(6.4)	32.8	47.1	20.5	(6.1)	29.5	(8.7)
30	1.3	(0.2)	1.9	(0.3)	23.3	(7.6)	33.4	(10.8)	45.1	64.7	26.9	(9.2)	38.6	(13.2)
Avg	0.7		1.1		21.7		31.2		38.8	55.8	26.5		38.2	
n	27		27		27		27		27	27	27		27	
SD	0.4		0.5		8		11.5		10.7	15.4	17.4		25	
Min	0.3		0.4		5.4		7.7		12.6	18.1	4.6		6.5	
Max	1.8		2.6		42.8		61.5		60.4	86.8	76.2		110.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for July, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	2.0	(0.4)	2.9	(0.6)	29.8	(9.2)	42.8	(13.1)	50.8	73.0	33.4	(12.1)	48.0	(17.4)
2	2.0	(0.2)	2.9	(0.3)	34.0	(13.3)	48.9	(19.0)	61.9	88.8	35.3	(15.4)	50.7	(22.1)
3	2.1	(0.4)	3.0	(0.6)	34.1	(13.3)	48.9	(19.1)	63.4	90.9	32.7	(14.3)	47.0	(20.6)
4	1.7	(0.3)	2.4	(0.4)	39.6	(14.9)	56.9	(21.3)	71.9	103.0	35.0	(12.3)	50.3	(17.6)
5	2.0	(0.6)	2.8	(0.8)	46.6	(20.0)	66.8	(28.7)	76.6	110.0	41.4	(17.5)	59.4	(25.2)
6	1.6	(0.5)	2.3	(0.7)	42.5	(22.4)	60.9	(32.1)	77.2	111.0	37.4	(17.9)	53.7	(25.7)
7	1.1	(0.2)	1.6	(0.3)	33.3	(19.6)	47.7	(28.0)	75.5	108.0	28.5	(14.8)	40.9	(21.3)
8	1.0	(0.3)	1.5	(0.4)	27.9	(12.8)	40.0	(18.4)	58.1	83.3	27.7	(11.6)	39.8	(16.6)
9	1.3	(0.3)	1.9	(0.5)	29.8	(12.6)	42.7	(18.0)	62.4	89.5	30.3	(13.2)	43.4	(19.0)
10	1.3	(0.4)	1.9	(0.6)	29.5	(15.3)	42.3	(21.8)	64.1	91.8	31.1	(14.1)	44.6	(20.3)
11	1.7	(0.3)	2.4	(0.5)	19.0	(2.7)	27.3	(3.8)	26.0	37.2	22.3	(4.9)	32.0	(6.9)
12	1.6	(0.2)	2.2	(0.3)	18.2	(2.3)	26.1	(3.3)	27.8	39.7	20.1	(3.1)	28.8	(4.4)
13	2.4	(1.3)	3.5	(1.8)	21.8	(3.8)	31.3	(5.4)	33.7	48.2	24.0	(5.3)	34.5	(7.5)
14	8.0	(0.9)	11.5	(1.2)	29.9	(20.9)	43.0	(30.1)	209.0	301.0	25.6	(6.1)	36.8	(8.7)
15	5.3	(0.7)	7.6	(1.1)										
16	3.0	(0.7)	4.4	(1.1)										
17	1.9	(0.4)	2.8	(0.6)	26.3	(4.4)	37.8	(6.4)	34.5	49.5	25.9	(4.3)	37.2	(6.2)
18	2.1	(0.2)	3.0	(0.3)	23.4	(3.5)	33.7	(5.2)	32.0	46.1	24.1	(3.5)	34.6	(5.1)
19	2.6	(0.4)	3.7	(0.6)	24.9	(3.7)	35.9	(5.4)	31.6	45.5	25.8	(3.5)	37.2	(5.2)
20	1.6	(0.3)	2.3	(0.4)	15.9	(5.0)	22.9	(7.1)	24.8	35.6	16.9	(5.0)	24.3	(7.2)
21	2.5	(0.5)	3.6	(0.8)	54.6	(67.9)	84.8	(100.0)	198.0	285.0				
22	1.7	(0.6)	2.4	(0.9)	44.0	(50.1)	63.1	(71.9)	152.0	218.0	18.8	(13.0)	27.0	(18.6)
23	1.5	(0.3)	2.2	(0.4)	19.2	(4.0)	27.5	(5.7)	26.3	37.7	20.2	(4.0)	29.0	(5.7)
24														
25														
26														
27														
28	0.4	(0.2)	0.6	(0.3)	32.7	(17.5)	47.0	(25.1)	54.1	77.7	33.0	(17.7)	47.4	(25.3)
29	0.3	(0.2)	0.4	(0.3)	31.8	(13.5)	45.7	(19.4)	48.0	68.9	31.6	(13.8)	45.3	(19.9)
30	0.4	(0.1)	0.5	(0.2)	25.4	(13.5)	36.6	(19.4)	41.1	59.1	27.8	(13.4)	40.0	(19.3)
31	0.3	(0.2)	0.5	(0.3)	23.5	(13.2)	33.8	(19.0)	39.0	56.0	26.4	(14.5)	38.0	(20.8)
Avg	2		2.8		30.3		43.8		65.6	94.2	28.1		40.4	
n	27		27		25		25		25	25	24		24	
SD	1.5		2.2		9.3		14.1		48.4	69.7	6.1		8.7	
Min	0.3		0.4		15.9		22.9		24.8	35.6	16.9		24.3	
Max	8.0		11.5		54.6		84.8		209.0	301.0	41.4		59.4	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for August, 2009.

Day	Ambient				House 10						House 12			
	ppb		$\mu g\ dsm^{-3}$		ppb		$\mu g\ dsm^{-3}$		ppb	μg/dsm	ppb		$\mu g\ dsm^{-3}$	
1	0.0	(0.2)	0.1	(0.3)	20.8	(12.3)	29.9	(17.7)	35.9	51.5	23.1	(13.9)	33.2	(19.9)
2	0.0	(0.1)	-0.1	(0.2)	17.3	(9.7)	24.9	(13.9)	28.4	40.7	20.7	(11.2)	29.7	(16.1)
3	0.1	(0.2)	0.1	(0.2)	14.6	(8.3)	21.0	(11.9)	25.6	36.8	16.3	(8.9)	23.4	(12.8)
4	0.6	(0.3)	0.8	(0.5)	12.5	(6.6)	18.9	(9.7)	21.8	31.3	14.7	(7.6)	21.0	(10.9)
5	0.2	(0.3)	0.2	(0.4)	13.5	(6.9)	19.5	(9.9)	21.3	30.5	12.0	(7.4)	17.3	(10.6)
6	-0.1	(0.2)	-0.1	(0.2)	11.8	(3.6)	17.0	(5.2)	16.7	23.9	12.4	(4.4)	17.8	(6.3)
7	0.2	(0.3)	0.2	(0.4)	11.3	(4.5)	16.3	(6.5)	17.4	25.0	11.2	(4.4)	16.1	(6.3)
8	0.7	(0.4)	1.0	(0.5)	9.9	(6.4)	14.2	(9.2)	18.0	25.8	8.5	(5.7)	12.1	(8.1)
9	0.8	(0.5)	1.1	(0.7)	8.8	(6.2)	12.7	(8.9)	17.4	25.0	9.1	(7.2)	13.1	(10.4)
10	1.2	(0.5)	1.7	(0.7)	8.4	(6.8)	12.0	(9.8)	22.2	31.8	13.6	(10.5)	19.6	(15.1)
11	1.1	(0.9)	1.6	(1.2)	6.8	(4.1)	9.7	(5.9)	12.7	18.3	12.7	(7.9)	18.3	(11.4)
12	-0.2	(0.2)	-0.2	(0.3)	6.8	(4.0)	9.7	(5.8)	12.4	17.9	9.8	(6.0)	14.1	(8.6)
13	0.0	(0.2)	0.0	(0.3)	6.1	(4.1)	8.8	(5.9)	11.7	16.8	7.8	(5.2)	11.2	(7.4)
14	0.0	(0.3)	0.1	(0.5)	7.0	(4.0)	10.0	(5.7)	11.8	16.9	7.4	(4.3)	10.7	(6.2)
15	0.3	(0.3)	0.4	(0.5)	7.2	(4.5)	10.3	(6.5)	15.5	22.3	7.0	(4.3)	10.0	(6.2)
16	0.3	(0.1)	0.4	(0.2)										
17	0.9	(0.2)	1.3	(0.3)										
18	0.8	(0.2)	1.2	(0.3)	8.1	(5.1)	11.6	(7.4)	17.1	24.6	7.2	(4.5)	10.3	(6.4)
19	0.6	(0.2)	0.8	(0.2)	9.3	(5.6)	13.4	(8.0)	19.3	27.8	8.1	(4.6)	11.7	(6.6)
20	0.5	(0.1)	0.7	(0.2)	14.1	(8.1)	20.2	(11.7)	27.1	39.0	11.4	(6.1)	16.4	(8.7)
21	1.3	(0.3)	1.9	(0.5)	16.7	(9.7)	24.0	(14.0)	35.4	50.9	12.9	(6.9)	18.5	(10.0)
22	1.1	(0.5)	1.5	(0.7)	14.9	(4.3)	21.4	(6.2)	26.3	37.8	12.3	(4.0)	17.6	(5.7)
23	1.8	(0.3)	2.5	(0.5)	24.6	(9.2)	35.3	(13.1)	42.8	61.3	22.6	(9.3)	32.5	(13.3)
24	1.5	(0.3)	2.1	(0.4)	36.4	(18.4)	52.3	(26.3)	72.4	104.0	31.9	(15.8)	45.7	(22.6)
25	1.5	(0.4)	2.2	(0.6)	35.8	(19.4)	51.4	(27.8)	71.9	103.0	35.4	(20.6)	50.8	(29.6)
26	1.9	(0.2)	2.8	(0.3)	43.3	(20.3)	62.1	(29.2)	79.0	113.0	38.2	(21.0)	55.1	(30.1)
27	4.0	(1.0)	5.8	(1.4)	38.4	(20.3)	55.4	(29.0)	83.3	119.0	35.9	(17.8)	51.8	(25.4)
28	3.1	(1.1)	4.4	(1.6)	35.1	(22.5)	50.4	(32.2)	82.3	118.0	32.5	(19.4)	46.6	(27.8)
29	2.9	(1.2)	4.1	(1.8)	28.4	(14.9)	40.8	(21.3)	61.8	88.7	28.7	(15.5)	41.2	(22.2)
30	2.4	(0.6)	3.5	(0.8)	22.2	(8.2)	31.9	(11.8)	44.6	64.0	24.8	(10.6)	35.6	(15.2)
31	3.1	(0.3)	4.4	(0.4)	32.0	(15.1)	45.9	(21.7)	72.9	105.0	33.0	(16.6)	47.4	(23.8)
Avg	1.1		1.5		18		25.9		35.3	50.7	18		25.8	
n	31		31		29		29		29	29	29		29	
SD	1.1		1.5		11.1		16		24	34.3	10.1		14.5	
Min	-0.2		-0.2		6.1		8.8		11.7	16.8	7.0		10.0	
Max	4.0		5.8		43.3		62.1		83.3	119.0	38.2		55.1	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for September, 2009.

Day	Ambient				House 10						House 12			
	ppb		µg dsm^{-3}		ppb		µg dsm^{-3}		ppb	µg/dsm	ppb		µg dsm^{-3}	
1	3.5	(0.6)	5.1	(0.8)	32.9	(12.8)	47.3	(18.4)	66.3	95.2	35.5	(15.9)	51.0	(22.7)
2	1.8	(0.2)	2.6	(0.3)	25.1	(4.3)	36.0	(6.1)	37.5	53.7	27.1	(5.9)	38.8	(8.4)
3	1.6	(0.2)	2.3	(0.3)	20.1	(2.5)	28.9	(3.5)	26.3	37.7	21.8	(3.2)	31.3	(4.5)
4	1.3	(0.3)	1.9	(0.4)	20.7	(4.4)	29.7	(6.2)	32.3	46.3	23.0	(6.3)	32.9	(9.0)
5	1.5	(0.4)	2.1	(0.5)	30.8	(9.8)	44.2	(14.0)	53.9	77.3	28.9	(9.4)	41.4	(13.5)
6	1.2	(0.6)	1.7	(0.8)	24.9	(9.4)	35.8	(13.5)	50.6	72.5	28.1	(10.9)	40.2	(15.7)
7	1.2	(0.6)	1.7	(0.9)	23.0	(4.0)	33.0	(5.8)	32.4	46.4	25.9	(6.5)	37.1	(9.3)
8	2.1	(0.9)	2.9	(1.3)	21.9	(4.5)	31.3	(6.4)	32.9	47.1	24.0	(5.3)	34.3	(7.5)
9	1.8	(0.4)	2.6	(0.6)							23.9	(6.3)		
10	2.4	(0.5)	3.4	(0.7)	14.2	(7.0)	21.3	(9.7)	23.7	34.0				
11	3.0	(0.6)	4.3	(0.8)	18.9	(3.0)	27.1	(4.3)	26.1	37.6	19.3	(2.7)	27.7	(4.0)
12	1.8	(0.4)	2.6	(0.5)	17.0	(2.4)	24.4	(3.4)	23.4	33.5	17.6	(3.3)	25.2	(4.8)
13	1.0	(0.1)	1.5	(0.1)	18.2	(7.6)	26.1	(10.9)	31.4	45.0				
14	1.9	(0.9)	2.7	(1.2)	18.5	(5.5)	26.5	(7.8)	36.5	52.5	17.4	(4.6)	24.9	(6.5)
15	0.6	(0.5)	0.9	(0.7)	9.4	(7.5)	13.4	(10.7)	51.9	74.4	9.1	(3.3)	13.0	(4.9)
16	0.3	(0.2)	0.4	(0.3)	2.7	(1.1)	3.9	(1.6)	5.6	8.0	2.8	(1.4)	4.1	(2.0)
17	0.1	(0.3)	0.2	(0.4)	2.2	(1.1)	3.1	(1.6)	8.2	11.7	1.9	(0.7)	2.7	(1.0)
18	0.8	(0.4)	1.2	(0.6)	2.0	(1.5)	2.8	(2.1)	7.5	10.8	2.4	(2.0)	3.4	(2.9)
19	0.9	(0.4)	1.3	(0.6)	1.7	(2.1)	2.5	(3.0)	12.1	17.4	1.1	(0.9)	1.5	(1.2)
20	0.4	(0.7)	0.6	(1.0)	1.0	(0.6)	1.4	(0.8)	2.5	3.6	0.6	(0.5)	0.9	(0.7)
21	1.3	(0.5)	1.8	(0.7)	1.1	(0.7)	1.5	(1.0)	2.9	4.1	1.1	(0.7)	1.5	(1.0)
22	2.9	(1.8)	4.2	(2.6)	1.4	(1.5)	2.0	(2.2)	6.0	8.6	1.2	(1.2)	1.7	(1.8)
23	0.4	(0.6)	0.5	(0.9)	1.1	(1.1)	1.6	(1.6)	5.2	7.4	1.0	(1.1)	1.4	(1.5)
24	-0.1	(0.2)	-0.2	(0.3)	0.6	(0.5)	0.9	(0.7)	2.1	3.0	0.6	(0.5)	0.8	(0.8)
25	0.5	(0.8)	0.8	(1.2)	1.7	(1.5)	2.4	(2.2)	8.2	11.7	1.5	(1.4)	2.2	(2.0)
26	4.5	(0.8)	6.5	(1.1)	2.4	(2.1)	3.5	(3.0)	6.7	9.6	2.5	(2.3)	3.6	(3.2)
27	2.3	(1.2)	3.2	(1.8)	3.8	(3.4)	5.5	(4.9)	12.1	17.3	3.5	(3.2)	5.0	(4.6)
28	0.7	(0.6)	1.0	(0.9)	1.9	(0.9)	2.7	(1.2)	4.0	5.7	1.6	(0.8)	2.2	(1.2)
29	-0.2	(0.2)	-0.3	(0.2)	3.1	(0.6)	4.4	(0.9)	4.6	6.6	3.3	(0.7)	4.8	(1.0)
30	0.4	(0.9)	0.6	(1.3)	4.6	(0.6)	6.5	(0.9)	6.2	8.9	4.9	(0.9)	7.0	(1.3)
Avg	1.4		2		11.3		16.2		21.3	30.6	11.8		16.3	
n	30		30		29		29		29	29	28		27	
SD	1.1		1.6		10.4		14.9		18	25.9	11.4		16.4	
Min	-0.2		-0.3		0.6		0.9		2.1	3.0	0.6		0.8	
Max	4.5		6.5		32.9		47.3		66.3	95.2	35.5		51.0	

Table E8. Daily means (SD) of H2S concentrations at Site CA1B for October, 2009.

Day	Ambient				House 10						House 12			
	ppb		μg dsm^{-3}		ppb		μg dsm^{-3}		ppb	μg/dsm	ppb		μg dsm^{-3}	
1	4.1	(2.8)	5.8	(4.0)	6.1	(2.6)	8.7	(3.7)	13.1	18.7	6.4	(2.3)	9.2	(3.4)
2	0.9	(0.3)	1.3	(0.4)	6.9	(3.8)	9.9	(5.5)	13.1	18.8	7.9	(4.2)	11.3	(6.0)
3	0.3	(0.5)	0.4	(0.7)	5.5	(1.5)	7.9	(2.2)	9.6	13.8	7.0	(1.7)	10.0	(2.5)
4	1.0	(1.1)	1.4	(1.5)	5.3	(0.9)	7.6	(1.3)	8.1	11.6	6.2	(1.0)	8.8	(1.5)
5	0.5	(0.5)	0.7	(0.7)	6.2	(1.2)	8.9	(1.7)	10.1	14.5	6.3	(0.8)	9.1	(1.2)
6	0.9	(0.7)	1.3	(1.0)	6.9	(3.1)	9.9	(4.4)	15.5	22.2	6.0	(2.6)	8.6	(3.8)
7	0.3	(0.2)	0.4	(0.3)										
8	-0.2	(0.2)	-0.3	(0.3)	6.3	(2.2)	9.0	(3.2)	11.2	16.1	4.6	(1.8)	6.6	(2.5)
9	0.4	(0.5)	0.6	(0.8)	6.6	(2.3)	9.4	(3.3)	9.4	13.5	5.3	(1.7)	7.6	(2.4)
10	0.8	(0.4)	1.1	(0.5)	7.9	(2.8)	11.3	(4.0)	11.6	16.7	6.3	(2.2)	9.0	(3.2)
11	0.1	(0.3)	0.1	(0.5)	9.5	(2.1)	13.6	(3.0)	12.5	18.0	8.3	(1.7)	12.0	(2.4)
12	0.3	(0.1)	0.4	(0.2)	12.5	(2.0)	18.0	(2.9)	16.3	23.4	12.1	(1.2)	17.3	(1.8)
13					15.9	(2.4)	22.9	(3.5)	20.8	29.9	16.9	(1.7)	24.3	(2.4)
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														
26														
27														
28														
29														
30														
31														
Avg	0.8		1.1		8		11.4		12.6	18.1	7.8		11.1	
n	12		12		12		12		12	12	12		12	
SD	1.1		1.5		3.1		4.4		3.4	4.9	3.3		4.8	
Min	-0.2		-0.3		5.3		7.6		8.1	11.6	4.6		6.6	
Max	4.1		5.8		15.9		22.9		20.8	29.9	16.9		24.3	

Table E9. H2S emissions

Table E9. Daily means (SD) of H2S emissions at Site CA1B for November, 2007.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15	0.22 (0.87)	0.14 (0.57)			0.12 (0.96)	0.08 (0.63)		
16	0.47 (0.72)	0.31 (0.47)	22.40 (34.20)	168.00 (257.00)	0.37 (0.65)	0.24 (0.43)	17.20 (30.60)	128.00 (227.00)
17	0.66 (0.96)	0.43 (0.63)	31.50 (45.60)	269.00 (391.00)	0.56 (0.93)	0.37 (0.61)	26.40 (43.80)	225.00 (377.00)
18	0.94 (1.57)	0.61 (1.03)	44.60 (74.70)	401.00 (671.00)	1.04 (1.89)	0.68 (1.24)	49.20 (89.50)	443.00 (804.00)
19	1.81 (2.71)	1.19 (1.78)	86.30 (129.00)	741.00 (1100.00)	2.20 (3.06)	1.44 (2.01)	104.00 (145.00)	895.00 (1240.00)
20					2.49 (3.79)	1.64 (2.49)	118.00 (180.00)	898.00 (1360.00)
21					2.97 (4.30)	1.95 (2.82)	141.00 (204.00)	902.00 (1310.00)
22								
23								
24	4.60 (6.18)	3.01 (4.05)	220.00 (296.00)	737.00 (981.00)	4.99 (6.91)	3.27 (4.53)	238.00 (329.00)	804.00 (1100.00)
25	8.60 (10.90)	5.64 (7.12)	412.00 (520.00)	1140.00 (1420.00)	8.20 (11.60)	5.38 (7.58)	391.00 (551.00)	1090.00 (1520.00)
26	12.90 (16.10)	8.47 (10.50)	620.00 (771.00)	1440.00 (1780.00)	11.20 (14.20)	7.37 (9.30)	536.00 (676.00)	1250.00 (1580.00)
27	14.20 (16.80)	9.33 (11.00)	683.00 (809.00)	1340.00 (1600.00)	11.90 (13.70)	7.80 (9.01)	567.00 (655.00)	1120.00 (1310.00)
28	12.10 (14.40)	7.94 (9.44)	582.00 (691.00)	973.00 (1160.00)	11.90 (12.80)	7.83 (8.41)	570.00 (612.00)	958.00 (1020.00)
29	11.60 (12.80)	7.61 (8.41)	557.00 (616.00)	804.00 (891.00)	12.10 (12.70)	7.91 (8.32)	576.00 (606.00)	836.00 (879.00)
30	15.20 (16.50)	9.95 (10.80)	730.00 (794.00)	916.00 (996.00)	15.40 (16.60)	10.10 (10.90)	737.00 (795.00)	930.00 (1000.00)
Avg	6.9	4.6	363.0	812.0	6.1	4.0	313.0	807.0
n	12	12	11	11	14	14	13	13
SD	5.8	3.8	272.0	394.0	5.3	3.4	247.0	325.0
Min	0.2	0.1	22.4	168.0	0.1	0.1	17.2	128.0
Max	15.2	10.0	730.0	1440.0	15.4	10.1	737.0	1250.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for December, 2007.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}
1	16.80 (16.90)	11.00 (11.10)	808.00 (813.00)	890.00 (890.00)	17.30 (17.50)	11.40 (11.50)	829.00 (836.00)	917.00 (918.00)
2	23.60 (21.10)	15.50 (13.80)	1130.00 (1010.00)	1110.00 (986.00)	24.60 (22.20)	16.20 (14.60)	1180.00 (1060.00)	1160.00 (1040.00)
3	33.00 (24.80)	21.70 (16.20)	1590.00 (1190.00)	1390.00 (1040.00)	34.30 (26.20)	22.50 (17.20)	1640.00 (1250.00)	1440.00 (1090.00)
4	45.30 (31.90)	29.70 (20.90)	2180.00 (1540.00)	1720.00 (1200.00)	45.40 (35.20)	29.80 (23.10)	2170.00 (1690.00)	1720.00 (1330.00)
5	68.40 (55.10)	44.80 (36.10)	3290.00 (2650.00)	2350.00 (1870.00)	65.10 (53.60)	42.70 (35.20)	3120.00 (2570.00)	2240.00 (1820.00)
6	78.90 (71.90)	51.70 (47.10)	3800.00 (3470.00)	2480.00 (2250.00)	74.40 (68.00)	48.80 (44.60)	3560.00 (3260.00)	2330.00 (2130.00)
7	93.00 (72.80)	61.00 (47.70)	4480.00 (3510.00)	2680.00 (2100.00)	84.30 (65.20)	55.30 (42.80)	4040.00 (3120.00)	2420.00 (1870.00)
8	83.70 (60.90)	54.90 (40.00)	4040.00 (2940.00)	2220.00 (1630.00)	79.90 (59.70)	52.40 (39.20)	3830.00 (2860.00)	2110.00 (1590.00)
9	70.50 (54.00)	46.20 (35.40)	3400.00 (2610.00)	1730.00 (1320.00)	68.80 (52.30)	45.10 (34.30)	3300.00 (2500.00)	1680.00 (1280.00)
10	70.40 (48.50)	46.10 (31.80)	3400.00 (2340.00)	1620.00 (1130.00)	65.80 (45.60)	43.10 (29.90)	3150.00 (2190.00)	1510.00 (1060.00)
11								
12	77.40 (61.20)	50.80 (40.20)	3740.00 (2960.00)	1540.00 (1210.00)	78.40 (61.90)	51.40 (40.60)	3760.00 (2970.00)	1550.00 (1220.00)
13	76.90 (53.20)	50.50 (34.90)	3720.00 (2570.00)	1440.00 (999.00)	77.10 (55.00)	50.50 (36.10)	3690.00 (2640.00)	1430.00 (1040.00)
14	78.20 (48.00)	51.30 (31.50)	3780.00 (2320.00)	1370.00 (837.00)	59.60 (36.40)	39.10 (23.90)	2860.00 (1750.00)	1040.00 (636.00)
15	83.10 (47.80)	54.50 (31.40)	4010.00 (2310.00)	1380.00 (791.00)	59.30 (34.10)	38.90 (22.30)	2850.00 (1640.00)	979.00 (561.00)
16	84.00 (42.00)	55.10 (27.50)	4060.00 (2030.00)	1320.00 (658.00)	56.70 (28.80)	37.20 (18.90)	2720.00 (1380.00)	888.00 (451.00)
17	90.10 (47.60)	59.10 (31.20)	4360.00 (2300.00)	1350.00 (709.00)	63.00 (33.50)	41.30 (21.90)	3030.00 (1610.00)	937.00 (496.00)
18	91.70 (53.50)	60.10 (35.10)	4430.00 (2590.00)	1300.00 (761.00)	86.00 (53.10)	56.40 (34.80)	4130.00 (2550.00)	1220.00 (745.00)
19	91.00 (46.50)	59.70 (30.50)	4400.00 (2250.00)	1240.00 (632.00)	94.20 (49.00)	61.80 (32.10)	4530.00 (2350.00)	1270.00 (664.00)
20	98.80 (45.60)	64.80 (29.90)	4780.00 (2210.00)	1280.00 (594.00)	91.70 (43.90)	60.10 (28.80)	4410.00 (2110.00)	1190.00 (570.00)
21	83.90 (42.10)	55.00 (27.60)	4060.00 (2040.00)	1040.00 (526.00)	78.60 (42.80)	51.50 (28.10)	3780.00 (2060.00)	973.00 (529.00)
22	82.40 (44.70)	54.10 (29.30)	4000.00 (2170.00)	985.00 (531.00)	84.10 (48.40)	55.20 (31.70)	4050.00 (2330.00)	999.00 (572.00)
23								
24	106.00 (47.60)	69.60 (31.20)	5150.00 (2310.00)	1180.00 (531.00)	97.70 (48.40)	64.10 (31.80)	4710.00 (2330.00)	1080.00 (539.00)
25	103.00 (41.40)	67.30 (27.20)	4980.00 (2010.00)	1100.00 (443.00)	94.70 (47.10)	62.10 (30.90)	4560.00 (2270.00)	1010.00 (498.00)
26	96.80 (34.00)	63.50 (22.30)	4700.00 (1650.00)	1010.00 (356.00)	96.10 (40.30)	63.00 (26.50)	4630.00 (1940.00)	993.00 (420.00)
27	86.10 (35.20)	56.40 (23.10)	4180.00 (1710.00)	865.00 (351.00)	84.70 (36.90)	55.50 (24.20)	4080.00 (1780.00)	846.00 (366.00)
28	92.00 (30.40)	60.30 (19.90)	4470.00 (1480.00)	900.00 (299.00)	105.00 (34.70)	68.90 (22.80)	5060.00 (1680.00)	1020.00 (340.00)
29	99.30 (26.70)	65.10 (17.50)	4830.00 (1300.00)	944.00 (255.00)	112.00 (26.40)	73.10 (17.30)	5380.00 (1280.00)	1050.00 (250.00)
30	73.10 (15.10)	47.90 (9.93)	3560.00 (737.00)	678.00 (144.00)	80.50 (23.60)	52.80 (15.50)	3890.00 (1140.00)	742.00 (222.00)
31	59.00 (14.10)	38.70 (9.23)	2870.00 (687.00)	534.00 (127.00)	42.60 (44.00)	27.90 (28.80)		
Avg	77.1	50.6	3730.0	1370.0	72.5	47.5	3530.0	1310.0
n	29	29	29	29	29	29	28	28
SD	22.1	14.5	1070.0	513.0	22.8	15.0	1090.0	465.0
Min	16.8	11.0	808.0	534.0	17.3	11.4	829.0	742.0
Max	106.0	69.6	5150.0	2680.0	112.0	73.1	5380.0	2420.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for January, 2008.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}
1	77.10 (45.60)	50.60 (29.90)	3640.00 (1980.00)	660.00 (354.00)	19.00 (14.60)	12.40 (9.54)		
2	41.70 (53.20)	27.40 (34.90)			12.90 (18.90)	8.44 (12.40)		
3	33.40 (33.40)	21.90 (21.90)			9.74 (41.30)	6.38 (27.10)		
4	13.10 (24.40)	8.60 (16.00)			9.70 (18.30)	6.36 (12.00)		
5	9.69 (19.70)	6.35 (12.90)			6.07 (12.40)	3.98 (8.13)		
6	8.32 (14.50)	5.45 (9.51)	911.00 (1590.00)	6570.00 (11400.00)	5.60 (9.66)	3.67 (6.33)		
7	5.50 (8.25)	3.60 (5.41)	465.00 (804.00)	3840.00 (6530.00)	4.17 (6.11)	2.73 (4.01)		
8	3.49 (4.52)	2.29 (2.96)	166.00 (215.00)	1490.00 (1920.00)	2.97 (3.83)	1.95 (2.51)	140.00 (180.00)	993.00 (1270.00)
9	1.75 (2.59)	1.15 (1.70)	83.20 (123.00)	727.00 (1080.00)	1.60 (2.33)	1.05 (1.53)	75.70 (110.00)	624.00 (905.00)
10	1.84 (2.64)	1.21 (1.73)	87.80 (126.00)	683.00 (984.00)	1.62 (2.34)	1.06 (1.54)	76.60 (111.00)	685.00 (993.00)
11	1.54 (2.05)	1.01 (1.35)	73.70 (98.10)	481.00 (640.00)	1.34 (1.82)	0.88 (1.19)	63.30 (86.30)	554.00 (752.00)
12	2.01 (3.32)	1.32 (2.18)	96.30 (159.00)	514.00 (830.00)	1.51 (2.35)	0.99 (1.54)	71.50 (112.00)	565.00 (875.00)
13	2.26 (4.03)	1.48 (2.64)	108.00 (193.00)	465.00 (824.00)	1.63 (3.02)	1.07 (1.98)	77.40 (143.00)	512.00 (945.00)
14	0.67 (3.01)	0.44 (1.98)	32.00 (144.00)	112.00 (534.00)	0.54 (2.96)	0.35 (1.94)	25.70 (141.00)	136.00 (801.00)
15	-0.15 (0.52)	-0.10 (0.34)	-7.14 (25.00)	-21.10 (71.90)	-0.05 (0.40)	-0.03 (0.27)	-2.35 (19.20)	-10.50 (83.40)
16	1.12 (2.68)	0.73 (1.76)	53.50 (129.00)	122.00 (295.00)	0.48 (1.56)	0.32 (1.02)	22.90 (74.30)	76.60 (252.00)
17	4.60 (8.46)	3.02 (5.55)	221.00 (406.00)	433.00 (790.00)	2.46 (5.52)	1.61 (3.62)	117.00 (263.00)	330.00 (736.00)
18	4.80 (8.69)	3.14 (5.70)	230.00 (417.00)	384.00 (696.00)	3.30 (5.59)	2.17 (3.67)	157.00 (266.00)	375.00 (637.00)
19	8.03 (11.70)	5.26 (7.65)	386.00 (561.00)	559.00 (800.00)	5.83 (7.26)	3.82 (4.76)	278.00 (346.00)	561.00 (686.00)
20	7.66 (10.70)	5.02 (6.99)	368.00 (513.00)	473.00 (660.00)	6.48 (8.42)	4.25 (5.52)	309.00 (402.00)	537.00 (695.00)
21	8.24 (12.00)	5.40 (7.89)	396.00 (579.00)	443.00 (639.00)	6.78 (9.56)	4.44 (6.27)	324.00 (457.00)	481.00 (673.00)
22	14.00 (17.90)	9.18 (11.70)	674.00 (860.00)	675.00 (866.00)	10.90 (14.10)	7.13 (9.25)	519.00 (674.00)	675.00 (878.00)
23	15.00 (19.20)	9.83 (12.60)	722.00 (924.00)	644.00 (825.00)	14.40 (18.00)	9.47 (11.80)	691.00 (859.00)	788.00 (978.00)
24	13.90 (18.50)	9.14 (12.10)	671.00 (891.00)	541.00 (724.00)	15.30 (19.40)	10.00 (12.70)	732.00 (931.00)	740.00 (943.00)
25	19.80 (20.90)	13.00 (13.70)	955.00 (1000.00)	694.00 (733.00)	20.60 (21.60)	13.50 (14.20)	986.00 (1040.00)	890.00 (943.00)
26	27.50 (25.80)	18.00 (16.90)	1330.00 (1240.00)	876.00 (817.00)	25.50 (23.30)	16.70 (15.30)	1220.00 (1120.00)	990.00 (904.00)
27	26.30 (24.90)	17.30 (16.30)	1270.00 (1200.00)	771.00 (735.00)	24.90 (22.80)	16.30 (15.00)	1190.00 (1090.00)	876.00 (809.00)
28	33.70 (37.10)	22.10 (24.30)	1630.00 (1790.00)	902.00 (981.00)	34.30 (40.40)	22.50 (26.50)	1650.00 (1940.00)	1090.00 (1270.00)
29	32.00 (38.50)	21.00 (25.20)	1540.00 (1860.00)	795.00 (959.00)	34.30 (43.30)	22.50 (28.40)	1650.00 (2080.00)	1010.00 (1270.00)
30	36.20 (39.40)	23.70 (25.80)	1750.00 (1900.00)	835.00 (907.00)	37.20 (41.90)	24.40 (27.50)	1790.00 (2010.00)	1000.00 (1130.00)
31	42.00 (47.00)	27.60 (30.80)	2030.00 (2270.00)	902.00 (1010.00)	44.00 (48.80)	28.90 (32.00)	2120.00 (2350.00)	1100.00 (1210.00)
Avg	16.0	10.5	736.0	947.0	11.8	7.7	595.0	649.0
n	31	31	27	27	31	31	24	24
SD	17.2	11.3	821.0	1290.0	12.2	8.0	650.0	310.0
Min	-0.1	-0.1	-7.1	-21.1	0.0	0.0	-2.4	-10.5
Max	77.1	50.6	3640.0	6570.0	44.0	28.9	2120.0	1100.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for February, 2008.

Day	House 10				House 12			
	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$\mu g\ d^{-1}hd^{-1}$	$mg\ d^{-1}AU^{-1}$	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$\mu g\ d^{-1}hd^{-1}$	$mg\ d^{-1}AU^{-1}$
1								
2								
3								
4								
5	72.70 (52.10)	47.70 (34.20)	3530.00 (2530.00)	1150.00 (823.00)	67.00 (47.40)	43.90 (31.10)	3230.00 (2290.00)	1190.00 (839.00)
6	85.90 (51.30)	56.30 (33.60)	4170.00 (2490.00)	1300.00 (774.00)	84.50 (54.50)	55.40 (35.70)	4080.00 (2630.00)	1420.00 (910.00)
7	94.80 (52.90)	62.20 (34.70)	4600.00 (2570.00)	1360.00 (760.00)	92.20 (58.60)	60.50 (38.40)	4460.00 (2830.00)	1470.00 (933.00)
8	90.20 (48.60)	59.20 (31.90)	4380.00 (2360.00)	1240.00 (669.00)	88.20 (51.00)	57.80 (33.50)	4260.00 (2470.00)	1330.00 (773.00)
9	114.00 (56.80)	75.10 (37.30)	5560.00 (2760.00)	1500.00 (741.00)	108.00 (56.40)	70.60 (37.00)	5210.00 (2730.00)	1550.00 (804.00)
10	125.00 (54.60)	82.20 (35.80)	6090.00 (2650.00)	1580.00 (687.00)	126.00 (58.20)	82.80 (38.20)	6110.00 (2820.00)	1730.00 (793.00)
11	110.00 (47.70)	72.20 (31.30)	5360.00 (2320.00)	1330.00 (579.00)	114.00 (48.90)	74.80 (32.10)	5520.00 (2370.00)	1500.00 (652.00)
12	114.00 (40.80)	74.60 (26.70)	5540.00 (1980.00)	1320.00 (475.00)	109.00 (34.10)	71.40 (22.40)	5280.00 (1650.00)	1370.00 (430.00)
13	117.00 (30.90)	76.40 (20.20)	5670.00 (1500.00)	1310.00 (348.00)	106.00 (35.50)	69.70 (23.30)	5150.00 (1720.00)	1290.00 (431.00)
14	80.00 (32.90)	52.50 (21.60)	3900.00 (1600.00)	868.00 (362.00)	71.70 (35.20)	47.00 (23.10)	3480.00 (1710.00)	835.00 (415.00)
15	93.20 (31.60)	61.10 (20.70)	4540.00 (1540.00)	975.00 (327.00)	87.50 (36.90)	57.40 (24.20)	4250.00 (1790.00)	980.00 (409.00)
16	118.00 (26.80)	77.10 (17.60)	5740.00 (1310.00)	1190.00 (271.00)	118.00 (34.10)	77.70 (22.40)	5750.00 (1660.00)	1280.00 (367.00)
17	126.00 (27.60)	82.90 (18.10)	6170.00 (1350.00)	1250.00 (272.00)	134.00 (29.50)	87.90 (19.30)	6510.00 (1430.00)	1400.00 (311.00)
18	123.00 (25.00)	80.50 (16.40)	6000.00 (1220.00)	1180.00 (241.00)	116.00 (25.80)	76.20 (16.90)	5650.00 (1260.00)	1180.00 (266.00)
19	104.00 (21.90)	68.20 (14.40)	5090.00 (1070.00)	975.00 (209.00)	103.00 (21.50)	67.70 (14.10)	5030.00 (1050.00)	1020.00 (215.00)
20	94.50 (7.47)	62.00 (4.90)	4640.00 (367.00)	866.00 (69.70)	115.00 (10.50)	75.10 (6.88)	5590.00 (512.00)	1100.00 (97.30)
21	46.60 (44.70)	30.60 (29.30)	2310.00 (2240.00)		91.30 (30.40)	59.90 (19.90)	4570.00 (1270.00)	877.00 (249.00)
22	98.60 (64.00)	64.60 (42.00)			48.00 (53.50)	31.50 (35.10)		
23	44.80 (9.67)	29.40 (6.34)			44.80 (26.00)	29.40 (17.00)		
24	40.10 (5.45)	26.30 (3.57)			35.00 (3.75)	23.00 (2.46)		
25	32.40 (18.70)	21.30 (12.30)			32.60 (9.95)	21.40 (6.52)		
26	29.30 (45.00)	19.20 (29.50)			24.10 (29.40)	15.80 (19.30)		
27	33.40 (59.60)	21.90 (39.10)			23.90 (41.80)	15.70 (27.40)		
28	33.50 (50.70)	22.00 (33.20)			23.60 (34.40)	15.50 (22.60)		
29	24.70 (31.80)	16.20 (20.90)	1160.00 (1500.00)	8440.00 (10600.00)	18.30 (23.20)	12.00 (15.20)	861.00 (1090.00)	6240.00 (7900.00)
Avg	81.8	53.7	4690.0	1640.0	79.3	52.0	4720.0	1540.0
n	25	25	18	17	25	25	18	18
SD	34.5	22.6	1300.0	1710.0	36.6	24.0	1270.0	1160.0
Min	24.7	16.2	1160.0	866.0	18.3	12.0	861.0	835.0
Max	126.0	82.9	6170.0	8440.0	134.0	87.9	6510.0	6240.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for March, 2008.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}
1	16.10 (20.20)	10.50 (13.20)	756.00 (951.00)	6360.00 (7970.00)	9.56 (19.20)	6.27 (12.60)	450.00 (903.00)	3790.00 (7560.00)
2	13.70 (18.80)	9.00 (12.30)	647.00 (885.00)	5820.00 (7960.00)	9.44 (14.50)	6.19 (9.48)	445.00 (682.00)	4000.00 (6130.00)
3	16.70 (17.70)	10.90 (11.60)	788.00 (836.00)	6830.00 (7280.00)	12.60 (13.20)	8.29 (8.68)	597.00 (626.00)	5180.00 (5460.00)
4	12.60 (14.50)	8.23 (9.52)	594.00 (687.00)	4550.00 (5220.00)	8.93 (9.92)	5.85 (6.50)	422.00 (469.00)	3240.00 (3580.00)
5	11.70 (14.10)	7.64 (9.25)	552.00 (668.00)	3550.00 (4310.00)	8.69 (10.20)	5.70 (6.72)	412.00 (485.00)	2650.00 (3130.00)
6	10.30 (11.70)	6.74 (7.68)	487.00 (555.00)	2550.00 (2880.00)	8.14 (8.75)	5.33 (5.74)	385.00 (414.00)	2020.00 (2160.00)
7	11.20 (12.50)	7.35 (8.19)	532.00 (592.00)	2250.00 (2460.00)	8.11 (9.20)	5.32 (6.03)	385.00 (436.00)	1630.00 (1820.00)
8	12.60 (14.50)	8.26 (9.51)	598.00 (688.00)	2060.00 (2360.00)	8.07 (10.20)	5.29 (6.72)	383.00 (486.00)	1330.00 (1690.00)
9	17.10 (18.40)	11.20 (12.00)	811.00 (871.00)	2300.00 (2470.00)	10.10 (12.50)	6.61 (8.20)	479.00 (594.00)	1360.00 (1710.00)
10	22.80 (21.40)	14.90 (14.10)	1080.00 (1020.00)	2560.00 (2430.00)	11.80 (12.00)	7.75 (7.88)	561.00 (571.00)	1330.00 (1370.00)
11	32.60 (34.70)	21.40 (22.80)	1550.00 (1650.00)	3080.00 (3260.00)	14.20 (15.30)	9.31 (10.00)	676.00 (727.00)	1350.00 (1450.00)
12	41.60 (45.00)	27.30 (29.50)	1980.00 (2140.00)	3360.00 (3640.00)	16.10 (17.80)	10.60 (11.60)	768.00 (845.00)	1300.00 (1440.00)
13	46.20 (44.60)	30.30 (29.20)	2200.00 (2120.00)	3230.00 (3170.00)	21.50 (21.00)	14.10 (13.80)	1020.00 (1000.00)	1500.00 (1470.00)
14	45.70 (43.50)	29.90 (28.60)	2170.00 (2070.00)	2770.00 (2680.00)	24.60 (24.90)	16.10 (16.30)	1170.00 (1190.00)	1500.00 (1540.00)
15	49.30 (45.80)	32.30 (30.10)	2350.00 (2180.00)	2630.00 (2460.00)	24.20 (24.30)	15.90 (15.90)	1160.00 (1160.00)	1300.00 (1300.00)
16	43.50 (42.20)	28.50 (27.70)	2070.00 (2010.00)	2060.00 (2020.00)	24.20 (23.10)	15.90 (15.10)	1160.00 (1100.00)	1150.00 (1110.00)
17	47.30 (36.70)	31.00 (24.10)	2250.00 (1750.00)	2000.00 (1570.00)	25.90 (20.50)	17.00 (13.50)	1240.00 (980.00)	1100.00 (880.00)
18	55.00 (40.40)	36.10 (26.50)	2620.00 (1930.00)	2090.00 (1540.00)	30.00 (21.80)	19.60 (14.30)	1430.00 (1040.00)	1140.00 (831.00)
19	83.30 (74.20)	54.60 (48.70)	3980.00 (3540.00)	2870.00 (2540.00)	47.40 (39.30)	31.10 (25.80)	2270.00 (1880.00)	1630.00 (1350.00)
20	97.20 (109.00)	63.70 (71.70)	4640.00 (5220.00)	3060.00 (3440.00)	66.50 (61.10)	43.60 (40.10)	3190.00 (2930.00)	2100.00 (1930.00)
21	89.90 (102.00)	59.00 (66.60)	4300.00 (4860.00)	2600.00 (2950.00)	73.60 (65.90)	48.30 (43.20)	3530.00 (3160.00)	2130.00 (1920.00)
22	82.60 (85.70)	54.20 (56.20)	3960.00 (4100.00)	2200.00 (2290.00)	81.70 (67.50)	53.60 (44.30)	3930.00 (3240.00)	2180.00 (1810.00)
23	93.10 (88.00)	61.00 (57.70)	4460.00 (4220.00)	2290.00 (2190.00)	87.90 (75.10)	57.60 (49.20)	4230.00 (3610.00)	2170.00 (1870.00)
24								
25	121.00 (97.40)	79.20 (63.90)	5800.00 (4680.00)	2580.00 (2090.00)	109.00 (86.40)	71.20 (56.70)	5240.00 (4170.00)	2330.00 (1870.00)
26	123.00 (95.50)	80.70 (62.60)	5910.00 (4590.00)	2450.00 (1910.00)	113.00 (84.20)	74.10 (55.20)	5450.00 (4070.00)	2260.00 (1690.00)
27								
28	113.00 (74.30)	74.10 (48.70)	5440.00 (3570.00)	1990.00 (1320.00)	123.00 (74.10)	80.70 (48.60)	5950.00 (3580.00)	2180.00 (1320.00)
29	135.00 (66.20)	88.40 (43.40)	6490.00 (3190.00)	2240.00 (1110.00)	144.00 (70.50)	94.60 (46.20)	6980.00 (3410.00)	2410.00 (1180.00)
30	121.00 (62.60)	79.50 (41.10)	5850.00 (3020.00)	1910.00 (997.00)	135.00 (69.10)	88.80 (45.30)	6560.00 (3350.00)	2150.00 (1100.00)
31	117.00 (64.30)	76.60 (42.10)	5640.00 (3100.00)	1750.00 (961.00)	126.00 (73.00)	82.80 (47.80)	6120.00 (3540.00)	1900.00 (1100.00)
Avg	58.0	38.0	2780.0	2970.0	47.7	31.3	2300.0	2080.0
n	29	29	29	29	29	29	29	29
SD	41.6	27.3	2010.0	1290.0	45.7	29.9	2210.0	935.0
Min	10.3	6.7	487.0	1750.0	8.1	5.3	383.0	1100.0
Max	135.0	88.4	6490.0	6830.0	144.0	94.6	6980.0	5180.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for April, 2008.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}
1	118.00 (61.40)	77.30 (40.30)	5690.00 (2970.00)	1680.00 (886.00)	125.00 (70.90)	81.70 (46.50)	6040.00 (3440.00)	1790.00 (1030.00)
2	128.00 (46.60)	83.80 (30.50)	6180.00 (2250.00)	1740.00 (640.00)	131.00 (56.00)	86.20 (36.70)	6380.00 (2720.00)	1800.00 (775.00)
3	155.00 (36.50)	102.00 (23.90)	7500.00 (1760.00)	2020.00 (476.00)	144.00 (43.60)	94.70 (28.60)	7010.00 (2120.00)	1890.00 (573.00)
4	154.00 (34.10)	101.00 (22.40)	7460.00 (1650.00)	1930.00 (439.00)	153.00 (45.90)	100.00 (30.10)	7410.00 (2230.00)	1920.00 (589.00)
5								
6								
7								
8								
9								
10								
11								
12	150.00 (21.80)	98.20 (14.30)	7300.00 (1060.00)	1430.00 (206.00)	126.00 (12.40)	82.40 (8.11)	6140.00 (605.00)	1200.00 (118.00)
13	124.00 (19.80)	81.10 (13.00)	6030.00 (966.00)	1150.00 (189.00)	99.60 (22.10)	65.30 (14.50)	4870.00 (1080.00)	931.00 (211.00)
14	99.80 (13.70)	65.40 (8.99)	4860.00 (667.00)	905.00 (125.00)	75.80 (12.20)	49.70 (7.97)	3710.00 (594.00)	690.00 (112.00)
15	40.50 (39.30)	26.60 (25.70)			22.20 (25.30)	14.60 (16.60)		
16	9.63 (19.40)	6.32 (12.70)			11.10 (23.50)	7.30 (15.40)		
17	5.98 (7.71)	3.92 (5.05)			4.27 (9.06)	2.80 (5.94)		
18	2.48 (5.50)	1.62 (3.61)			1.16 (1.73)	0.76 (1.13)		
19	0.27 (0.41)	0.18 (0.27)			0.40 (0.50)	0.26 (0.33)		
20	0.62 (0.88)	0.41 (0.58)			0.59 (0.99)	0.38 (0.65)		
21	0.28 (0.42)	0.18 (0.27)			0.29 (0.32)	0.19 (0.21)		
22	0.21 (0.37)	0.14 (0.24)			0.25 (0.44)	0.17 (0.29)	9.77 (18.50)	62.00 (117.00)
23	0.21 (0.41)	0.14 (0.27)	9.75 (19.20)	71.20 (136.00)	0.24 (0.47)	0.16 (0.31)	11.30 (22.30)	84.40 (162.00)
24	0.34 (0.45)	0.22 (0.29)	15.90 (21.00)	135.00 (180.00)	0.35 (0.51)	0.23 (0.33)	16.40 (23.80)	143.00 (209.00)
25	0.82 (1.17)	0.53 (0.77)	38.30 (55.10)	344.00 (496.00)	0.93 (1.26)	0.61 (0.83)	43.60 (59.40)	391.00 (533.00)
26	1.23 (1.50)	0.81 (0.98)	58.00 (70.50)	503.00 (616.00)	0.96 (1.22)	0.63 (0.80)	45.00 (57.60)	385.00 (500.00)
27	1.68 (1.61)	1.10 (1.06)	78.90 (75.80)	609.00 (597.00)	1.20 (1.22)	0.79 (0.80)	56.40 (57.40)	426.00 (443.00)
28	1.77 (1.64)	1.16 (1.08)	83.50 (77.40)	538.00 (507.00)	1.30 (1.16)	0.85 (0.76)	61.40 (54.80)	382.00 (343.00)
29	1.68 (2.05)	1.10 (1.34)	79.30 (96.70)	417.00 (513.00)	1.21 (1.42)	0.79 (0.93)	57.00 (67.00)	290.00 (342.00)
30	1.82 (2.25)	1.20 (1.48)	86.20 (106.00)	366.00 (452.00)	1.15 (1.46)	0.75 (0.96)	54.30 (69.00)	223.00 (284.00)
Avg	43.4	28.4	3030.0	923.0	39.2	25.7	2620.0	788.0
n	23	23	15	15	23	23	16	16
SD	60.5	39.7	3240.0	655.0	56.6	37.1	3030.0	677.0
Min	0.2	0.1	9.8	71.2	0.2	0.2	9.8	62.0
Max	155.0	102.0	7500.0	2020.0	153.0	100.0	7410.0	1920.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for May, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	2.30	(2.92)	1.51	(1.92)	109.00	(138.00)	375.00	(474.00)	1.65	(2.10)	1.08	(1.38)	78.00	(99.20)	260.00	(327.00)
2	3.39	(5.38)	2.23	(3.53)	161.00	(254.00)	462.00	(747.00)	2.26	(3.63)	1.48	(2.38)	107.00	(172.00)	298.00	(491.00)
3	4.44	(5.41)	2.91	(3.55)	210.00	(256.00)	494.00	(607.00)	2.49	(2.96)	1.63	(1.94)	118.00	(140.00)	269.00	(326.00)
4	6.01	(6.20)	3.94	(4.07)	285.00	(294.00)	566.00	(590.00)	2.94	(3.14)	1.93	(2.06)	139.00	(149.00)	268.00	(285.00)
5	6.64	(6.13)	4.36	(4.02)	315.00	(290.00)	535.00	(502.00)	4.54	(4.40)	2.97	(2.88)	215.00	(208.00)	354.00	(345.00)
6	7.09	(6.38)	4.65	(4.18)	336.00	(302.00)	490.00	(442.00)	5.93	(5.62)	3.89	(3.68)	281.00	(266.00)	399.00	(378.00)
7	7.96	(8.12)	5.22	(5.32)	377.00	(385.00)	480.00	(493.00)	6.94	(7.16)	4.55	(4.70)	329.00	(340.00)	409.00	(425.00)
8	10.10	(7.10)	6.61	(4.66)	478.00	(337.00)	536.00	(384.00)	8.67	(6.20)	5.69	(4.07)	411.00	(294.00)	452.00	(330.00)
9	11.30	(8.29)	7.42	(5.44)	537.00	(393.00)	532.00	(391.00)	9.44	(6.81)	6.19	(4.47)	448.00	(323.00)	435.00	(314.00)
10	13.50	(8.53)	8.87	(5.59)	642.00	(405.00)	569.00	(363.00)	10.80	(6.99)	7.11	(4.58)	515.00	(332.00)	448.00	(291.00)
11	15.20	(10.60)	9.95	(6.96)	721.00	(504.00)	575.00	(404.00)	12.50	(8.59)	8.18	(5.63)	592.00	(408.00)	464.00	(320.00)
12	18.30	(12.30)	12.00	(8.09)	872.00	(587.00)	629.00	(426.00)	15.40	(10.80)	10.10	(7.06)	730.00	(512.00)	518.00	(364.00)
13	19.00	(13.70)	12.40	(8.95)	904.00	(650.00)	595.00	(431.00)	14.60	(10.90)	9.58	(7.13)	695.00	(517.00)	451.00	(338.00)
14	22.40	(14.70)	14.70	(9.63)	1070.00	(700.00)	643.00	(427.00)	19.70	(14.50)	12.90	(9.48)	937.00	(688.00)	556.00	(408.00)
15																
16																
17																
18																
19																
20	81.20	(38.40)	53.30	(25.20)	3880.00	(1840.00)	1510.00	(724.00)	56.00	(26.20)	36.70	(17.20)	2670.00	(1250.00)	1030.00	(488.00)
21	76.40	(35.70)	50.10	(23.40)	3660.00	(1710.00)	1340.00	(633.00)	62.90	(25.00)	41.20	(16.40)	3000.00	(1190.00)	1090.00	(435.00)
22	79.90	(30.50)	52.40	(20.00)	3830.00	(1460.00)	1320.00	(510.00)	56.30	(20.40)	36.90	(13.40)	2690.00	(974.00)	922.00	(338.00)
23	91.90	(33.10)	60.30	(21.70)	4400.00	(1580.00)	1440.00	(516.00)	59.80	(20.20)	39.20	(13.30)	2860.00	(968.00)	926.00	(310.00)
24	110.00	(36.70)	72.20	(24.10)	5280.00	(1760.00)	1640.00	(545.00)	87.50	(31.90)	57.40	(20.90)	4190.00	(1530.00)	1290.00	(460.00)
25	134.00	(37.60)	88.10	(24.70)	6450.00	(1810.00)	1900.00	(526.00)	128.00	(38.50)	83.90	(25.30)	6130.00	(1850.00)	1790.00	(533.00)
26	131.00	(40.80)	85.70	(26.70)	6270.00	(1960.00)	1770.00	(562.00)	133.00	(43.00)	87.50	(28.20)	6400.00	(2060.00)	1790.00	(582.00)
27	118.00	(23.10)	77.10	(15.20)	5650.00	(1110.00)	1520.00	(304.00)	137.00	(36.90)	90.10	(24.20)	6600.00	(1770.00)	1760.00	(477.00)
28	102.00	(25.40)	66.90	(16.70)	4910.00	(1220.00)	1270.00	(321.00)	129.00	(36.20)	84.70	(23.70)	6200.00	(1740.00)	1590.00	(455.00)
29	100.00	(19.20)	65.80	(12.60)	4830.00	(923.00)	1200.00	(233.00)	121.00	(23.80)	79.60	(15.60)	5840.00	(1150.00)	1440.00	(290.00)
30	99.20	(13.20)	65.10	(8.65)	4780.00	(636.00)	1140.00	(155.00)	115.00	(16.10)	75.20	(10.60)	5520.00	(774.00)	1310.00	(189.00)
31	98.50	(14.00)	64.60	(9.15)	4750.00	(673.00)	1090.00	(157.00)	108.00	(15.80)	71.00	(10.30)	5220.00	(759.00)	1190.00	(175.00)
Avg	52.7		34.6		2530.0		947.0		50.5		33.1		2420.0		835.0	
n	26		26		26		26		26		26		26		26	
SD	47.3		31.0		2280.0		477.0		50.4		33.0		2420.0		522.0	
Min	2.3		1.5		109.0		375.0		1.7		1.1		78.0		260.0	
Max	134.0		88.1		6450.0		1900.0		137.0		90.1		6600.0		1790.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for June, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	102.00	(16.60)	67.10	(10.90)	4940.00	(803.00)	1100.00	(182.00)	105.00	(17.10)	68.80	(11.20)	5060.00	(823.00)	1120.00	(186.00)
2	100.00	(14.50)	65.60	(9.48)	4840.00	(699.00)	1040.00	(151.00)	104.00	(14.10)	68.00	(9.26)	5000.00	(681.00)	1070.00	(147.00)
3	110.00	(17.20)	72.20	(11.30)	5330.00	(832.00)	1110.00	(174.00)	117.00	(16.80)	76.70	(11.00)	5650.00	(812.00)	1170.00	(168.00)
4	102.00	(14.30)	67.00	(9.36)	4960.00	(692.00)	1000.00	(142.00)	102.00	(13.30)	66.80	(8.75)	4920.00	(645.00)	988.00	(134.00)
5	85.60	(19.60)	56.10	(12.90)	4160.00	(953.00)	816.00	(191.00)	84.70	(18.70)	55.60	(12.30)	4100.00	(906.00)	800.00	(181.00)
6	54.10	(22.50)	35.50	(14.70)					74.50	(19.00)	48.80	(12.50)	3550.00	(666.00)	675.00	(130.00)
7	3.74	(7.25)	2.45	(4.76)					6.17	(13.00)	4.04	(8.54)				
8	0.00	(0.00)	0.00	(0.00)					0.00	(0.00)	0.00	(0.00)				
9	0.00	(0.00)	0.00	(0.00)					0.00	(0.00)	0.00	(0.00)				
10	4.42	(6.57)	2.90	(4.31)					5.43	(8.32)	3.56	(5.45)				
11	5.61	(2.93)	3.68	(1.92)					9.59	(8.64)	6.29	(5.66)				
12	7.66	(8.65)	5.02	(5.67)					7.42	(7.27)	4.87	(4.77)				
13	7.17	(6.74)	4.70	(4.42)					7.01	(8.32)	4.60	(5.46)				
14	6.15	(7.51)	4.03	(4.92)					6.64	(8.55)	4.35	(5.61)				
15	5.47	(7.55)	3.58	(4.95)	257.00	(355.00)	1900.00	(2530.00)	5.87	(8.13)	3.85	(5.33)	277.00	(383.00)	2030.00	(2710.00)
16	4.98	(4.78)	3.26	(3.14)	234.00	(225.00)	1990.00	(1900.00)	5.10	(5.24)	3.34	(3.44)	240.00	(247.00)	2030.00	(2080.00)
17	4.84	(4.76)	3.17	(3.12)	228.00	(224.00)	2050.00	(2010.00)	4.92	(5.38)	3.22	(3.53)	232.00	(254.00)	2090.00	(2280.00)
18	4.39	(4.48)	2.88	(2.93)	207.00	(211.00)	1790.00	(1830.00)	4.37	(4.52)	2.86	(2.96)	207.00	(214.00)	1790.00	(1870.00)
19	3.61	(4.05)	2.36	(2.66)	170.00	(191.00)	1300.00	(1490.00)	3.72	(3.67)	2.44	(2.41)	176.00	(174.00)	1360.00	(1360.00)
20	3.52	(3.48)	2.31	(2.28)	166.00	(164.00)	1060.00	(1090.00)	3.10	(3.50)	2.03	(2.30)	147.00	(166.00)	949.00	(1100.00)
21	4.16	(3.92)	2.73	(2.57)	197.00	(185.00)	1030.00	(1000.00)	4.55	(4.33)	2.98	(2.84)	216.00	(205.00)	1130.00	(1080.00)
22	3.20	(3.12)	2.10	(2.05)	151.00	(148.00)	642.00	(649.00)	3.23	(2.97)	2.12	(1.95)	153.00	(141.00)	654.00	(617.00)
23	3.63	(2.88)	2.38	(1.89)	172.00	(136.00)	588.00	(472.00)	3.44	(2.88)	2.25	(1.89)	163.00	(136.00)	562.00	(477.00)
24	4.08	(3.22)	2.68	(2.11)	193.00	(152.00)	545.00	(437.00)	3.31	(2.82)	2.17	(1.85)	157.00	(134.00)	447.00	(389.00)
25	3.45	(3.35)	2.26	(2.20)	163.00	(159.00)	381.00	(374.00)	2.91	(3.19)	1.91	(2.09)	138.00	(152.00)	325.00	(356.00)
26	4.92	(3.42)	3.23	(2.25)	233.00	(162.00)	458.00	(324.00)	3.50	(3.12)	2.29	(2.05)	166.00	(148.00)	331.00	(301.00)
27	3.68	(3.81)	2.41	(2.50)	174.00	(180.00)	294.00	(309.00)	3.11	(3.01)	2.04	(1.98)	148.00	(143.00)	250.00	(245.00)
28	4.61	(3.60)	3.02	(2.36)	219.00	(171.00)	316.00	(250.00)	3.83	(2.71)	2.51	(1.78)	182.00	(129.00)	265.00	(189.00)
29	4.53	(3.23)	2.97	(2.12)	215.00	(153.00)	272.00	(196.00)	3.48	(2.53)	2.28	(1.66)	166.00	(120.00)	211.00	(155.00)
30	6.01	(3.50)	3.94	(2.29)	285.00	(166.00)	316.00	(184.00)	4.66	(2.67)	3.06	(1.75)	222.00	(127.00)	246.00	(141.00)
Avg	21.9		14.4		1310.0		952.0		23.1		15.1		1420.0		931.0	
n	30		30		21		21		30		30		22		22	
SD	36.2		23.8		1990.0		568.0		37.9		24.9		2050.0		602.0	
Min	0.0		0.0		151.0		272.0		0.0		0.0		138.0		211.0	
Max	110.0		72.2		5330.0		2050.0		117.0		76.7		5650.0		2090.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for July, 2008.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		μg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		μg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$	
1	6.69	(3.79)	4.38	(2.48)	317.00	(180.00)	312.00	(179.00)	4.70	(2.84)	3.08	(1.86)	224.00	(135.00)	221.00	(134.00)
2	7.16	(3.65)	4.70	(2.39)	340.00	(174.00)	299.00	(154.00)	5.32	(2.96)	3.49	(1.94)	254.00	(141.00)	224.00	(127.00)
3	7.94	(4.06)	5.21	(2.66)	378.00	(193.00)	298.00	(154.00)	5.53	(3.13)	3.63	(2.05)	264.00	(149.00)	209.00	(118.00)
4	10.30	(5.04)	6.73	(3.30)	488.00	(240.00)	350.00	(173.00)	6.49	(3.62)	4.26	(2.37)	310.00	(173.00)	223.00	(126.00)
5	15.20	(7.45)	9.94	(4.89)	721.00	(355.00)	470.00	(232.00)	8.86	(4.43)	5.81	(2.91)	423.00	(212.00)	277.00	(138.00)
6	23.40	(9.96)	15.30	(6.53)	1110.00	(475.00)	667.00	(291.00)	14.60	(6.04)	9.61	(3.96)	700.00	(289.00)	420.00	(176.00)
7	34.70	(11.10)	22.80	(7.27)	1660.00	(529.00)	912.00	(295.00)	24.20	(8.57)	15.90	(5.62)	1160.00	(410.00)	638.00	(225.00)
8	43.20	(8.14)	28.30	(5.34)	2060.00	(389.00)	1050.00	(187.00)	38.70	(9.85)	25.40	(6.46)	1850.00	(472.00)	946.00	(236.00)
9	45.10	(6.86)	29.60	(4.50)	2150.00	(328.00)	1020.00	(153.00)	42.30	(6.36)	27.70	(4.17)	2030.00	(305.00)	962.00	(149.00)
10	46.50	(9.80)	30.50	(6.43)	2220.00	(468.00)	976.00	(196.00)	45.70	(8.11)	30.00	(5.32)	2200.00	(389.00)	969.00	(163.00)
11	56.90	(9.16)	37.30	(6.01)	2720.00	(438.00)	1120.00	(172.00)	51.40	(5.02)	33.70	(3.29)	2470.00	(241.00)	1020.00	(93.90)
12	73.10	(11.80)	47.90	(7.75)	3500.00	(566.00)	1350.00	(211.00)	65.70	(11.60)	43.10	(7.63)	3160.00	(559.00)	1220.00	(207.00)
13	90.50	(12.30)	59.30	(8.09)	4330.00	(591.00)	1580.00	(199.00)	86.00	(8.72)	56.40	(5.72)	4140.00	(420.00)	1510.00	(137.00)
14	87.90	(11.20)	57.60	(7.37)	4220.00	(539.00)	1450.00	(187.00)	92.00	(9.93)	60.30	(6.51)	4430.00	(479.00)	1530.00	(158.00)
15	90.70	(12.50)	59.50	(8.19)	4350.00	(600.00)	1420.00	(191.00)	110.00	(14.20)	71.90	(9.30)	5300.00	(684.00)	1730.00	(221.00)
16	89.60	(12.70)	58.70	(8.30)	4300.00	(608.00)	1330.00	(184.00)	104.00	(11.70)	68.30	(7.64)	5030.00	(563.00)	1560.00	(178.00)
17	81.00	(12.20)	53.10	(8.02)	3900.00	(588.00)	1150.00	(179.00)	94.40	(12.50)	61.90	(8.18)	4570.00	(604.00)	1350.00	(185.00)
18	81.90	(17.70)	53.70	(11.60)	3940.00	(854.00)	1110.00	(238.00)	85.70	(21.60)	56.20	(14.20)	4150.00	(1050.00)	1170.00	(298.00)
19	113.00	(16.30)	74.30	(10.70)	5460.00	(785.00)	1460.00	(205.00)	103.00	(12.90)	67.30	(8.48)	4980.00	(627.00)	1340.00	(167.00)
20	117.00	(18.00)	76.90	(11.80)	5660.00	(870.00)	1450.00	(219.00)	112.00	(13.60)	73.20	(8.92)	5420.00	(660.00)	1400.00	(167.00)
21	118.00	(15.30)	77.60	(10.00)	5720.00	(740.00)	1410.00	(187.00)	103.00	(11.20)	67.80	(7.33)	5030.00	(544.00)	1250.00	(142.00)
22	110.00	(11.80)	72.00	(7.76)	5310.00	(573.00)	1260.00	(135.00)	105.00	(15.10)	69.10	(9.90)	5140.00	(736.00)	1220.00	(173.00)
23	101.00	(14.50)	66.50	(9.53)	4910.00	(704.00)	1130.00	(158.00)	100.00	(13.60)	65.80	(8.91)	4910.00	(664.00)	1130.00	(150.00)
24	107.00	(21.10)	70.40	(13.90)	5210.00	(1030.00)	1150.00	(218.00)	102.00	(17.90)	67.20	(11.80)	5020.00	(879.00)	1110.00	(186.00)
25	117.00	(25.70)	76.60	(16.90)	5680.00	(1250.00)	1210.00	(263.00)	105.00	(23.10)	69.10	(15.10)	5180.00	(1130.00)	1110.00	(239.00)
26	117.00	(14.90)	76.70	(9.77)	5690.00	(725.00)	1180.00	(147.00)	103.00	(14.40)	67.70	(9.46)	5080.00	(709.00)	1050.00	(144.00)
27	119.00	(13.60)	78.40	(8.92)	5820.00	(663.00)	1170.00	(133.00)	108.00	(14.20)	70.80	(9.29)	5320.00	(699.00)	1070.00	(138.00)
28	102.00	(12.10)	67.00	(7.92)	4980.00	(590.00)	975.00	(114.00)	104.00	(12.90)	68.30	(8.46)	5150.00	(638.00)	1010.00	(126.00)
29	88.50	(15.80)	58.00	(10.30)	4330.00	(770.00)	824.00	(149.00)	86.90	(15.40)	57.00	(10.10)	4310.00	(763.00)	822.00	(148.00)
30	95.30	(12.60)	62.50	(8.29)	4670.00	(619.00)	868.00	(117.00)	88.40	(14.00)	57.90	(9.18)	4420.00	(700.00)	822.00	(133.00)
31	80.40	(28.30)	52.70	(18.50)	3950.00	(1390.00)	717.00	(253.00)	72.90	(18.50)	47.80	(12.10)	3680.00	(933.00)	669.00	(172.00)
Avg	73.5		48.2		3550.0		1020.0		70.3		46.1		3430.0		973.0	
n	31		31		31		31		31		31		31		31	
SD	38.0		24.9		1850.0		368.0		38.2		25.1		1870.0		425.0	
Min	6.7		4.4		317.0		298.0		4.7		3.1		224.0		209.0	
Max	119.0		78.4		5820.0		1580.0		112.0		73.2		5420.0		1730.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for August, 2008.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		µg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		µg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$	
1	29.20	(33.70)	19.20	(22.10)					49.60	(59.20)	32.50	(38.80)				
2	73.50	(183.00)	48.20	(120.00)					50.90	(70.20)	33.40	(46.10)				
3	10.80	(3.14)	7.11	(2.06)					12.00	(2.58)	7.87	(1.69)				
4	6.28	(2.56)	4.12	(1.68)					4.74	(2.65)	3.11	(1.74)				
5	3.61	(1.41)	2.36	(0.93)					2.45	(0.90)	1.61	(0.59)				
6	2.18	(2.96)	1.43	(1.94)					2.61	(3.17)	1.71	(2.08)				
7	3.34	(4.88)	2.19	(3.20)					3.28	(4.37)	2.15	(2.87)				
8	3.25	(2.26)	2.13	(1.48)					3.25	(2.20)	2.13	(1.44)				
9	2.93	(1.00)	1.92	(0.66)					2.84	(0.96)	1.87	(0.63)				
10	2.54	(2.37)	1.67	(1.56)					2.53	(2.15)	1.66	(1.41)				
11	1.93	(3.17)	1.26	(2.08)					2.05	(2.52)	1.34	(1.66)				
12	1.88	(3.20)	1.23	(2.10)	87.90	(149.00)	634.00	(1060.00)	1.85	(2.80)	1.21	(1.84)	86.40	(131.00)	623.00	(941.00)
13	2.17	(3.05)	1.42	(2.00)	101.00	(143.00)	851.00	(1180.00)	2.38	(3.16)	1.56	(2.08)	111.00	(148.00)	936.00	(1230.00)
14	4.00	(3.41)	2.62	(2.24)	187.00	(160.00)	1680.00	(1430.00)	3.44	(3.22)	2.26	(2.11)	161.00	(151.00)	1450.00	(1350.00)
15	3.08	(3.04)	2.02	(1.99)	144.00	(142.00)	1260.00	(1260.00)	2.62	(2.82)	1.72	(1.85)	123.00	(132.00)	1070.00	(1160.00)
16	2.80	(2.64)	1.83	(1.73)	131.00	(124.00)	1020.00	(978.00)	2.34	(2.29)	1.53	(1.50)	110.00	(108.00)	856.00	(858.00)
17	3.04	(2.87)	1.99	(1.88)	143.00	(135.00)	932.00	(900.00)	2.42	(2.23)	1.59	(1.46)	114.00	(105.00)	742.00	(698.00)
18	2.89	(3.21)	1.90	(2.10)	136.00	(150.00)	723.00	(811.00)								
19	3.12	(3.07)	2.04	(2.01)	146.00	(144.00)	629.00	(628.00)	2.48	(2.30)	1.62	(1.51)	116.00	(108.00)	501.00	(472.00)
20	4.06	(3.45)	2.66	(2.26)	191.00	(162.00)	664.00	(569.00)	2.67	(2.36)	1.75	(1.55)	125.00	(111.00)	438.00	(387.00)
21	5.90	(4.65)	3.87	(3.05)	277.00	(218.00)	801.00	(640.00)	3.34	(2.97)	2.19	(1.95)	157.00	(140.00)	454.00	(414.00)
22	8.08	(5.74)	5.30	(3.76)	379.00	(269.00)	906.00	(654.00)	4.39	(2.97)	2.88	(1.94)	207.00	(140.00)	493.00	(339.00)
23	8.96	(6.92)	5.87	(4.54)	421.00	(325.00)	848.00	(673.00)	3.88	(3.25)	2.54	(2.13)	182.00	(153.00)	367.00	(313.00)
24	12.00	(7.01)	7.87	(4.60)	563.00	(329.00)	964.00	(576.00)	5.43	(3.61)	3.56	(2.37)	255.00	(170.00)	437.00	(293.00)
25	12.70	(7.98)	8.32	(5.23)	596.00	(375.00)	882.00	(567.00)	6.56	(4.46)	4.30	(2.93)	309.00	(210.00)	455.00	(317.00)
26	12.60	(8.47)	8.26	(5.55)	592.00	(398.00)	760.00	(522.00)	6.34	(4.59)	4.16	(3.01)	299.00	(216.00)	383.00	(281.00)
27	17.90	(9.47)	11.80	(6.21)	843.00	(445.00)	948.00	(507.00)	9.81	(5.59)	6.44	(3.66)	462.00	(263.00)	519.00	(298.00)
28	23.40	(12.30)	15.40	(8.04)	1100.00	(576.00)	1100.00	(593.00)	10.30	(6.47)	6.75	(4.25)	485.00	(305.00)	483.00	(308.00)
29	31.00	(13.10)	20.30	(8.60)	1460.00	(617.00)	1300.00	(561.00)	17.90	(7.35)	11.70	(4.82)	843.00	(347.00)	747.00	(302.00)
30	31.10	(14.00)	20.40	(9.21)	1460.00	(661.00)	1170.00	(535.00)	21.40	(11.10)	14.00	(7.25)	1010.00	(521.00)	810.00	(421.00)
31	32.40	(20.00)	21.20	(13.10)	1520.00	(942.00)	1110.00	(699.00)	23.70	(14.40)	15.50	(9.44)	1120.00	(679.00)	813.00	(501.00)
Avg	11.7		7.7		524.0		959.0		9.0		5.9		330.0		662.0	
n	31		31		20		20		30		30		19		19	
SD	14.8		9.7		481.0		252.0		12.4		8.1		310.0		272.0	
Min	1.9		1.2		87.9		629.0		1.9		1.2		86.4		367.0	
Max	73.5		48.2		1520.0		1680.0		50.9		33.4		1120.0		1450.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for September, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	34.60	(19.30)	22.70	(12.60)	1630.00	(907.00)	1080.00	(608.00)	25.90	(15.00)	17.00	(9.85)	1220.00	(709.00)	808.00	(476.00)
2	47.60	(23.00)	31.20	(15.10)	2240.00	(1080.00)	1360.00	(667.00)	35.00	(16.00)	23.00	(10.50)	1650.00	(757.00)	1000.00	(461.00)
3	53.30	(24.70)	35.00	(16.20)	2510.00	(1170.00)	1400.00	(669.00)	40.00	(19.20)	26.20	(12.60)	1890.00	(907.00)	1050.00	(516.00)
4	41.60	(20.30)	27.20	(13.30)	1960.00	(956.00)	1010.00	(504.00)	41.90	(20.90)	27.50	(13.70)	1980.00	(987.00)	1020.00	(519.00)
5	46.60	(16.80)	30.60	(11.00)	2200.00	(794.00)	1050.00	(380.00)	50.00	(18.10)	32.80	(11.90)	2370.00	(858.00)	1130.00	(420.00)
6	49.90	(17.00)	32.70	(11.10)	2360.00	(803.00)	1050.00	(355.00)	49.30	(19.30)	32.30	(12.60)	2330.00	(912.00)	1040.00	(409.00)
7	63.70	(15.20)	41.80	(9.96)	3010.00	(718.00)	1250.00	(298.00)	61.80	(16.10)	40.60	(10.60)	2930.00	(765.00)	1220.00	(321.00)
8	73.60	(26.20)	48.30	(17.20)	3480.00	(1240.00)	1360.00	(490.00)	77.70	(27.70)	51.00	(18.20)	3680.00	(1310.00)	1440.00	(517.00)
9	80.20	(31.20)	52.60	(20.40)	3790.00	(1470.00)	1390.00	(542.00)	94.10	(36.20)	61.70	(23.70)	4460.00	(1720.00)	1640.00	(630.00)
10	102.00	(37.50)	66.70	(24.60)	4820.00	(1780.00)	1670.00	(621.00)	103.00	(39.60)	67.50	(25.90)	4880.00	(1880.00)	1690.00	(662.00)
11	116.00	(36.40)	75.90	(23.90)	5480.00	(1720.00)	1800.00	(570.00)	98.30	(34.20)	64.40	(22.40)	4660.00	(1620.00)	1530.00	(541.00)
12	117.00	(35.40)	76.90	(23.20)	5560.00	(1680.00)	1730.00	(530.00)	93.00	(30.30)	61.00	(19.90)	4420.00	(1440.00)	1380.00	(456.00)
13	122.00	(26.10)	80.00	(17.10)	5790.00	(1240.00)	1710.00	(366.00)	103.00	(25.20)	67.70	(16.50)	4910.00	(1200.00)	1450.00	(350.00)
14	144.00	(28.20)	94.50	(18.50)	6840.00	(1340.00)	1930.00	(377.00)	122.00	(23.60)	79.70	(15.50)	5780.00	(1120.00)	1630.00	(316.00)
15	165.00	(23.50)	109.00	(15.40)	7860.00	(1120.00)	2120.00	(298.00)	150.00	(21.60)	98.50	(14.10)	7150.00	(1030.00)	1930.00	(273.00)
16	155.00	(24.40)	102.00	(16.00)	7370.00	(1160.00)	1910.00	(298.00)	146.00	(22.80)	96.00	(14.90)	6980.00	(1080.00)	1800.00	(281.00)
17	135.00	(20.50)	88.50	(13.50)	6420.00	(976.00)	1590.00	(241.00)	133.00	(19.50)	87.00	(12.80)	6330.00	(930.00)	1570.00	(229.00)
18	148.00	(18.30)	96.80	(12.00)	7030.00	(871.00)	1680.00	(208.00)	146.00	(15.70)	95.60	(10.30)	6970.00	(753.00)	1670.00	(182.00)
19	149.00	(16.00)	97.40	(10.50)	7080.00	(764.00)	1630.00	(174.00)	152.00	(19.30)	99.70	(12.60)	7280.00	(922.00)	1670.00	(213.00)
20	166.00	(21.90)	109.00	(14.30)	7910.00	(1040.00)	1760.00	(230.00)	155.00	(21.40)	101.00	(14.10)	7410.00	(1030.00)	1650.00	(231.00)
21	173.00	(25.40)	113.00	(16.70)	8260.00	(1220.00)	1780.00	(260.00)	153.00	(21.10)	101.00	(13.90)	7350.00	(1010.00)	1580.00	(216.00)
22	150.00	(24.80)	98.40	(16.30)	7170.00	(1190.00)	1490.00	(253.00)	137.00	(23.60)	89.60	(15.50)	6550.00	(1130.00)	1370.00	(242.00)
23	114.00	(17.00)	75.00	(11.10)	5470.00	(812.00)	1110.00	(165.00)	117.00	(16.40)	76.80	(10.70)	5620.00	(786.00)	1140.00	(162.00)
24	106.00	(25.80)	69.40	(16.90)	5070.00	(1240.00)	995.00	(240.00)	107.00	(22.80)	70.00	(14.90)	5130.00	(1090.00)	1010.00	(212.00)
25	105.00	(19.10)	68.70	(12.50)	5030.00	(914.00)	962.00	(179.00)	102.00	(16.40)	67.10	(10.80)	4920.00	(789.00)	941.00	(154.00)
26	89.90	(16.40)	58.90	(10.80)	4270.00	(761.00)	797.00	(142.00)	91.00	(14.70)	59.70	(9.65)	4370.00	(708.00)	816.00	(135.00)
27																
28																
29																
30																
Avg	106.0		69.3		5020.0		1450.0		99.4		65.2		4740.0		1350.0	
n	26		26		26		26		26		26		26		26	
SD	43.1		28.2		2060.0		352.0		40.4		26.5		1940.0		320.0	
Min	34.6		22.7		1630.0		797.0		25.9		17.0		1220.0		808.0	
Max	173.0		113.0		8260.0		2120.0		155.0		101.0		7410.0		1930.0	

Table E9. Daily means (SD) of H_2S emissions at Site CA1B for November, 2008.

Day	House 10				House 12			
	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$\mu g\ d^{-1}hd^{-1}$	$mg\ d^{-1}AU^{-1}$	$g\ d^{-1}$	$mg\ d^{-1}m^{-2}$	$\mu g\ d^{-1}hd^{-1}$	$mg\ d^{-1}AU^{-1}$
1								
2								
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19								
20	69.50 (37.00)	45.50 (24.20)	3320.00 (1760.00)	1090.00 (575.00)	68.80 (39.40)	45.10 (25.80)	3280.00 (1870.00)	1060.00 (604.00)
21	68.40 (43.70)	44.80 (28.70)	3260.00 (2090.00)	1020.00 (650.00)	65.40 (44.90)	42.90 (29.50)	3110.00 (2140.00)	959.00 (660.00)
22	71.40 (41.50)	46.80 (27.20)	3410.00 (1980.00)	1010.00 (588.00)	69.70 (42.70)	45.70 (28.00)	3320.00 (2030.00)	972.00 (595.00)
23	73.00 (41.50)	47.90 (27.20)	3490.00 (1980.00)	985.00 (557.00)	76.10 (44.00)	49.90 (28.90)	3620.00 (2100.00)	1010.00 (582.00)
24	78.60 (38.40)	51.50 (25.20)	3760.00 (1840.00)	1020.00 (500.00)	80.30 (39.50)	52.70 (25.90)	3830.00 (1880.00)	1020.00 (507.00)
25	73.70 (30.00)	48.30 (19.60)	3530.00 (1430.00)	913.00 (374.00)				
26	84.60 (19.80)	55.40 (13.00)	4050.00 (949.00)	1010.00 (238.00)	91.30 (23.90)	59.90 (15.60)	4350.00 (1140.00)	1070.00 (285.00)
27	81.80 (6.67)	53.60 (4.37)	3920.00 (319.00)	937.00 (80.60)	81.70 (7.84)	53.60 (5.14)	3890.00 (374.00)	924.00 (94.70)
28	74.70 (7.63)	49.00 (5.00)	3580.00 (365.00)	825.00 (88.20)	58.50 (10.50)	38.40 (6.88)	2790.00 (500.00)	638.00 (118.00)
29	78.20 (16.20)	51.20 (10.60)	3750.00 (776.00)	833.00 (170.00)	81.50 (27.10)	53.40 (17.70)	3890.00 (1290.00)	857.00 (281.00)
30	79.00 (20.10)	51.80 (13.20)	3790.00 (964.00)	814.00 (206.00)	90.80 (25.90)	59.50 (17.00)	4330.00 (1230.00)	924.00 (263.00)
Avg	75.7	49.6	3620.0	950.0	76.4	50.1	3640.0	945.0
n	11	11	11	11	10	10	10	10
SD	4.9	3.2	239.0	88.0	10.2	6.7	488.0	120.0
Min	68.4	44.8	3260.0	814.0	58.5	38.4	2790.0	638.0
Max	84.6	55.4	4050.0	1090.0	91.3	59.9	4350.0	1070.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for December, 2008.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	73.70	(12.80)	48.40	(8.39)	3540.00	(614.00)	738.00	(130.00)	81.40	(14.30)	53.40	(9.40)	3890.00	(684.00)	804.00	(144.00)
2	75.40	(9.96)	49.50	(6.53)	3620.00	(478.00)	732.00	(95.30)	80.70	(12.20)	52.90	(7.99)	3850.00	(581.00)	773.00	(115.00)
3	83.60	(19.40)	54.80	(12.70)	4010.00	(931.00)	789.00	(182.00)	78.00	(13.60)	51.10	(8.91)	3720.00	(648.00)	727.00	(131.00)
4	18.10	(34.40)	11.90	(22.50)					17.20	(18.50)	11.30	(12.10)				
5	6.86	(2.25)	4.50	(1.47)					11.10	(2.92)	7.30	(1.91)				
6	4.86	(1.03)	3.19	(0.67)					6.98	(0.94)	4.58	(0.62)				
7	3.57	(0.96)	2.34	(0.63)					5.91	(1.20)	3.88	(0.79)				
8	4.30	(5.44)	2.82	(3.57)					5.52	(7.64)	3.62	(5.01)				
9	3.66	(7.35)	2.40	(4.82)					6.03	(11.40)	3.95	(7.50)				
10	2.96	(5.97)	1.94	(3.91)					4.40	(8.82)	2.89	(5.79)				
11	2.87	(5.78)	1.88	(3.79)					4.08	(8.25)	2.68	(5.41)				
12	2.45	(4.99)	1.61	(3.27)					3.64	(7.36)	2.39	(4.83)				
13	1.96	(4.01)	1.28	(2.63)	92.30	(189.00)	667.00	(1340.00)	2.90	(5.38)	1.90	(3.53)	136.00	(253.00)	966.00	(1760.00)
14	1.70	(2.78)	1.11	(1.83)	80.40	(132.00)	683.00	(1120.00)	2.41	(3.58)	1.58	(2.35)	114.00	(169.00)	949.00	(1410.00)
15	2.45	(3.61)	1.60	(2.37)	116.00	(171.00)	1040.00	(1530.00)	2.99	(4.11)	1.96	(2.70)	141.00	(194.00)	1260.00	(1740.00)
16	2.19	(2.90)	1.43	(1.90)	104.00	(137.00)	898.00	(1200.00)	2.52	(3.54)	1.65	(2.32)	119.00	(167.00)	1040.00	(1470.00)
17	1.52	(2.06)	1.00	(1.35)	71.90	(97.40)	554.00	(753.00)	1.60	(2.78)	1.05	(1.82)	75.60	(132.00)	592.00	(1030.00)
18	1.55	(2.09)	1.01	(1.37)	73.30	(99.20)	470.00	(629.00)	1.89	(3.35)	1.24	(2.20)	89.50	(159.00)	589.00	(1030.00)
19	2.55	(3.25)	1.68	(2.13)	121.00	(154.00)	638.00	(811.00)	2.63	(4.29)	1.73	(2.82)	125.00	(203.00)	676.00	(1110.00)
20	1.54	(2.22)	1.01	(1.45)	73.20	(105.00)	311.00	(443.00)	1.55	(2.76)	1.02	(1.81)	73.60	(131.00)	322.00	(572.00)
21	1.05	(1.97)	0.69	(1.29)	50.00	(93.30)	176.00	(340.00)	0.97	(1.95)	0.63	(1.28)	45.80	(92.40)	164.00	(345.00)
22	6.12	(8.77)	4.01	(5.75)	290.00	(416.00)	801.00	(1130.00)	3.34	(5.53)	2.19	(3.63)	159.00	(262.00)	451.00	(731.00)
23	8.63	(11.60)	5.66	(7.62)	410.00	(551.00)	968.00	(1310.00)	5.75	(7.64)	3.77	(5.01)	273.00	(363.00)	660.00	(878.00)
24	9.70	(12.20)	6.36	(7.99)	461.00	(578.00)	917.00	(1150.00)	6.79	(8.46)	4.45	(5.55)	322.00	(402.00)	655.00	(814.00)
25	11.00	(13.70)	7.21	(8.95)	522.00	(648.00)	889.00	(1110.00)	7.51	(9.30)	4.92	(6.10)	357.00	(442.00)	620.00	(772.00)
26	10.50	(12.80)	6.87	(8.39)	498.00	(608.00)	734.00	(911.00)	6.92	(8.34)	4.54	(5.47)	329.00	(396.00)	494.00	(605.00)
27	14.60	(15.90)	9.55	(10.40)	692.00	(756.00)	877.00	(950.00)	8.75	(8.92)	5.74	(5.85)	416.00	(424.00)	538.00	(547.00)
28	20.20	(19.60)	13.20	(12.90)	958.00	(934.00)	1070.00	(1040.00)	11.90	(11.30)	7.81	(7.38)	567.00	(536.00)	645.00	(607.00)
29	16.70	(21.70)	11.00	(14.20)	795.00	(1030.00)	778.00	(994.00)	5.48	(14.20)	3.60	(9.30)	261.00	(675.00)	254.00	(658.00)
30	35.00	(32.40)	23.00	(21.30)	1670.00	(1540.00)	1480.00	(1360.00)	22.50	(22.80)	14.70	(14.90)	1070.00	(1090.00)	960.00	(971.00)
31	37.20	(37.70)	24.40	(24.70)	1770.00	(1790.00)	1410.00	(1440.00)	29.70	(29.20)	19.40	(19.20)	1410.00	(1390.00)	1140.00	(1130.00)
Avg	15.1		9.9		910.0		801.0		14.0		9.2		797.0		695.0	
n	31		31		22		22		31		31		22		22	
SD	22.3		14.6		1220.0		294.0		22.5		14.7		1240.0		273.0	
Min	1.1		0.7		50.0		176.0		1.0		0.6		45.8		164.0	
Max	83.6		54.8		4010.0		1480.0		81.4		53.4		3890.0		1260.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for January, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	49.90	(43.00)	32.70	(28.20)	2370.00	(2040.00)	1720.00	(1480.00)	48.50	(41.60)	31.80	(27.30)	2310.00	(1990.00)	1690.00	(1450.00)
2	47.50	(38.10)	31.20	(25.00)	2260.00	(1810.00)	1490.00	(1210.00)	53.10	(41.70)	34.80	(27.40)	2530.00	(1990.00)	1690.00	(1340.00)
3	32.70	(27.80)	21.40	(18.20)	1560.00	(1320.00)	938.00	(796.00)	39.40	(31.70)	25.80	(20.80)	1880.00	(1510.00)	1150.00	(927.00)
4	31.90	(32.40)	20.90	(21.30)	1520.00	(1540.00)	836.00	(844.00)	36.30	(36.20)	23.80	(23.80)	1730.00	(1730.00)	964.00	(957.00)
5	42.40	(39.00)	27.80	(25.60)	2020.00	(1860.00)	1030.00	(948.00)	47.80	(43.80)	31.40	(28.70)	2290.00	(2090.00)	1180.00	(1080.00)
6	48.50	(44.60)	31.80	(29.30)	2310.00	(2130.00)	1100.00	(1010.00)	52.50	(48.40)	34.50	(31.70)	2510.00	(2310.00)	1200.00	(1110.00)
7	33.80	(40.40)	22.20	(26.50)	1610.00	(1930.00)	713.00	(852.00)	32.50	(41.10)	21.30	(27.00)	1550.00	(1970.00)	693.00	(879.00)
8	33.70	(33.90)	22.10	(22.30)	1610.00	(1620.00)	670.00	(682.00)	33.80	(35.20)	22.20	(23.10)	1620.00	(1690.00)	680.00	(718.00)
9	58.20	(35.90)	38.10	(23.50)	2770.00	(1710.00)	1080.00	(659.00)	54.50	(35.40)	35.70	(23.20)	2610.00	(1690.00)	1020.00	(656.00)
10	66.20	(47.80)	43.40	(31.30)	3160.00	(2280.00)	1150.00	(828.00)	64.60	(46.10)	42.30	(30.20)	3090.00	(2210.00)	1140.00	(810.00)
11	71.40	(48.50)	46.80	(31.80)	3410.00	(2310.00)	1180.00	(797.00)	70.40	(47.10)	46.20	(30.90)	3370.00	(2260.00)	1170.00	(783.00)
12	85.60	(46.50)	56.10	(30.50)	4080.00	(2220.00)	1340.00	(727.00)	85.90	(45.90)	56.30	(30.10)	4120.00	(2200.00)	1350.00	(726.00)
13	90.30	(42.60)	59.20	(27.90)	4310.00	(2030.00)	1340.00	(633.00)	94.00	(44.60)	61.60	(29.30)	4510.00	(2140.00)	1410.00	(670.00)
14	89.50	(40.70)	58.70	(26.70)	4270.00	(1940.00)	1260.00	(575.00)	94.90	(43.00)	62.20	(28.20)	4550.00	(2060.00)	1350.00	(616.00)
15	78.30	(31.70)	51.40	(20.80)	3740.00	(1520.00)	1060.00	(431.00)	84.90	(36.00)	55.70	(23.60)	4080.00	(1730.00)	1160.00	(494.00)
16	91.10	(35.00)	59.70	(23.00)	4350.00	(1670.00)	1170.00	(444.00)	92.80	(46.70)	60.90	(30.60)	4460.00	(2240.00)	1210.00	(598.00)
17	98.70	(35.50)	64.70	(23.30)	4720.00	(1700.00)	1220.00	(440.00)	100.00	(50.70)	65.60	(33.30)	4810.00	(2440.00)	1250.00	(634.00)
18	94.10	(29.50)	61.70	(19.30)	4500.00	(1410.00)	1120.00	(354.00)	96.60	(35.40)	63.30	(23.20)	4650.00	(1700.00)	1160.00	(430.00)
19	81.30	(26.60)	53.30	(17.50)	3890.00	(1270.00)	930.00	(310.00)	76.80	(26.00)	50.40	(17.00)	3700.00	(1250.00)	888.00	(306.00)
20	79.80	(17.70)	52.30	(11.60)	3820.00	(845.00)	877.00	(194.00)	72.10	(20.10)	47.30	(13.10)	3470.00	(966.00)	801.00	(222.00)
21	78.90	(10.90)	51.70	(7.12)	3780.00	(520.00)	838.00	(120.00)	97.30	(8.46)	63.80	(5.54)	4690.00	(407.00)	1040.00	(87.10)
22	83.80	(8.31)	55.00	(5.45)	4010.00	(398.00)	859.00	(81.40)	95.50	(7.65)	62.60	(5.02)	4610.00	(369.00)	993.00	(84.80)
23	107.00	(7.59)	69.90	(4.98)	5110.00	(364.00)	1060.00	(74.20)	98.40	(5.79)	64.50	(3.80)	4750.00	(280.00)	992.00	(60.20)
24	97.60	(12.00)	64.00	(7.84)	4680.00	(573.00)	944.00	(122.00)	91.20	(8.48)	59.80	(5.56)	4410.00	(410.00)	893.00	(88.00)
25	91.50	(4.56)	60.00	(2.99)	4390.00	(219.00)	862.00	(47.90)	87.40	(3.52)	57.30	(2.31)	4230.00	(170.00)	832.00	(36.50)
26	82.30	(3.86)	54.00	(2.53)	3950.00	(185.00)	755.00	(37.40)	76.50	(5.77)	50.20	(3.78)	3710.00	(280.00)	711.00	(56.70)
27	74.90	(8.60)	49.10	(5.64)	3600.00	(413.00)	670.00	(73.30)	68.70	(8.47)	45.10	(5.55)	3330.00	(410.00)	622.00	(74.70)
28	51.90	(32.50)	34.10	(21.30)					44.30	(32.10)	29.10	(21.10)				
29	7.00	(6.22)	4.59	(4.08)					8.09	(9.02)	5.30	(5.92)				
30	16.50	(34.00)	10.80	(22.30)					13.90	(30.50)	9.12	(20.00)				
31	22.60	(47.00)	14.80	(30.80)					23.70	(48.60)	15.50	(31.90)				
Avg	65.1		42.7		3400.0		1040.0		65.7		43.1		3470.0		1080.0	
n	31		31		27		27		31		31		27		27	
SD	27.0		17.7		1090.0		247.0		27.0		17.7		1080.0		272.0	
Min	7.0		4.6		1520.0		670.0		8.1		5.3		1550.0		622.0	
Max	107.0		69.9		5110.0		1720.0		100.0		65.6		4810.0		1690.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for February, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	13.40	(27.50)	8.81	(18.00)					15.30	(31.30)	10.10	(20.50)				
2	7.94	(17.10)	5.21	(11.20)					9.34	(18.10)	6.12	(11.90)				
3	5.76	(11.60)	3.78	(7.63)					6.72	(8.52)	4.41	(5.59)				
4	8.20	(14.20)	5.38	(9.32)					10.60	(14.90)	6.93	(9.76)				
5	6.23	(11.50)	4.08	(7.56)					3.46	(5.82)	2.27	(3.82)				
6	3.97	(7.54)	2.60	(4.95)					4.07	(8.13)	2.67	(5.33)				
7	3.98	(7.99)	2.61	(5.24)					3.84	(7.71)	2.52	(5.06)				
8	4.27	(8.59)	2.80	(5.63)					3.87	(7.81)	2.54	(5.12)				
9									4.32	(8.55)	2.83	(5.60)				
10	5.02	(10.10)	3.29	(6.60)	236.00	(474.00)	1710.00	(3440.00)	4.95	(8.11)	3.25	(5.32)	231.00	(378.00)	1650.00	(2720.00)
11	4.80	(9.66)	3.15	(6.33)	226.00	(456.00)	1870.00	(3760.00)	4.84	(6.96)	3.18	(4.57)	226.00	(325.00)	1880.00	(2700.00)
12									5.58	(7.35)	3.66	(4.82)	261.00	(343.00)	2340.00	(3080.00)
13	5.76	(10.10)	3.78	(6.62)	273.00	(478.00)	2380.00	(4180.00)	5.80	(8.54)	3.80	(5.60)	271.00	(399.00)	2370.00	(3490.00)
14	6.00	(7.78)	3.93	(5.10)	284.00	(369.00)	2220.00	(2890.00)	5.63	(7.36)	3.69	(4.83)	264.00	(345.00)	2070.00	(2730.00)
15	5.60	(6.97)	3.67	(4.57)	266.00	(331.00)	1740.00	(2170.00)	4.99	(6.21)	3.27	(4.07)	234.00	(291.00)	1550.00	(1920.00)
16	6.26	(7.72)	4.11	(5.07)	297.00	(367.00)	1590.00	(1960.00)	5.17	(6.41)	3.39	(4.20)	243.00	(301.00)	1310.00	(1630.00)
17	5.00	(6.82)	3.28	(4.47)	238.00	(324.00)	1050.00	(1450.00)	3.88	(5.27)	2.54	(3.46)	182.00	(247.00)	810.00	(1110.00)
18	10.50	(13.90)	6.88	(9.09)	499.00	(660.00)	1740.00	(2290.00)	7.44	(9.83)	4.88	(6.44)	349.00	(461.00)	1230.00	(1620.00)
19	14.40	(16.40)	9.42	(10.80)	684.00	(782.00)	1980.00	(2250.00)	9.44	(11.30)	6.19	(7.40)	444.00	(531.00)	1300.00	(1550.00)
20	14.50	(19.20)	9.54	(12.60)	693.00	(914.00)	1670.00	(2210.00)	9.61	(12.90)	6.30	(8.46)	452.00	(607.00)	1100.00	(1470.00)
21	17.20	(20.70)	11.20	(13.60)	817.00	(989.00)	1650.00	(2010.00)	11.70	(14.20)	7.67	(9.30)	550.00	(668.00)	1120.00	(1350.00)
22	19.90	(23.80)	13.10	(15.60)	949.00	(1140.00)	1630.00	(1930.00)	14.50	(17.50)	9.49	(11.50)	682.00	(825.00)	1180.00	(1410.00)
23	29.20	(32.20)	19.10	(21.10)	1390.00	(1540.00)	2060.00	(2280.00)	20.70	(22.70)	13.60	(14.90)	975.00	(1070.00)	1450.00	(1600.00)
24	35.60	(35.80)	23.30	(23.50)	1700.00	(1710.00)	2200.00	(2250.00)	24.20	(24.10)	15.90	(15.80)	1140.00	(1140.00)	1490.00	(1510.00)
25	35.90	(32.60)	23.60	(21.40)	1720.00	(1560.00)	1950.00	(1780.00)	24.80	(22.20)	16.30	(14.50)	1170.00	(1050.00)	1340.00	(1200.00)
26	52.10	(42.60)	34.20	(27.90)	2490.00	(2040.00)	2490.00	(2040.00)	34.30	(28.30)	22.50	(18.50)	1620.00	(1340.00)	1630.00	(1340.00)
27	69.60	(54.40)	45.60	(35.70)	3330.00	(2600.00)	2970.00	(2310.00)	45.50	(35.70)	29.80	(23.40)	2150.00	(1690.00)	1930.00	(1510.00)
28	94.00	(66.00)	61.60	(43.30)	4500.00	(3160.00)	3610.00	(2530.00)	60.50	(44.00)	39.70	(28.90)	2870.00	(2090.00)	2310.00	(1670.00)
Avg	18.7		12.2		1140.0		2030.0		13.0		8.6		754.0		1580.0	
n	26		26		18		18		28		28		19		19	
SD	22.0		14.4		1180.0		561.0		13.5		8.9		729.0		445.0	
Min	4.0		2.6		226.0		1050.0		3.5		2.3		182.0		810.0	
Max	94.0		61.6		4500.0		3610.0		60.5		39.7		2870.0		2370.0	

Table E9. **Daily means (SD) of H2S emissions at Site CA1B for March, 2009.**

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	115.00	(68.30)	75.30	(44.80)	5500.00	(3270.00)	4010.00	(2390.00)	82.40	(54.60)	54.00	(35.80)	3910.00	(2590.00)	2860.00	(1890.00)
2	96.40	(55.50)	63.20	(36.40)	4610.00	(2650.00)	3070.00	(1790.00)	89.40	(47.10)	58.60	(30.90)	4250.00	(2240.00)	2830.00	(1500.00)
3	83.00	(65.00)	54.40	(42.60)	3980.00	(3110.00)	2410.00	(1890.00)	83.00	(59.50)	54.40	(39.00)	3950.00	(2830.00)	2400.00	(1720.00)
4	94.40	(76.70)	61.90	(50.30)	4530.00	(3680.00)	2530.00	(2060.00)	90.40	(74.10)	59.30	(48.60)	4300.00	(3530.00)	2410.00	(1980.00)
5	94.60	(73.60)	62.00	(48.30)	4540.00	(3530.00)	2340.00	(1830.00)	90.40	(74.30)	59.30	(48.70)	4300.00	(3540.00)	2230.00	(1840.00)
6	91.10	(69.90)	59.70	(45.80)	4370.00	(3350.00)	2090.00	(1610.00)	86.80	(70.70)	56.90	(46.40)	4130.00	(3370.00)	1990.00	(1630.00)
7	101.00	(78.10)	66.10	(51.20)	4840.00	(3750.00)	2160.00	(1680.00)	90.70	(68.40)	59.40	(44.80)	4320.00	(3260.00)	1930.00	(1470.00)
8	110.00	(79.40)	72.00	(52.10)	5280.00	(3820.00)	2200.00	(1600.00)	95.90	(71.10)	62.90	(46.60)	4580.00	(3390.00)	1910.00	(1420.00)
9	120.00	(91.80)	78.70	(60.20)	5780.00	(4420.00)	2260.00	(1730.00)	101.00	(79.30)	66.00	(52.00)	4810.00	(3790.00)	1890.00	(1490.00)
10	122.00	(96.40)	79.80	(63.20)	5860.00	(4640.00)	2150.00	(1700.00)	117.00	(91.60)	76.60	(60.10)	5580.00	(4380.00)	2060.00	(1610.00)
11	130.00	(94.80)	85.40	(62.20)	6270.00	(4570.00)	2180.00	(1590.00)	134.00	(95.90)	87.90	(62.90)	6420.00	(4590.00)	2230.00	(1600.00)
12	140.00	(87.90)	91.90	(57.70)	6760.00	(4240.00)	2220.00	(1400.00)	143.00	(85.00)	94.10	(55.70)	6870.00	(4070.00)	2260.00	(1350.00)
13	148.00	(83.80)	97.10	(55.00)	7150.00	(4050.00)	2230.00	(1260.00)	140.00	(71.90)	91.80	(47.10)	6710.00	(3440.00)	2100.00	(1080.00)
14	152.00	(76.30)	99.80	(50.10)	7350.00	(3690.00)	2180.00	(1090.00)	167.00	(85.30)	109.00	(55.90)	8000.00	(4090.00)	2380.00	(1210.00)
15	150.00	(54.10)	98.10	(35.50)	7230.00	(2610.00)	2040.00	(744.00)	164.00	(70.80)	107.00	(46.40)	7860.00	(3400.00)	2230.00	(969.00)
16	167.00	(48.00)	110.00	(31.50)	8080.00	(2320.00)	2190.00	(635.00)	174.00	(55.90)	114.00	(36.70)	8360.00	(2690.00)	2270.00	(740.00)
17	151.00	(48.80)	99.10	(32.00)	7310.00	(2360.00)	1900.00	(628.00)	157.00	(38.20)	103.00	(25.00)	7570.00	(1840.00)	1970.00	(492.00)
18	127.00	(31.50)	83.40	(20.70)	6160.00	(1530.00)	1530.00	(382.00)	142.00	(33.80)	93.20	(22.10)	6840.00	(1630.00)	1700.00	(407.00)
19	136.00	(46.90)	88.90	(30.70)	6570.00	(2270.00)	1570.00	(551.00)	138.00	(39.70)	90.50	(26.10)	6650.00	(1920.00)	1590.00	(463.00)
20	135.00	(31.60)	88.50	(20.70)	6560.00	(1540.00)	1510.00	(353.00)	138.00	(41.00)	90.20	(26.90)	6640.00	(1980.00)	1530.00	(460.00)
21	128.00	(33.60)	84.20	(22.00)	6240.00	(1630.00)	1390.00	(365.00)	138.00	(38.40)	90.40	(25.20)	6670.00	(1860.00)	1480.00	(411.00)
22	115.00	(35.70)	75.40	(23.40)	5590.00	(1740.00)	1200.00	(380.00)	130.00	(50.80)	85.40	(33.30)	6300.00	(2460.00)	1360.00	(536.00)
23	104.00	(35.60)	68.30	(23.40)	5090.00	(1740.00)	1060.00	(362.00)	109.00	(42.60)	71.20	(27.90)	5270.00	(2060.00)	1100.00	(432.00)
24	122.00	(49.10)	79.90	(32.20)	5960.00	(2400.00)	1200.00	(484.00)	117.00	(49.10)	77.00	(32.20)	5700.00	(2380.00)	1150.00	(481.00)
25	128.00	(39.50)	84.10	(25.90)	6290.00	(1940.00)	1240.00	(384.00)	130.00	(42.40)	85.30	(27.80)	6330.00	(2070.00)	1250.00	(410.00)
26	104.00	(30.50)	68.00	(20.00)	5100.00	(1500.00)	976.00	(291.00)	118.00	(29.00)	77.10	(19.00)	5730.00	(1410.00)	1100.00	(276.00)
27	55.30	(53.50)	36.30	(35.10)					96.80	(23.00)	63.50	(15.10)	4720.00	(1120.00)	883.00	(213.00)
28	31.30	(63.20)	20.50	(41.40)					63.50	(46.70)	41.60	(30.60)				
29	18.00	(4.22)	11.80	(2.77)					19.70	(3.12)	12.90	(2.05)				
30	6.55	(10.60)	4.29	(6.98)					7.25	(10.80)	4.76	(7.06)				
31	0.49	(1.33)	0.32	(0.87)					2.55	(7.95)	1.67	(5.21)				
Avg	106.0		69.3		5880.0		1990.0		108.0		71.0		5810.0		1890.0	
n	31		31		26		26		31		31		27		27	
SD	42.3		27.7		1050.0		648.0		42.4		27.8		1330.0		517.0	
Min	0.5		0.3		3980.0		976.0		2.6		1.7		3910.0		883.0	
Max	167.0		110.0		8080.0		4010.0		174.0		114.0		8360.0		2860.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for April, 2009.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		µg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		µg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$	
1	0.23	(0.84)	0.15	(0.55)					0.11	(0.65)	0.07	(0.43)				
2	0.81	(2.39)	0.53	(1.57)					1.05	(1.74)	0.69	(1.14)				
3	-0.41	(1.66)	-0.27	(1.09)					-0.88	(1.29)	-0.58	(0.85)				
4	-3.79	(7.90)	-2.48	(5.18)					-2.21	(11.40)	-1.45	(7.46)				
5	-10.60	(12.80)	-6.98	(8.42)					-11.50	(12.50)	-7.56	(8.21)				
6	-8.51	(13.30)	-5.58	(8.69)					-11.20	(15.20)	-7.33	(9.96)				
7	-0.20	(2.55)	-0.13	(1.67)					-1.81	(2.78)	-1.19	(1.82)				
8	0.06	(0.31)	0.04	(0.20)					0.07	(0.19)	0.05	(0.12)				
9	0.12	(0.28)	0.08	(0.19)					0.18	(0.38)	0.12	(0.25)				
10	0.09	(0.18)	0.06	(0.12)												
11	0.16	(0.24)	0.11	(0.16)	7.50	(11.30)	53.70	(80.20)	0.18	(0.39)	0.12	(0.26)	8.49	(18.30)	61.20	(133.00)
12	0.31	(0.45)	0.21	(0.29)	14.80	(21.10)	125.00	(180.00)	0.36	(0.70)	0.24	(0.46)	17.00	(33.20)	143.00	(282.00)
13	0.75	(1.02)	0.49	(0.67)	35.20	(48.00)	316.00	(432.00)	0.79	(1.64)	0.52	(1.07)	37.30	(77.40)	335.00	(696.00)
14	0.83	(1.34)	0.55	(0.88)	39.40	(63.50)	345.00	(551.00)	0.85	(1.71)	0.56	(1.12)	40.00	(80.80)	349.00	(704.00)
15	1.33	(2.56)	0.87	(1.68)	63.00	(121.00)	489.00	(939.00)	1.24	(2.40)	0.81	(1.58)	58.80	(114.00)	457.00	(884.00)
16	1.83	(2.97)	1.20	(1.94)	86.70	(141.00)	565.00	(914.00)	1.67	(2.50)	1.09	(1.64)	79.20	(119.00)	517.00	(776.00)
17	2.47	(3.26)	1.62	(2.14)	118.00	(155.00)	630.00	(834.00)	2.03	(2.58)	1.33	(1.69)	96.50	(123.00)	519.00	(664.00)
18	2.55	(3.08)	1.67	(2.02)	121.00	(147.00)	526.00	(651.00)	2.39	(2.67)	1.57	(1.75)	114.00	(127.00)	496.00	(565.00)
19	3.23	(3.32)	2.12	(2.18)	153.00	(158.00)	547.00	(579.00)	2.62	(3.00)	1.72	(1.96)	125.00	(143.00)	444.00	(519.00)
20																
21																
22																
23																
24																
25																
26																
27																
28																
29	15.70	(12.20)	10.30	(7.97)	748.00	(581.00)	601.00	(466.00)	8.69	(7.12)	5.70	(4.67)	415.00	(340.00)	334.00	(273.00)
30	25.20	(17.10)	16.50	(11.20)	1200.00	(817.00)	875.00	(594.00)	11.00	(8.40)	7.21	(5.51)	526.00	(401.00)	382.00	(293.00)
Avg	1.5		1.0		236.0		461.0		0.3		0.2		138.0		367.0	
n	21		21		11		11		20		20		11		11	
SD	7.1		4.7		365.0		225.0		4.9		3.2		162.0		142.0	
Min	-10.6		-7.0		7.5		53.7		-11.5		-7.6		8.5		61.2	
Max	25.2		16.5		1200.0		875.0		11.0		7.2		526.0		519.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for May, 2009.

Day	House 10				House 12			
	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}	g d^{-1}	mg d^{-1}m^{-2}	µg d^{-1}hd^{-1}	mg d^{-1}AU^{-1}
1	50.30 (33.60)	33.00 (22.00)	2410.00 (1610.00)	1590.00 (1040.00)	24.60 (17.90)	16.10 (11.70)	1180.00 (856.00)	776.00 (555.00)
2	109.00 (81.70)	71.80 (53.60)	5230.00 (3910.00)	3170.00 (2340.00)	59.00 (49.70)	38.70 (32.60)	2820.00 (2380.00)	1700.00 (1410.00)
3	157.00 (96.90)	103.00 (63.50)	7520.00 (4640.00)	4200.00 (2610.00)	105.00 (67.50)	68.70 (44.20)	5010.00 (3230.00)	2790.00 (1790.00)
4	152.00 (69.40)	99.40 (45.50)	7260.00 (3320.00)	3750.00 (1760.00)	130.00 (63.40)	85.40 (41.60)	6240.00 (3040.00)	3220.00 (1590.00)
5	133.00 (53.90)	87.20 (35.30)	6370.00 (2580.00)	3060.00 (1260.00)	138.00 (68.30)	90.20 (44.80)	6590.00 (3270.00)	3160.00 (1590.00)
6	116.00 (49.60)	76.10 (32.50)	5570.00 (2380.00)	2480.00 (1080.00)	125.00 (66.70)	81.80 (43.70)	5980.00 (3200.00)	2670.00 (1450.00)
7	107.00 (46.70)	70.00 (30.60)	5120.00 (2240.00)	2140.00 (952.00)	120.00 (55.80)	79.00 (36.60)	5780.00 (2680.00)	2410.00 (1130.00)
8	99.90 (39.00)	65.50 (25.60)	4800.00 (1870.00)	1880.00 (747.00)	111.00 (50.20)	72.90 (32.90)	5340.00 (2410.00)	2090.00 (962.00)
9	100.00 (38.90)	65.70 (25.50)	4810.00 (1870.00)	1780.00 (706.00)	110.00 (43.00)	72.30 (28.20)	5300.00 (2070.00)	1950.00 (778.00)
10	78.00 (21.90)	51.20 (14.40)	3750.00 (1050.00)	1310.00 (377.00)	115.00 (30.60)	75.30 (20.10)	5520.00 (1470.00)	1920.00 (518.00)
11	99.00 (30.10)	64.90 (19.70)	4770.00 (1450.00)	1560.00 (471.00)	113.00 (29.60)	73.80 (19.40)	5420.00 (1420.00)	1780.00 (473.00)
12	128.00 (29.40)	83.90 (19.30)	6160.00 (1420.00)	1920.00 (448.00)	127.00 (30.50)	83.20 (20.00)	6110.00 (1470.00)	1910.00 (459.00)
13	126.00 (25.90)	82.90 (17.00)	6100.00 (1250.00)	1810.00 (386.00)	131.00 (34.30)	85.70 (22.50)	6300.00 (1650.00)	1870.00 (505.00)
14	130.00 (16.50)	85.50 (10.80)	6290.00 (796.00)	1780.00 (222.00)	133.00 (26.40)	87.30 (17.30)	6420.00 (1270.00)	1820.00 (363.00)
15	169.00 (24.20)	111.00 (15.90)	8180.00 (1170.00)	2210.00 (314.00)	167.00 (19.70)	110.00 (12.90)	8090.00 (953.00)	2190.00 (251.00)
16	166.00 (28.90)	109.00 (18.90)	8020.00 (1400.00)	2070.00 (343.00)	172.00 (26.30)	113.00 (17.20)	8330.00 (1270.00)	2160.00 (311.00)
17	168.00 (23.70)	110.00 (15.50)	8130.00 (1150.00)	2020.00 (271.00)	181.00 (27.20)	119.00 (17.80)	8790.00 (1320.00)	2180.00 (317.00)
18	144.00 (21.90)	94.70 (14.40)	6990.00 (1060.00)	1670.00 (243.00)	158.00 (22.80)	103.00 (14.90)	7640.00 (1100.00)	1830.00 (250.00)
19	122.00 (15.10)	80.30 (9.88)	5930.00 (730.00)	1370.00 (166.00)	133.00 (17.70)	87.30 (11.60)	6470.00 (858.00)	1490.00 (196.00)
20	107.00 (11.10)	70.10 (7.30)	5180.00 (539.00)	1150.00 (119.00)	117.00 (14.50)	76.80 (9.50)	5700.00 (705.00)	1270.00 (158.00)
21	127.00 (15.50)	83.20 (10.20)	6160.00 (752.00)	1320.00 (155.00)	125.00 (13.70)	82.30 (8.96)	6140.00 (668.00)	1320.00 (142.00)
22	136.00 (18.40)	89.50 (12.00)	6640.00 (894.00)	1380.00 (180.00)	131.00 (16.60)	85.80 (10.90)	6420.00 (816.00)	1340.00 (167.00)
23	127.00 (15.80)	83.50 (10.40)	6200.00 (770.00)	1250.00 (157.00)	126.00 (14.20)	82.90 (9.29)	6220.00 (697.00)	1260.00 (139.00)
24	117.00 (12.20)	76.90 (8.02)	5720.00 (596.00)	1120.00 (117.00)	120.00 (10.30)	78.50 (6.77)	5910.00 (510.00)	1160.00 (103.00)
25	121.00 (15.20)	79.30 (10.00)	5900.00 (744.00)	1130.00 (140.00)	119.00 (13.80)	77.70 (9.08)	5860.00 (685.00)	1120.00 (130.00)
26	99.60 (23.80)	65.30 (15.60)	4870.00 (1160.00)	909.00 (221.00)	103.00 (25.00)	67.80 (16.40)	5120.00 (1240.00)	958.00 (236.00)
27	64.50 (41.70)	42.30 (27.30)			60.20 (24.80)	39.50 (16.20)		
28	65.90 (51.00)	43.20 (33.40)			68.00 (45.10)	44.60 (29.50)		
29	59.00 (21.90)	38.70 (14.30)			63.50 (13.80)	41.70 (9.03)		
30	21.60 (12.00)	14.20 (7.84)			25.10 (9.22)	16.50 (6.05)		
31	8.05 (2.49)	5.28 (1.63)			11.20 (3.16)	7.37 (2.07)		
Avg	110.0	72.1	5930.0	1920.0	110.0	72.4	5950.0	1860.0
n	31	31	26	26	31	31	26	26
SD	39.4	25.9	1310.0	805.0	41.1	26.9	1500.0	627.0
Min	8.1	5.3	2410.0	909.0	11.2	7.4	1180.0	776.0
Max	169.0	111.0	8180.0	4200.0	181.0	119.0	8790.0	3220.0

Table E9. Daily means (SD) of H2S emissions at Site CA1B for June, 2009.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		μg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		μg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$	
1	9.16	(6.80)	6.01	(4.46)					10.60	(19.40)	6.93	(12.70)				
2																
3																
4																
5	4.45	(9.16)	2.92	(6.00)	210.00	(432.00)	1550.00	(3190.00)	8.60	(11.90)	5.64	(7.80)				
6	5.66	(10.10)	3.71	(6.64)	267.00	(478.00)	2270.00	(4050.00)	9.48	(11.80)	6.22	(7.76)	448.00	(559.00)	3300.00	(4110.00)
7	6.69	(9.89)	4.38	(6.49)	316.00	(468.00)	2840.00	(4200.00)	10.40	(13.60)	6.79	(8.89)	490.00	(642.00)	4150.00	(5480.00)
8	6.29	(8.48)	4.12	(5.56)	298.00	(402.00)	2570.00	(3510.00)	8.90	(12.40)	5.84	(8.12)	421.00	(586.00)	3790.00	(5250.00)
9	6.09	(7.23)	4.00	(4.74)	289.00	(343.00)	2210.00	(2630.00)	8.65	(10.20)	5.67	(6.66)	410.00	(482.00)	3550.00	(4180.00)
10	6.38	(7.30)	4.18	(4.79)	303.00	(346.00)	1950.00	(2240.00)	8.51	(9.21)	5.58	(6.04)	404.00	(437.00)	3100.00	(3410.00)
11	5.96	(6.68)	3.91	(4.38)	283.00	(317.00)	1480.00	(1700.00)	7.66	(7.52)	5.02	(4.93)	363.00	(357.00)	2340.00	(2340.00)
12	6.32	(6.21)	4.15	(4.07)	300.00	(294.00)	1260.00	(1260.00)	8.35	(7.66)	5.47	(5.02)	396.00	(363.00)	2070.00	(1910.00)
13	7.80	(7.13)	5.11	(4.67)	370.00	(338.00)	1270.00	(1170.00)	9.03	(8.44)	5.92	(5.54)	429.00	(401.00)	1810.00	(1710.00)
14	8.86	(9.33)	5.81	(6.12)	421.00	(443.00)	1190.00	(1260.00)	8.16	(9.38)	5.35	(6.15)	387.00	(446.00)	1340.00	(1540.00)
15	10.50	(11.60)	6.87	(7.61)	498.00	(551.00)	1170.00	(1310.00)	8.97	(11.40)	5.88	(7.47)	426.00	(541.00)	1210.00	(1540.00)
16	11.10	(9.86)	7.26	(6.46)	526.00	(468.00)	1050.00	(957.00)	9.34	(9.91)	6.12	(6.50)	444.00	(471.00)	1050.00	(1140.00)
17	10.50	(7.89)	6.88	(5.18)	499.00	(375.00)	845.00	(651.00)	8.98	(8.44)	5.89	(5.53)	427.00	(401.00)	850.00	(815.00)
18	11.00	(7.49)	7.25	(4.91)	526.00	(356.00)	768.00	(535.00)	9.56	(8.35)	6.27	(5.47)	455.00	(397.00)	771.00	(690.00)
19	12.20	(7.63)	7.97	(5.00)	579.00	(363.00)	736.00	(474.00)	11.10	(8.15)	7.31	(5.34)	530.00	(388.00)	774.00	(576.00)
20	12.50	(8.19)	8.20	(5.37)	596.00	(390.00)	664.00	(436.00)	10.70	(8.32)	7.03	(5.45)	510.00	(396.00)	647.00	(507.00)
21	16.40	(10.00)	10.70	(6.59)	780.00	(479.00)	771.00	(475.00)	13.40	(9.55)	8.76	(6.26)	637.00	(455.00)	710.00	(508.00)
22	23.00	(14.00)	15.10	(9.19)	1100.00	(669.00)	971.00	(603.00)	17.00	(12.10)	11.20	(7.92)	812.00	(576.00)	804.00	(583.00)
23	23.40	(13.70)	15.40	(8.99)	1120.00	(655.00)	893.00	(544.00)	18.60	(10.50)	12.20	(6.92)	889.00	(504.00)	789.00	(465.00)
24	26.30	(9.49)	17.30	(6.22)	1260.00	(453.00)	906.00	(336.00)	22.30	(9.09)	14.60	(5.96)	1070.00	(434.00)	846.00	(351.00)
25	24.90	(11.70)	16.30	(7.64)	1190.00	(557.00)	782.00	(371.00)	26.50	(13.30)	17.40	(8.74)	1270.00	(638.00)	915.00	(464.00)
26	30.80	(12.90)	20.20	(8.49)	1480.00	(620.00)	886.00	(380.00)	30.70	(13.40)	20.10	(8.77)	1470.00	(641.00)	965.00	(431.00)
27	52.30	(13.60)	34.30	(8.91)	2510.00	(652.00)	1380.00	(349.00)	47.20	(14.00)	31.00	(9.18)	2270.00	(672.00)	1360.00	(395.00)
28	70.50	(20.40)	46.20	(13.40)	3380.00	(981.00)	1720.00	(491.00)	66.40	(15.60)	43.50	(10.20)	3190.00	(748.00)	1760.00	(392.00)
29	76.40	(19.20)	50.10	(12.60)	3670.00	(921.00)	1740.00	(421.00)	78.50	(20.40)	51.50	(13.40)	3780.00	(981.00)	1930.00	(488.00)
30	73.50	(22.60)	48.20	(14.80)	3530.00	(1090.00)	1560.00	(471.00)	78.80	(18.40)	51.60	(12.10)	3790.00	(885.00)	1790.00	(408.00)
Avg	20.7		13.6		1010.0		1360.0		20.6		13.5		1030.0		1700.0	
n	27		27		26		26		27		27		25		25	
SD	21.3		14.0		1040.0		590.0		21.0		13.8		1040.0		1060.0	
Min	4.5		2.9		210.0		664.0		7.7		5.0		363.0		647.0	
Max	76.4		50.1		3670.0		2840.0		78.8		51.6		3790.0		4150.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for July, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	95.30	(23.00)	62.50	(15.10)	4590.00	(1110.00)	1890.00	(446.00)	99.50	(27.60)	65.20	(18.10)	4790.00	(1330.00)	2110.00	(575.00)
2	114.00	(25.60)	74.70	(16.80)	5500.00	(1240.00)	2130.00	(476.00)	112.00	(22.80)	73.60	(15.00)	5420.00	(1100.00)	2240.00	(459.00)
3	117.00	(24.90)	76.70	(16.30)	5650.00	(1200.00)	2060.00	(429.00)	105.00	(18.60)	69.20	(12.20)	5090.00	(899.00)	1980.00	(350.00)
4	137.00	(31.90)	89.60	(20.90)	6600.00	(1540.00)	2280.00	(528.00)	116.00	(23.50)	76.20	(15.40)	5620.00	(1140.00)	2050.00	(407.00)
5	142.00	(28.40)	93.30	(18.60)	6880.00	(1380.00)	2250.00	(450.00)	124.00	(23.40)	81.10	(15.40)	5990.00	(1130.00)	2060.00	(392.00)
6	131.00	(29.90)	86.00	(19.60)	6350.00	(1450.00)	1970.00	(458.00)	114.00	(28.40)	74.70	(18.60)	5520.00	(1370.00)	1800.00	(455.00)
7	115.00	(25.90)	75.50	(17.00)	5580.00	(1260.00)	1650.00	(380.00)	95.90	(19.50)	62.90	(12.80)	4650.00	(945.00)	1440.00	(298.00)
8	116.00	(17.70)	76.40	(11.60)	5650.00	(858.00)	1590.00	(238.00)	111.00	(17.60)	72.80	(11.50)	5390.00	(852.00)	1590.00	(243.00)
9	128.00	(17.90)	84.20	(11.70)	6240.00	(870.00)	1680.00	(230.00)	120.00	(15.70)	78.60	(10.30)	5820.00	(764.00)	1640.00	(211.00)
10	130.00	(12.00)	85.00	(7.86)	6300.00	(583.00)	1620.00	(150.00)	137.00	(16.70)	89.60	(11.00)	6640.00	(813.00)	1790.00	(212.00)
11	118.00	(11.60)	77.20	(7.58)	5730.00	(563.00)	1420.00	(128.00)	130.00	(13.10)	85.30	(8.60)	6330.00	(638.00)	1630.00	(160.00)
12	115.00	(13.10)	75.30	(8.61)	5590.00	(639.00)	1330.00	(144.00)	124.00	(10.10)	81.10	(6.63)	6030.00	(493.00)	1490.00	(120.00)
13	125.00	(18.90)	82.10	(12.40)	6110.00	(920.00)	1400.00	(202.00)	132.00	(21.20)	86.40	(13.90)	6430.00	(1040.00)	1530.00	(239.00)
14	169.00	(180.00)	111.00	(118.00)	8250.00	(8780.00)	1820.00	(1940.00)	127.00	(47.50)	83.30	(31.20)	6230.00	(2330.00)	1420.00	(524.00)
15																
16																
17	181.00	(29.80)	119.00	(19.60)	8910.00	(1470.00)	1790.00	(285.00)	181.00	(28.90)	118.00	(18.90)	8910.00	(1420.00)	1850.00	(284.00)
18	157.00	(24.20)	103.00	(15.90)	7700.00	(1190.00)	1510.00	(224.00)	164.00	(24.20)	107.00	(15.90)	8110.00	(1200.00)	1630.00	(231.00)
19	164.00	(25.50)	107.00	(16.70)	8070.00	(1260.00)	1540.00	(231.00)	173.00	(24.00)	114.00	(15.80)	8590.00	(1190.00)	1680.00	(223.00)
20	104.00	(37.20)	68.00	(24.40)	5140.00	(1850.00)	958.00	(349.00)	113.00	(37.60)	74.10	(24.70)	5630.00	(1880.00)	1080.00	(365.00)
21	98.00	(47.00)	64.30	(30.80)												
22	60.20	(58.80)	39.50	(38.60)					49.40	(55.00)	32.40	(36.10)				
23	36.70	(9.98)	24.00	(6.54)					37.00	(9.02)	24.20	(5.91)				
24																
25																
26																
27																
28	7.03	(9.68)	4.61	(6.35)					6.69	(9.75)	4.39	(6.40)				
29	6.22	(7.83)	4.08	(5.13)					6.03	(8.88)	3.96	(5.82)				
30	5.59	(7.03)	3.66	(4.61)					6.00	(7.13)	3.93	(4.68)				
31	5.00	(7.84)	3.28	(5.14)	259.00	(407.00)	1940.00	(3000.00)	5.60	(7.90)	3.67	(5.18)	291.00	(410.00)	2090.00	(2940.00)
Avg	103.0		67.6		6060.0		1730.0		99.5		65.3		5870.0		1740.0	
n	25		25		19		19		24		24		19		19	
SD	51.9		34.0		1760.0		329.0		51.7		33.9		1750.0		289.0	
Min	5.0		3.3		259.0		958.0		5.6		3.7		291.0		1080.0	
Max	181.0		119.0		8910.0		2280.0		181.0		118.0		8910.0		2240.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for August, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	5.07	(7.09)	3.32	(4.65)	263.00	(368.00)	2250.00	(3090.00)	5.30	(7.90)	3.48	(5.18)	276.00	(411.00)	2310.00	(3390.00)
2	4.62	(5.17)	3.03	(3.39)	240.00	(269.00)	2160.00	(2410.00)	5.05	(6.34)	3.31	(4.16)	263.00	(330.00)	2360.00	(2950.00)
3	4.29	(4.76)	2.82	(3.12)	223.00	(247.00)	1920.00	(2140.00)	4.57	(5.06)	3.00	(3.32)	238.00	(264.00)	2080.00	(2310.00)
4																
5																
6																
7																
8	4.25	(4.79)	2.78	(3.14)	222.00	(250.00)	751.00	(857.00)	3.35	(4.31)	2.20	(2.83)	176.00	(226.00)	624.00	(816.00)
9	5.14	(5.03)	3.37	(3.30)	268.00	(263.00)	751.00	(753.00)	4.85	(5.86)	3.18	(3.84)	254.00	(307.00)	736.00	(886.00)
10	5.20	(5.04)	3.41	(3.30)	272.00	(263.00)	631.00	(637.00)	9.50	(8.05)	6.23	(5.28)	498.00	(422.00)	1190.00	(1040.00)
11	5.21	(3.74)	3.42	(2.45)	273.00	(195.00)	530.00	(381.00)	11.50	(7.19)	7.55	(4.71)	604.00	(377.00)	1220.00	(784.00)
12	7.62	(4.11)	5.00	(2.69)	399.00	(215.00)	662.00	(362.00)	11.20	(6.34)	7.33	(4.15)	587.00	(332.00)	1010.00	(581.00)
13	6.65	(3.90)	4.36	(2.56)	348.00	(204.00)	501.00	(300.00)	8.52	(5.07)	5.59	(3.32)	448.00	(266.00)	664.00	(405.00)
14	6.57	(4.04)	4.31	(2.65)	344.00	(212.00)	431.00	(270.00)	7.13	(4.64)	4.68	(3.04)	375.00	(244.00)	484.00	(319.00)
15	7.57	(4.27)	4.97	(2.80)	397.00	(224.00)	437.00	(249.00)	7.08	(4.52)	4.64	(2.96)	372.00	(237.00)	420.00	(273.00)
16																
17																
18	9.40	(4.55)	6.17	(2.98)	493.00	(239.00)	388.00	(191.00)	8.11	(4.49)	5.32	(2.95)	427.00	(236.00)	343.00	(192.00)
19	13.60	(4.95)	8.89	(3.25)	711.00	(260.00)	506.00	(187.00)	11.50	(4.95)	7.57	(3.24)	607.00	(261.00)	441.00	(192.00)
20	18.70	(7.14)	12.20	(4.68)	980.00	(375.00)	636.00	(244.00)	15.10	(6.49)	9.91	(4.26)	795.00	(342.00)	526.00	(226.00)
21	29.30	(8.39)	19.20	(5.50)	1540.00	(441.00)	914.00	(259.00)	22.60	(8.27)	14.80	(5.42)	1190.00	(435.00)	720.00	(261.00)
22	48.60	(12.40)	31.90	(8.10)	2550.00	(649.00)	1390.00	(332.00)	38.50	(12.40)	25.30	(8.13)	2030.00	(653.00)	1120.00	(344.00)
23	56.70	(17.80)	37.20	(11.70)	2980.00	(936.00)	1510.00	(467.00)	48.50	(17.00)	31.80	(11.10)	2550.00	(895.00)	1310.00	(457.00)
24	70.30	(33.30)	46.10	(21.90)	3700.00	(1750.00)	1740.00	(836.00)	59.00	(28.30)	38.70	(18.60)	3110.00	(1490.00)	1490.00	(721.00)
25	77.10	(31.70)	50.60	(20.80)	4060.00	(1670.00)	1780.00	(738.00)	69.60	(33.00)	45.70	(21.60)	3670.00	(1740.00)	1630.00	(783.00)
26	89.00	(37.20)	58.30	(24.40)	4680.00	(1960.00)	1920.00	(812.00)	85.50	(35.80)	56.10	(23.50)	4510.00	(1890.00)	1880.00	(792.00)
27	94.90	(31.20)	62.20	(20.50)	5000.00	(1650.00)	1920.00	(637.00)	84.00	(31.20)	55.10	(20.40)	4440.00	(1650.00)	1730.00	(647.00)
28	117.00	(30.00)	76.90	(19.70)	6180.00	(1580.00)	2240.00	(588.00)	109.00	(24.30)	71.20	(15.90)	5730.00	(1280.00)	2110.00	(480.00)
29	111.00	(17.60)	72.80	(11.50)	5850.00	(927.00)	2000.00	(306.00)	110.00	(18.20)	71.90	(11.90)	5800.00	(962.00)	2010.00	(327.00)
30	104.00	(13.60)	67.90	(8.90)	5460.00	(716.00)	1770.00	(232.00)	107.00	(19.00)	70.40	(12.50)	5680.00	(1010.00)	1860.00	(329.00)
31	124.00	(19.40)	81.30	(12.70)	6550.00	(1020.00)	2020.00	(305.00)	120.00	(22.60)	78.90	(14.80)	6370.00	(1200.00)	1980.00	(371.00)
Avg	41.0		26.9		2160.0		1270.0		38.7		25.3		2040.0		1290.0	
n	25		25		25		25		25		25		25		25	
SD	42.6		27.9		2250.0		682.0		40.3		26.4		2130.0		654.0	
Min	4.3		2.8		222.0		388.0		3.4		2.2		176.0		343.0	
Max	124.0		81.3		6550.0		2250.0		120.0		78.9		6370.0		2360.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for September, 2009.

Day	House 10								House 12							
	g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}		g d^{-1}		mg d^{-1}m^{-2}		µg d^{-1}hd^{-1}		mg d^{-1}AU^{-1}	
1	145.00	(23.00)	94.80	(15.10)	7640.00	(1210.00)	2240.00	(332.00)	150.00	(24.60)	98.00	(16.10)	7920.00	(1300.00)	2340.00	(365.00)
2	158.00	(21.70)	103.00	(14.30)	8340.00	(1150.00)	2330.00	(304.00)	165.00	(24.10)	108.00	(15.80)	8730.00	(1280.00)	2470.00	(341.00)
3	133.00	(13.20)	87.00	(8.63)	7020.00	(696.00)	1880.00	(180.00)	142.00	(16.80)	93.40	(11.00)	7550.00	(890.00)	2040.00	(231.00)
4	118.00	(17.90)	77.40	(11.70)	6250.00	(945.00)	1600.00	(239.00)	124.00	(17.70)	81.20	(11.60)	6570.00	(937.00)	1700.00	(243.00)
5	159.00	(31.80)	105.00	(20.90)	8440.00	(1690.00)	2080.00	(396.00)	146.00	(28.70)	96.00	(18.80)	7770.00	(1520.00)	1930.00	(362.00)
6	129.00	(16.70)	84.30	(11.00)	6820.00	(886.00)	1620.00	(215.00)	140.00	(21.10)	91.50	(13.90)	7410.00	(1120.00)	1770.00	(273.00)
7	127.00	(28.60)	83.20	(18.80)	6730.00	(1520.00)	1540.00	(338.00)	138.00	(25.20)	90.30	(16.50)	7320.00	(1340.00)	1680.00	(296.00)
8	120.00	(19.50)	78.60	(12.80)	6360.00	(1040.00)	1400.00	(222.00)	129.00	(19.40)	84.40	(12.70)	6850.00	(1030.00)	1520.00	(220.00)
9																
10	86.10	(46.00)	56.50	(30.10)	4580.00	(2450.00)	949.00	(505.00)								
11	125.00	(25.90)	81.70	(17.00)	6640.00	(1380.00)	1330.00	(268.00)	128.00	(24.70)	83.70	(16.20)	6820.00	(1320.00)	1380.00	(257.00)
12	116.00	(17.80)	76.00	(11.70)	6190.00	(952.00)	1210.00	(186.00)	120.00	(23.00)	78.80	(15.10)	6430.00	(1230.00)	1260.00	(242.00)
13	85.60	(19.60)	56.20	(12.90)	4590.00	(1050.00)	875.00	(204.00)								
14	67.80	(23.80)	44.50	(15.60)					70.70	(27.50)	46.30	(18.10)				
15	30.70	(32.50)	20.10	(21.30)					37.30	(28.00)	24.40	(18.40)				
16	5.59	(5.64)	3.66	(3.70)					7.41	(8.55)	4.86	(5.61)				
17	4.04	(1.83)	2.65	(1.20)					5.10	(3.72)	3.34	(2.44)				
18	2.18	(3.55)	1.43	(2.33)					3.22	(5.58)	2.11	(3.66)				
19	2.60	(9.09)	1.70	(5.96)					0.05	(1.06)	0.03	(0.69)				
20	0.60	(0.75)	0.40	(0.49)					0.48	(1.07)	0.32	(0.70)				
21	-0.31	(0.97)	-0.21	(0.64)					-0.46	(0.91)	-0.30	(0.59)				
22	-4.47	(6.53)	-2.93	(4.28)					-7.51	(10.70)	-4.93	(7.01)				
23	0.28	(0.55)	0.19	(0.36)					0.13	(0.52)	0.08	(0.34)				
24	0.32	(0.43)	0.21	(0.28)					0.15	(0.34)	0.10	(0.22)				
25	0.16	(0.57)	0.11	(0.37)					0.17	(0.44)	0.11	(0.29)				
26	-2.36	(3.30)	-1.55	(2.16)					-2.23	(3.08)	-1.46	(2.02)				
27	0.06	(1.54)	0.04	(1.01)	3.04	(79.80)	14.80	(575.00)	-0.08	(1.14)	-0.05	(0.75)	-4.09	(59.00)	-37.60	(424.00)
28	0.23	(0.46)	0.15	(0.30)	12.00	(23.60)	103.00	(204.00)	0.17	(0.44)	0.11	(0.29)	8.78	(22.90)	75.40	(198.00)
29	0.69	(0.88)	0.45	(0.57)	35.80	(45.60)	322.00	(410.00)	0.71	(1.23)	0.47	(0.81)	37.00	(63.90)	332.00	(574.00)
30	0.93	(1.18)	0.61	(0.77)	48.20	(61.40)	418.00	(535.00)	0.95	(1.57)	0.62	(1.03)	49.20	(81.60)	428.00	(712.00)
Avg	55.5		36.4		4980.0		1240.0		55.4		36.4		5250.0		1350.0	
n	29		29		16		16		27		27		14		14	
SD	61.5		40.3		3030.0		717.0		65.5		43.0		3350.0		799.0	
Min	-4.5		-2.9		3.0		14.8		-7.5		-4.9		-4.1		-37.6	
Max	159.0		105.0		8440.0		2330.0		165.0		108.0		8730.0		2470.0	

Table E9. Daily means (SD) of H2S emissions at Site CA1B for October, 2009.

Day	House 10								House 12							
	g d^{-1}		mg $d^{-1}m^{-2}$		µg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$		g d^{-1}		mg $d^{-1}m^{-2}$		µg $d^{-1}hd^{-1}$		mg $d^{-1}AU^{-1}$	
1	0.36	(1.58)	0.23	(1.04)	18.50	(82.40)	132.00	(599.00)	0.46	(1.52)	0.30	(1.00)	23.80	(79.20)	173.00	(582.00)
2	1.77	(2.25)	1.16	(1.48)	92.40	(118.00)	593.00	(754.00)	2.10	(2.72)	1.38	(1.78)	110.00	(142.00)	709.00	(916.00)
3	1.74	(1.78)	1.14	(1.17)	90.80	(92.70)	479.00	(499.00)	2.32	(2.40)	1.52	(1.57)	121.00	(125.00)	642.00	(676.00)
4	1.40	(1.52)	0.92	(1.00)	73.20	(79.50)	307.00	(329.00)	1.74	(1.89)	1.14	(1.24)	90.90	(98.60)	385.00	(414.00)
5	2.04	(2.36)	1.34	(1.55)	106.00	(123.00)	365.00	(416.00)	1.96	(2.46)	1.29	(1.61)	102.00	(128.00)	355.00	(439.00)
6	2.61	(2.88)	1.71	(1.89)	136.00	(151.00)	387.00	(437.00)	2.31	(2.81)	1.52	(1.85)	121.00	(147.00)	344.00	(424.00)
7																
8	3.56	(3.30)	2.33	(2.16)	186.00	(172.00)	369.00	(346.00)	2.65	(2.59)	1.74	(1.70)	138.00	(135.00)	276.00	(272.00)
9	3.32	(3.36)	2.18	(2.21)	174.00	(176.00)	294.00	(304.00)	2.65	(2.79)	1.74	(1.83)	139.00	(146.00)	237.00	(253.00)
10	4.15	(3.94)	2.72	(2.58)	217.00	(206.00)	316.00	(300.00)	3.26	(3.25)	2.14	(2.13)	170.00	(170.00)	250.00	(249.00)
11	6.34	(6.11)	4.16	(4.01)	332.00	(320.00)	420.00	(403.00)	5.60	(5.96)	3.68	(3.91)	293.00	(312.00)	372.00	(393.00)
12	9.64	(8.31)	6.32	(5.45)	505.00	(435.00)	561.00	(484.00)	8.72	(8.66)	5.72	(5.68)	456.00	(453.00)	509.00	(504.00)
13																
14																
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29																
30																
31																
Avg	3.4		2.2		175.0		384.0		3.1		2.0		160.0		387.0	
n	11		11		11		11		11		11		11		11	
SD	2.5		1.7		131.0		124.0		2.2		1.4		112.0		161.0	
Min	0.4		0.2		18.5		132.0		0.5		0.3		23.8		173.0	
Max	9.6		6.3		505.0		593.0		8.7		5.7		456.0		709.0	

Table E10. NH3 concentrations

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for December, 2007.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
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24												
25												
26												
27												
28												
29	-0.1	(0.2)	-0.1	(0.1)	38.5	(1.8)	27.6	(1.3)	35.5	(1.6)	25.5	(1.1)
30	0.2	(0.2)	0.1	(0.1)	41.8	(1.9)	30.0	(1.4)	36.6	(2.2)	26.3	(1.6)
31	0.3	(0.4)	0.2	(0.3)	41.2	(1.9)	29.5	(1.4)	104.0	(104.0)	37.2	(29.8)
Avg	0.2		0.1		40.5		29		58.8		29.7	
n	3		3		3		3		3		3	
SD	0.2		0.1		1.5		1.1		32.1		5.4	
Min	-0.1		-0.1		38.5		27.6		35.5		25.5	
Max	0.3		0.2		41.8		30.0		104.0		37.2	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for January, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	1.0	(0.7)	0.7	(0.5)	38.6	(8.9)	27.6	(6.4)	148.0	(159.0)		
2	0.4	(0.4)	0.3	(0.3)	27.4	(10.4)	19.5	(7.5)	76.2	(61.9)		
3	0.7	(0.4)	0.5	(0.3)	159.0	(130.0)	115.0	(93.8)	104.0	(60.7)		
4	0.8	(0.2)	0.5	(0.1)	208.0	(56.9)	149.0	(41.0)	149.0	(28.2)	108.0	(20.8)
5	1.0	(0.2)	0.7	(0.1)	219.0	(35.8)	157.0	(25.8)	170.0	(14.4)	122.0	(10.4)
6	0.9	(0.1)	0.6	(0.1)	194.0	(6.4)	139.0	(4.6)	162.0	(7.2)	116.0	(5.2)
7	0.8	(0.2)	0.5	(0.1)	160.0	(8.7)	115.0	(6.3)	139.0	(5.8)	99.4	(4.2)
8	0.4	(0.1)	0.3	(0.1)	129.0	(7.0)	92.9	(5.0)	122.0	(2.7)	87.4	(1.9)
9	0.7	(0.3)	0.5	(0.2)	123.0	(3.8)	88.9	(2.8)	114.0	(3.4)	82.1	(2.4)
10	0.5	(0.0)	0.3	(0.0)	110.0	(6.3)	79.2	(4.6)	101.0	(5.8)		
11	0.4	(0.1)	0.3	(0.1)	90.1	(5.1)	64.8	(3.7)	81.9	(4.6)	57.9	(2.8)
12	0.3	(0.0)	0.2	(0.0)	74.4	(9.2)	53.5	(6.6)	67.6	(5.8)	48.7	(4.2)
13	0.2	(0.1)	0.1	(0.1)	60.8	(8.3)	43.7	(6.0)	53.4	(7.6)	38.4	(5.5)
14	0.0	(0.1)	0.0	(0.1)	50.5	(7.6)	36.3	(5.5)	43.5	(6.0)	31.3	(4.4)
15	0.0	(0.1)	0.0	(0.0)	57.6	(5.1)	41.6	(3.7)	48.1	(4.6)	34.7	(3.3)
16	0.0	(0.0)	0.0	(0.0)	48.3	(7.3)	34.8	(5.3)	40.3	(5.3)	29.0	(3.8)
17	0.0	(0.1)	0.0	(0.1)	41.7	(5.3)	30.0	(3.8)	33.7	(6.4)	24.2	(4.6)
18	-0.1	(0.0)	0.0	(0.0)	42.2	(8.0)	30.4	(5.8)	32.0	(6.0)	23.0	(4.3)
19	0.0	(0.1)	0.0	(0.1)	37.3	(7.8)	26.8	(5.6)	27.5	(5.5)	19.8	(4.0)
20	-0.1	(0.1)	0.0	(0.0)	34.7	(3.5)	25.0	(2.6)	25.1	(2.9)	18.0	(2.1)
21	0.0	(0.1)	0.0	(0.1)	34.7	(3.3)	25.0	(2.4)	23.2	(2.7)	16.7	(1.9)
22	-0.2	(0.0)	-0.1	(0.0)	30.1	(2.7)	21.7	(2.0)	19.7	(2.8)	14.2	(2.0)
23	-0.2	(0.0)	-0.1	(0.0)	30.2	(2.3)	21.7	(1.6)	18.0	(2.0)	12.9	(1.4)
24	-0.3	(0.0)	-0.2	(0.0)	31.9	(2.5)	22.9	(1.8)	18.7	(2.2)	13.4	(1.6)
25	1.9	(1.3)	1.3	(0.9)	31.4	(3.0)	22.6	(2.1)	20.5	(2.0)	14.7	(1.4)
26	4.0	(0.9)	2.9	(0.7)	29.1	(1.8)	20.9	(1.3)	22.6	(2.0)	16.2	(1.5)
27	5.3	(0.7)	3.8	(0.5)	30.5	(1.8)	21.9	(1.3)	24.2	(2.0)	17.4	(1.5)
28	1.6	(1.7)			30.9	(2.5)	22.2	(1.8)	25.7	(2.3)	18.4	(1.7)
29	-0.3	(0.0)	-0.2	(0.0)	32.6	(2.6)	23.4	(1.9)	29.0	(3.8)	20.8	(2.7)
30	-0.2	(0.1)	-0.1	(0.0)	32.8	(3.0)	23.5	(2.2)	27.9	(3.2)	20.0	(2.3)
31	-0.2	(0.0)	-0.2	(0.0)	36.8	(2.7)	26.4	(1.9)	29.2	(2.1)	20.9	(1.5)
Avg	0.6		0.4		72.9		52.4		64.4		41.7	
n	31		30		31		31		31		27	
SD	1.2		0.9		58.1		41.8		48.9		34.8	
Min	-0.3		-0.2		27.4		19.5		18.0		12.9	
Max	5.3		3.8		219.0		157.0		170.0		122.0	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for February, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1					37.9	(3.4)	27.2	(2.4)	30.0	(3.0)	21.5	(2.2)
2												
3												
4												
5	-0.1	(0.1)	-0.1	(0.0)	38.3	(5.9)	27.5	(4.2)	31.6	(4.6)	22.7	(3.3)
6	-0.1	(0.1)	0.0	(0.1)	33.8	(5.7)	24.2	(4.1)	28.0	(3.7)	20.1	(2.7)
7	-0.1	(0.1)	-0.1	(0.0)	33.3	(2.8)	23.9	(2.0)	30.6	(3.6)	21.9	(2.6)
8	0.0	(0.1)	0.0	(0.1)	35.9	(3.8)	25.7	(2.7)	31.5	(3.7)	22.6	(2.7)
9	0.2	(0.1)	0.2	(0.0)	35.7	(6.3)	25.6	(4.5)	30.8	(4.0)	22.1	(2.9)
10	0.2	(0.1)	0.2	(0.1)	37.4	(7.6)	26.8	(5.4)	32.6	(5.2)	23.4	(3.7)
11	0.3	(0.2)	0.2	(0.2)	34.8	(6.7)	25.0	(4.8)	31.2	(6.8)	22.4	(4.9)
12	0.1	(0.1)	0.0	(0.1)	28.8	(9.2)	20.6	(6.6)	25.3	(7.0)	18.1	(5.0)
13	0.2	(0.3)	0.1	(0.2)	28.7	(5.7)	20.5	(4.1)	27.1	(3.7)	19.4	(2.7)
14	0.2	(0.1)	0.1	(0.1)	26.1	(4.8)	18.8	(3.4)	24.7	(4.1)	17.8	(2.9)
15	0.1	(0.2)	0.1	(0.2)	25.9	(6.7)	18.5	(4.8)	25.0	(5.5)	17.9	(3.9)
16	0.2	(0.1)	0.1	(0.1)	25.8	(5.4)	18.5	(3.8)	23.7	(5.2)	17.0	(3.7)
17	0.0	(0.1)	0.0	(0.1)	27.8	(6.3)	19.9	(4.5)	26.0	(5.6)	18.6	(4.0)
18	0.1	(0.1)	0.1	(0.1)	30.5	(6.0)	21.8	(4.3)	27.6	(5.2)	19.8	(3.7)
19	0.2	(0.1)	0.2	(0.0)	32.1	(4.8)	23.0	(3.4)	29.2	(3.0)	20.9	(2.2)
20	0.3	(0.1)	0.2	(0.0)	28.8	(5.0)	20.6	(3.6)	28.4	(3.9)	20.3	(2.8)
21	0.1	(0.1)	0.1	(0.0)	18.2	(11.4)	12.8	(8.2)	32.5	(7.3)	23.2	(5.3)
22	-0.2	(0.2)	-0.1	(0.1)								
23	-0.4	(0.0)	-0.3	(0.0)								
24	-0.4	(0.1)	-0.3	(0.0)	10.2	(1.1)	7.3	(0.8)	7.7	(1.6)	5.5	(1.2)
25	0.1	(0.4)	0.0	(0.3)	13.1	(6.8)	9.3	(4.9)	12.3	(5.9)	8.8	(4.2)
26	0.1	(0.4)	0.1	(0.3)	113.0	(92.4)	80.9	(68.5)	99.6	(82.5)	71.0	(61.2)
27	0.6	(0.0)	0.5	(0.0)	218.0	(36.0)	157.0	(26.0)	190.0	(29.8)	137.0	(21.5)
28	0.6	(0.1)	0.5	(0.1)	174.0	(35.6)	125.0	(25.6)	152.0	(32.4)	109.0	(23.2)
29	0.5	(0.1)	0.4	(0.1)	141.0	(20.0)	102.0	(14.3)	124.0	(20.0)	89.3	(14.4)
Avg	0.1		0.1		51.3		36.8		45.9		32.9	
n	25		25		24		24		24		24	
SD	0.3		0.2		52.4		37.7		45.2		32.5	
Min	-0.4		-0.3		10.2		7.3		7.7		5.5	
Max	0.6		0.5		218.0		157.0		190.0		137.0	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for March, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.3	(0.1)	0.2	(0.0)	122.0	(14.6)	87.3	(10.5)	115.0	(15.1)	82.5	(10.9)
2	0.2	(0.0)	0.1	(0.0)	87.2	(17.4)	62.5	(12.5)	83.6	(18.6)	60.0	(13.4)
3	0.1	(0.0)	0.1	(0.0)	60.9	(13.5)	43.7	(9.7)	59.3	(14.8)	42.5	(10.6)
4	0.2	(0.1)	0.1	(0.0)	61.8	(14.8)	44.4	(10.6)	56.8	(17.3)	40.7	(12.5)
5	0.1	(0.0)	0.0	(0.0)	62.3	(7.0)	44.7	(5.0)	56.5	(8.9)	40.6	(6.4)
6	0.1	(0.0)	0.1	(0.0)	59.5	(12.1)	42.8	(8.7)	54.4	(12.5)	39.1	(9.0)
7	0.0	(0.0)	0.0	(0.0)	53.3	(12.2)	38.3	(8.8)	45.3	(11.3)	32.6	(8.1)
8	-0.1	(0.1)	-0.1	(0.1)	33.6	(24.2)	24.3	(17.4)	26.9	(19.4)	19.4	(14.0)
9	-0.4	(0.1)	-0.3	(0.0)	10.9	(1.7)	7.9	(1.3)	8.4	(1.4)	6.0	(1.0)
10	-0.3	(0.0)	-0.2	(0.0)	12.6	(3.1)	9.1	(2.2)	8.3	(2.0)	6.0	(1.5)
11	-0.3	(0.0)	-0.2	(0.0)	18.6	(2.1)	13.4	(1.5)	10.2	(0.7)	7.3	(0.5)
12	-0.3	(0.1)	-0.2	(0.0)	22.7	(3.1)	16.3	(2.2)	11.4	(1.8)	8.2	(1.3)
13	-0.3	(0.0)	-0.2	(0.0)	26.1	(3.6)	18.8	(2.6)	13.7	(1.5)	9.9	(1.1)
14	-0.4	(0.0)	-0.3	(0.0)	26.7	(2.5)	19.2	(1.8)	15.5	(1.3)	11.2	(1.0)
15	-0.4	(0.0)	-0.3	(0.0)	27.0	(2.1)	19.4	(1.5)	15.2	(1.1)	10.9	(0.8)
16	-0.5	(0.0)	-0.3	(0.0)	24.6	(2.6)	17.6	(1.9)	14.3	(1.0)	10.2	(0.7)
17	-0.5	(0.1)	-0.3	(0.0)	21.1	(3.7)	15.1	(2.7)	12.7	(2.1)	9.1	(1.5)
18	-0.4	(0.0)	-0.3	(0.0)	17.5	(4.1)	12.6	(3.0)	10.0	(2.0)	7.2	(1.4)
19	-0.4	(0.0)	-0.3	(0.0)	20.2	(3.4)	14.5	(2.5)	10.8	(1.4)	7.8	(1.0)
20	-0.4	(0.0)	-0.3	(0.0)	24.4	(2.1)	17.5	(1.5)	13.6	(0.9)	9.7	(0.7)
21	-0.4	(0.1)	-0.3	(0.0)	27.4	(3.5)	19.6	(2.5)	16.0	(1.6)	11.5	(1.2)
22	-0.2	(0.1)	-0.2	(0.1)	23.3	(5.8)	16.7	(4.1)	15.9	(2.8)	11.4	(2.0)
23	-0.2	(0.1)	-0.2	(0.1)	19.8	(6.1)	14.2	(4.4)	15.4	(4.1)	11.1	(3.0)
24	-0.2	(0.0)										
25	-0.3	(0.0)	-0.2	(0.0)	22.9	(6.0)	16.9	(4.0)	17.7	(4.0)	13.0	(2.7)
26	-0.2	(0.0)	-0.1	(0.0)	26.6	(4.3)	19.1	(3.1)	20.0	(2.3)	14.3	(1.7)
27	-0.2	(0.1)										
28	-0.3	(0.1)	-0.2	(0.1)	26.3	(7.0)	18.8	(5.0)	21.3	(4.2)	15.3	(3.0)
29	-0.1	(0.0)	-0.1	(0.0)	28.7	(3.9)	20.6	(2.8)	23.6	(2.3)	17.0	(1.6)
30	-0.1	(0.0)	-0.1	(0.0)	26.9	(6.4)	19.3	(4.6)	22.7	(3.8)	16.3	(2.7)
31	0.0	(0.0)	0.0	(0.0)	24.6	(6.8)	17.6	(4.9)	21.2	(5.8)	15.2	(4.1)
Avg	-0.2		-0.1		35.1		25.2		28.1		20.2	
n	31		29		29		29		29		29	
SD	0.2		0.2		24.1		17.3		25		18	
Min	-0.5		-0.3		10.9		7.9		8.3		6.0	
Max	0.3		0.2		122.0		87.3		115.0		82.5	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for April, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.2	(0.2)	0.2	(0.1)	22.9	(6.8)	16.3	(4.9)	19.8	(5.6)	14.1	(4.0)
2	0.0	(0.1)	0.0	(0.1)	22.1	(6.2)	15.8	(4.5)	19.5	(5.2)	13.9	(3.8)
3	-0.2	(0.1)	-0.1	(0.1)	20.2	(6.5)	14.4	(4.7)	17.7	(5.3)	12.7	(3.8)
4	-0.2	(0.0)	-0.2	(0.0)	18.9	(5.0)	13.5	(3.6)	19.1	(4.2)	13.6	(3.0)
5					18.8	(5.9)	13.5	(4.2)	18.9	(4.1)	13.6	(2.9)
6												
7												
8												
9												
10												
11												
12	-0.1	(0.1)	-0.1	(0.1)	15.6	(6.5)	11.1	(4.6)	13.0	(5.2)	9.3	(3.7)
13	-0.2	(0.1)	-0.1	(0.1)	12.0	(5.2)	8.6	(3.7)	10.3	(4.3)	7.4	(3.1)
14	0.0	(0.1)	0.0	(0.1)	14.4	(3.6)	10.3	(2.6)	11.4	(3.1)	8.1	(2.2)
15	-0.2	(0.0)	-0.1	(0.0)	37.7	(28.7)	26.9	(20.5)	19.9	(15.7)	14.2	(11.2)
16	-0.1	(0.1)	0.0	(0.1)	24.5	(29.8)	18.8	(22.0)	14.6	(15.3)		
17	-0.2	(0.2)	-0.1	(0.1)	9.8	(7.1)	7.0	(5.1)	12.4	(10.7)		
18	-0.5	(0.1)	-0.4	(0.0)	0.9	(0.8)	0.7	(0.6)	0.8	(0.6)		
19	-0.7	(0.0)	-0.5	(0.0)	-0.4	(0.2)	-0.3	(0.2)	-0.4	(0.2)		
20	-0.7	(0.0)	-0.5	(0.0)	-0.4	(0.2)	-0.3	(0.2)	-0.3	(0.4)	-0.2	(0.3)
21	-0.6	(0.0)	-0.4	(0.0)	0.0	(0.3)	0.0	(0.2)	-0.1	(0.4)	0.0	(0.3)
22	-0.6	(0.1)	-0.4	(0.0)	0.8	(0.8)	0.6	(0.6)	0.6	(0.7)	0.4	(0.5)
23	-0.4	(0.0)	-0.3	(0.0)	1.9	(0.6)	1.4	(0.4)	1.3	(0.6)	0.9	(0.5)
24	-0.5	(0.0)	-0.4	(0.0)	2.1	(0.7)	1.5	(0.5)	1.3	(0.7)	0.9	(0.5)
25	-0.4	(0.1)	-0.3	(0.0)	2.7	(0.6)	1.9	(0.5)	1.7	(0.7)	1.2	(0.5)
26	-0.3	(0.1)	-0.2	(0.0)	2.5	(0.6)	1.8	(0.4)	1.6	(0.5)	1.2	(0.4)
27	-0.3	(0.0)	-0.2	(0.0)	2.2	(0.6)	1.6	(0.4)	1.5	(0.4)	1.0	(0.3)
28	-0.3	(0.0)	-0.2	(0.0)	1.9	(0.3)	1.3	(0.2)	1.2	(0.2)	0.9	(0.2)
29	-0.3	(0.0)	-0.2	(0.0)	2.1	(0.4)	1.5	(0.3)	1.4	(0.3)	1.0	(0.3)
30	-0.3	(0.0)	-0.2	(0.0)	3.2	(1.0)	2.3	(0.7)	2.2	(0.9)	1.5	(0.6)
Avg	-0.3		-0.2		9.9		7.1		7.9		5.8	
n	23		23		24		24		24		20	
SD	0.2		0.2		10.3		7.5		7.9		5.8	
Min	-0.7		-0.5		-0.4		-0.3		-0.4		-0.2	
Max	0.2		0.2		37.7		26.9		19.9		14.2	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for May, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	-0.2	(0.0)	-0.2	(0.0)	3.4	(1.0)	2.4	(0.7)	2.3	(0.7)	1.7	(0.5)
2	-0.2	(0.0)	-0.1	(0.0)	3.3	(0.9)	2.4	(0.7)	2.2	(0.6)	1.5	(0.4)
3	-0.2	(0.0)	-0.2	(0.0)	4.0	(1.0)	2.9	(0.7)	2.5	(0.6)	1.8	(0.5)
4	-0.2	(0.0)	-0.2	(0.0)	3.5	(0.9)	2.5	(0.7)	2.1	(0.5)	1.5	(0.3)
5	-0.2	(0.0)	-0.1	(0.0)	3.1	(0.9)	2.3	(0.7)	2.0	(0.5)	1.4	(0.3)
6	-0.1	(0.0)	-0.1	(0.0)	3.6	(0.8)	2.6	(0.6)	2.5	(0.4)	1.8	(0.3)
7	-0.1	(0.0)	-0.1	(0.0)	3.6	(0.3)	2.6	(0.2)	3.1	(0.3)	2.2	(0.2)
8	0.0	(0.0)	0.0	(0.0)	3.1	(0.8)	2.2	(0.6)	2.8	(0.7)	2.0	(0.5)
9	-0.1	(0.0)	-0.1	(0.0)	3.7	(0.8)	2.6	(0.6)	3.4	(0.7)	2.4	(0.5)
10	-0.1	(0.0)	-0.1	(0.0)	3.9	(1.2)	2.8	(0.8)	3.4	(0.9)	2.5	(0.7)
11	0.0	(0.0)	0.0	(0.0)	4.7	(1.3)	3.4	(0.9)	3.8	(0.8)	2.7	(0.6)
12	-0.1	(0.0)	0.0	(0.0)	5.7	(1.0)	4.1	(0.7)	4.8	(0.6)	3.4	(0.4)
13	-0.1	(0.0)	-0.1	(0.0)	4.5	(1.9)	3.3	(1.4)	3.9	(1.5)	2.8	(1.1)
14	0.0	(0.1)	0.0	(0.0)	3.9	(1.6)	2.8	(1.2)	3.5	(1.3)	2.5	(0.9)
15	0.2	(0.1)	0.1	(0.1)	3.9	(1.3)	2.8	(0.9)	3.7	(1.1)	2.6	(0.8)
16												
17												
18												
19												
20	0.2	(0.0)	0.2	(0.0)	10.0	(3.3)	7.2	(2.4)	6.6	(1.8)	4.7	(1.3)
21	0.1	(0.0)	0.1	(0.0)	11.4	(3.7)	8.1	(2.6)	7.4	(1.6)	5.3	(1.2)
22	0.0	(0.0)	0.0	(0.0)	11.1	(3.4)	7.9	(2.4)	7.8	(1.9)	5.6	(1.3)
23	0.2	(0.0)	0.1	(0.0)	12.1	(3.4)	8.7	(2.5)	7.6	(1.6)	5.5	(1.1)
24	0.3	(0.1)	0.2	(0.0)	20.0	(3.1)	14.3	(2.2)	12.8	(2.7)	9.2	(1.9)
25	0.6	(0.1)	0.5	(0.1)	21.7	(4.9)	15.6	(3.6)	18.2	(3.6)	13.0	(2.6)
26	0.4	(0.2)	0.3	(0.1)	22.3	(6.9)	16.0	(5.0)	19.5	(5.9)	14.0	(4.2)
27	0.6	(0.1)	0.4	(0.1)	21.9	(6.3)	15.7	(4.5)	20.0	(5.5)	14.3	(4.0)
28	0.6	(0.0)	0.5	(0.0)	21.5	(7.2)	15.4	(5.2)	19.5	(6.3)	14.0	(4.5)
29	0.5	(0.1)	0.4	(0.1)	18.2	(7.0)	13.0	(5.0)	16.7	(6.4)	12.0	(4.6)
30	0.5	(0.1)	0.4	(0.1)	16.3	(6.0)	11.7	(4.3)	14.9	(5.5)	10.7	(4.0)
31	0.4	(0.0)	0.3	(0.0)	16.3	(5.6)	11.7	(4.0)	14.4	(4.8)	10.3	(3.5)
Avg	0.1		0.1		9.7		6.9		7.8		5.6	
n	27		27		27		27		27		27	
SD	0.3		0.2		7.2		5.1		6.3		4.5	
Min	-0.2		-0.2		3.1		2.2		2.0		1.4	
Max	0.6		0.5		22.3		16.0		20.0		14.3	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for June, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.4	(0.0)	0.3	(0.0)	16.6	(6.7)	11.9	(4.8)	14.0	(5.2)	10.1	(3.7)
2	0.5	(0.1)	0.3	(0.0)	15.9	(6.5)	11.4	(4.6)	13.9	(5.3)	10.0	(3.8)
3	0.5	(0.1)	0.4	(0.0)	14.9	(4.9)	10.7	(3.5)	13.4	(4.2)	9.6	(3.0)
4	0.4	(0.1)	0.3	(0.1)	15.6	(5.4)	11.2	(3.9)	14.1	(4.7)	10.1	(3.4)
5	0.5	(0.2)	0.3	(0.1)	13.3	(6.4)	9.6	(4.6)	11.9	(5.1)	8.5	(3.7)
6	0.5	(0.2)	0.3	(0.1)	14.0	(4.0)	10.0	(2.9)	10.1	(4.6)	7.2	(3.3)
7	0.6	(0.3)	0.4	(0.2)	19.3	(16.9)	13.8	(12.1)	14.2	(14.6)	10.1	(10.5)
8	2.5	(0.6)	1.8	(0.4)	66.3	(18.7)	47.5	(13.5)	61.1	(16.9)	43.8	(12.1)
9	3.8	(0.4)	2.7	(0.3)	79.7	(17.4)	57.1	(12.5)	67.6	(16.8)	48.5	(12.0)
10	0.6	(0.9)	0.4	(0.7)	20.3	(26.8)	14.5	(19.2)	16.2	(22.5)	11.6	(16.1)
11	-0.1	(0.2)	-0.1	(0.1)	4.2	(2.9)	3.0	(2.1)	2.5	(1.5)	1.8	(1.1)
12	0.0	(0.1)	0.0	(0.1)	12.9	(9.6)	9.2	(6.9)	11.0	(7.2)	7.8	(5.1)
13	0.2	(0.0)	0.1	(0.0)	17.4	(8.1)	12.5	(5.8)	15.3	(7.2)	11.0	(5.1)
14	0.2	(0.0)	0.1	(0.0)	21.1	(8.8)	15.1	(6.3)	19.6	(8.2)	14.0	(5.9)
15	0.2	(0.1)	0.1	(0.1)	19.5	(8.9)	13.9	(6.4)	18.0	(7.9)	12.9	(5.7)
16	0.1	(0.0)	0.1	(0.0)	16.6	(6.1)	11.9	(4.3)	15.1	(5.7)	10.8	(4.1)
17	0.2	(0.0)	0.2	(0.0)	14.3	(5.5)	10.3	(4.0)	12.7	(4.7)	9.1	(3.4)
18	0.0	(0.0)	0.0	(0.0)	11.4	(4.9)	8.2	(3.5)	9.9	(4.1)	7.1	(2.9)
19	0.1	(0.0)	0.1	(0.0)	10.0	(4.1)	7.2	(3.0)	8.8	(3.4)	6.3	(2.5)
20	0.1	(0.1)	0.1	(0.0)	7.7	(4.6)	5.5	(3.3)	6.9	(3.8)	4.9	(2.7)
21	0.0	(0.1)	0.0	(0.1)	6.6	(3.9)	4.7	(2.8)	5.8	(2.9)	4.1	(2.1)
22	-0.1	(0.1)	-0.1	(0.0)	5.8	(2.6)	4.1	(1.9)	5.3	(2.2)	3.8	(1.6)
23	0.0	(0.0)	0.0	(0.0)	7.1	(2.6)	5.1	(1.9)	6.7	(2.4)	4.8	(1.7)
24	0.0	(0.1)	0.0	(0.0)	8.0	(3.3)	5.8	(2.4)	7.0	(3.1)	5.0	(2.2)
25	0.0	(0.0)	0.0	(0.0)	6.7	(2.7)	4.8	(1.9)	5.4	(2.0)	3.9	(1.4)
26	0.0	(0.0)	0.0	(0.0)	6.6	(2.0)	4.8	(1.5)	5.1	(1.6)	3.6	(1.2)
27	0.0	(0.1)	0.0	(0.1)	4.7	(2.1)	3.4	(1.5)	4.0	(1.5)	2.8	(1.1)
28	-0.1	(0.0)	-0.1	(0.0)	4.2	(1.7)	3.0	(1.2)	3.5	(1.2)	2.5	(0.9)
29	-0.2	(0.0)	-0.1	(0.0)	3.5	(1.4)	2.5	(1.0)	2.9	(0.9)	2.1	(0.7)
30	-0.1	(0.0)	-0.1	(0.0)	3.2	(1.2)	2.3	(0.8)	2.6	(0.7)	1.9	(0.5)
Avg	0.4		0.3		15.6		11.2		13.5		9.7	
n	30		30		30		30		30		30	
SD	0.8		0.6		16.4		11.7		14.4		10.4	
Min	-0.2		-0.1		3.2		2.3		2.5		1.8	
Max	3.8		2.7		79.7		57.1		67.6		48.5	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for July, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.1	(0.1)	0.0	(0.1)	3.3	(1.1)	2.4	(0.8)	2.6	(0.7)	1.8	(0.5)
2	-0.1	(0.0)	-0.1	(0.0)	2.7	(1.0)	1.9	(0.7)	2.1	(0.6)	1.5	(0.5)
3	-0.2	(0.0)	-0.1	(0.0)	2.3	(0.7)	1.7	(0.5)	1.9	(0.5)	1.4	(0.4)
4	-0.2	(0.0)	-0.1	(0.0)	2.5	(0.7)	1.8	(0.5)	1.8	(0.4)	1.3	(0.3)
5	-0.1	(0.0)	-0.1	(0.0)	2.2	(0.8)	1.6	(0.5)	1.7	(0.4)	1.2	(0.3)
6	-0.1	(0.0)	-0.1	(0.0)	2.2	(0.4)	1.6	(0.3)	1.7	(0.4)	1.2	(0.3)
7	0.0	(0.1)	0.0	(0.1)	2.6	(0.4)	1.9	(0.3)	2.1	(0.4)	1.5	(0.3)
8	0.2	(0.1)	0.2	(0.1)	2.8	(0.6)	2.0	(0.4)	2.4	(0.6)	1.7	(0.4)
9	0.0	(0.1)	0.0	(0.0)	2.7	(0.5)	1.9	(0.4)	2.4	(0.6)	1.8	(0.4)
10	0.1	(0.0)	0.1	(0.0)	3.1	(0.7)	2.2	(0.5)	2.7	(0.7)	1.9	(0.5)
11	0.1	(0.0)	0.1	(0.0)	4.4	(1.0)	3.2	(0.7)	3.3	(0.8)	2.3	(0.6)
12	0.1	(0.1)	0.1	(0.1)	5.8	(1.6)	4.2	(1.1)	4.7	(1.4)	3.3	(1.0)
13	0.2	(0.1)	0.1	(0.0)	6.8	(1.9)	4.9	(1.4)	5.6	(1.5)	4.0	(1.1)
14	0.2	(0.1)	0.1	(0.1)	6.6	(1.6)	4.7	(1.1)	5.7	(1.4)	4.1	(1.0)
15	0.2	(0.1)	0.1	(0.1)	8.6	(2.4)	6.2	(1.7)	8.0	(2.3)	5.8	(1.7)
16	0.3	(0.1)	0.2	(0.1)	9.8	(3.1)	7.1	(2.2)	9.2	(2.8)	6.6	(2.0)
17	0.3	(0.1)	0.2	(0.1)	8.7	(2.8)	6.3	(2.0)	8.7	(2.5)	6.3	(1.8)
18	0.5	(0.1)	0.3	(0.1)	9.4	(2.4)	6.7	(1.7)	9.4	(2.4)	6.8	(1.7)
19	0.6	(0.1)	0.4	(0.1)	9.7	(1.6)	7.0	(1.1)	8.7	(1.6)	6.3	(1.2)
20	0.4	(0.0)	0.3	(0.0)	11.8	(2.8)	8.4	(2.0)	10.7	(2.5)	7.7	(1.8)
21	0.5	(0.0)	0.3	(0.0)	14.1	(4.2)	10.1	(3.0)	13.2	(4.3)	9.5	(3.1)
22	0.5	(0.1)	0.3	(0.1)	12.5	(4.0)	9.0	(2.8)	11.4	(3.3)	8.2	(2.4)
23	0.5	(0.2)	0.3	(0.1)	9.1	(1.5)	6.5	(1.0)	8.9	(1.7)	6.4	(1.2)
24	0.4	(0.2)	0.3	(0.1)	8.6	(0.6)	6.2	(0.4)	8.1	(0.7)	5.8	(0.5)
25	0.5	(0.3)	0.4	(0.2)	10.0	(0.9)	7.2	(0.6)	9.2	(0.9)	6.6	(0.7)
26	0.3	(0.1)	0.2	(0.1)	9.8	(1.0)	7.0	(0.7)	8.7	(1.0)	6.3	(0.7)
27	0.3	(0.1)	0.2	(0.1)	9.9	(1.1)	7.1	(0.8)	8.3	(1.0)	5.9	(0.7)
28	0.3	(0.1)	0.2	(0.1)	10.2	(1.8)	7.3	(1.3)	9.3	(2.2)	6.7	(1.6)
29	0.4	(0.1)	0.3	(0.1)	9.2	(1.7)	6.6	(1.2)	8.5	(1.9)	6.1	(1.4)
30	0.7	(0.1)	0.5	(0.1)	9.6	(2.1)	6.9	(1.5)	8.4	(2.0)	6.0	(1.4)
31	0.6	(0.1)	0.4	(0.0)	9.7	(3.2)	6.9	(2.3)	7.6	(1.5)	5.4	(1.1)
Avg	0.2		0.2		7.1		5.1		6.4		4.6	
n	31		31		31		31		31		31	
SD	0.2		0.2		3.6		2.6		3.4		2.5	
Min	-0.2		-0.1		2.2		1.6		1.7		1.2	
Max	0.7		0.5		14.1		10.1		13.2		9.5	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for August, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.7	(0.1)	0.5	(0.1)	87.6	(102.0)	63.2	(74.0)	56.8	(66.5)	40.9	(48.0)
2	0.9	(0.2)	0.6	(0.1)	72.4	(89.0)	52.1	(64.1)	64.7	(69.5)		
3	0.4	(0.0)	0.3	(0.0)	17.6	(1.9)	12.6	(1.4)	19.3	(1.9)		
4	0.2	(0.1)	0.2	(0.1)	8.3	(3.1)	5.9	(2.2)	8.0	(3.2)		
5	0.1	(0.0)	0.1	(0.0)	4.0	(1.4)	2.9	(1.0)	3.6	(1.1)		
6	0.0	(0.1)	0.0	(0.0)	8.0	(10.2)	5.7	(7.3)	8.9	(10.2)		
7	0.3	(0.1)	0.2	(0.1)	19.4	(9.3)	13.8	(6.6)	17.8	(8.8)		
8	0.0	(0.1)	0.0	(0.1)	7.6	(4.2)	5.4	(3.0)	7.3	(4.0)		
9	-0.1	(0.0)	-0.1	(0.0)	4.1	(1.8)	3.0	(1.3)	3.6	(1.6)		
10	0.0	(0.1)	0.0	(0.0)	7.6	(5.3)	5.4	(3.8)	6.1	(4.1)		
11	0.2	(0.0)	0.2	(0.0)	11.6	(5.9)	8.7	(4.1)	9.9	(4.5)		
12	0.1	(0.0)	0.1	(0.0)	11.1	(5.7)	7.9	(4.1)	9.4	(3.9)	6.7	(2.8)
13	0.1	(0.0)	0.1	(0.0)	9.0	(4.8)	6.5	(3.4)	8.0	(3.4)	5.8	(2.4)
14	0.1	(0.1)	0.1	(0.1)	6.8	(3.2)	5.0	(2.3)	6.3	(2.3)	4.5	(1.7)
15	0.0	(0.0)	0.0	(0.0)	5.2	(2.5)	3.8	(1.8)	4.9	(1.8)	3.5	(1.3)
16	-0.1	(0.0)	0.0	(0.0)	4.7	(1.9)	3.4	(1.4)	4.2	(1.4)	3.0	(1.0)
17	0.0	(0.1)	0.0	(0.0)	4.7	(1.6)	3.4	(1.1)	4.0	(1.0)	2.9	(0.7)
18												
19												
20					4.5	(1.6)	3.2	(1.2)	4.0	(1.1)	2.9	(0.8)
21	0.0	(0.1)	0.0	(0.1)	4.7	(2.2)	3.4	(1.6)	3.9	(1.4)	2.8	(1.0)
22	-0.1	(0.0)	-0.1	(0.0)	4.1	(2.1)	2.9	(1.5)	3.1	(1.2)	2.2	(0.8)
23	0.0	(0.0)	0.0	(0.0)	4.3	(1.8)	3.1	(1.3)	3.0	(0.9)	2.1	(0.6)
24	0.0	(0.1)	0.0	(0.0)	4.1	(1.7)	2.9	(1.2)	2.7	(0.8)	1.9	(0.6)
25	-0.2	(0.1)	-0.1	(0.0)	4.3	(1.5)	3.1	(1.1)	2.6	(0.6)	1.9	(0.4)
26	-0.1	(0.0)	-0.1	(0.0)	3.9	(1.4)	2.8	(1.0)	2.5	(0.7)	1.8	(0.5)
27	0.0	(0.0)	0.0	(0.0)	3.7	(1.4)	2.7	(1.0)	2.6	(0.6)	1.8	(0.5)
28	0.1	(0.0)	0.1	(0.0)	3.9	(1.4)	2.8	(1.0)	2.6	(0.7)	1.9	(0.5)
29	0.0	(0.0)	0.0	(0.0)	3.8	(1.0)	2.8	(0.7)	2.5	(0.5)	1.8	(0.4)
30												
31												
Avg	0.1		0.1		12.3		8.8		10.1		5.2	
n	26		26		27		27		27		17	
SD	0.2		0.2		19.7		14.2		15		9	
Min	-0.2		-0.1		3.7		2.7		2.5		1.8	
Max	0.9		0.6		87.6		63.2		64.7		40.9	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for November, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20	0.3	(0.2)	0.2	(0.1)	26.7	(5.2)	19.3	(3.8)	27.8	(5.9)	20.0	(4.2)
21	0.1	(0.1)	0.1	(0.1)	28.2	(3.4)	20.2	(2.5)	29.8	(4.3)	21.3	(3.1)
22	0.4	(0.2)			28.2	(4.6)	20.2	(3.3)	28.0	(4.8)	20.0	(3.4)
23	0.2	(0.3)			29.5	(5.0)	21.2	(3.6)	28.5	(5.3)	20.4	(3.8)
24	0.3	(0.1)			29.3	(3.2)	21.0	(2.3)	26.7	(4.0)	19.1	(2.9)
25	0.7	(0.1)			26.4	(3.7)	18.9	(2.6)				
26	0.5	(0.2)			24.1	(3.0)	17.4	(2.2)	25.1	(3.7)	18.0	(2.7)
27	0.2	(0.2)			22.2	(1.5)			24.2	(1.4)	17.3	(1.0)
28	0.3	(0.1)			19.9	(2.0)	14.6	(1.5)	20.1	(2.5)	14.4	(1.8)
29	0.1	(0.2)			21.6	(3.6)	15.6	(2.6)	21.1	(3.6)	15.1	(2.6)
30	0.1	(0.1)			23.3	(4.1)	16.6	(3.0)	22.9	(4.2)	16.4	(3.0)
Avg	0.3		0.1		25.4		18.5		25.4		18.2	
n	11		2		11		10		10		10	
SD	0.2		0.1		3.2		2.2		3.1		2.2	
Min	0.1		0.1		19.9		14.6		20.1		14.4	
Max	0.7		0.2		29.5		21.2		29.8		21.3	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for December, 2008.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.1	(0.0)			25.1	(1.0)	18.0	(0.7)	24.5	(1.1)	17.6	(0.8)
2	0.1	(0.0)			24.7	(2.3)	17.7	(1.6)	25.1	(2.5)	18.0	(1.8)
3	0.2	(0.0)	0.1	(0.0)	24.1	(4.4)	17.0	(3.4)	23.1	(5.9)	16.5	(4.3)
4	-0.1	(0.1)	0.0	(0.1)	18.7	(25.4)	14.1	(18.7)	7.1	(4.7)	5.0	(3.3)
5	-0.4	(0.1)	-0.3	(0.0)	4.0	(0.7)	2.9	(0.5)	4.7	(0.7)	3.3	(0.5)
6	-0.4	(0.0)	-0.3	(0.0)	3.1	(0.3)	2.2	(0.2)	4.0	(0.3)	2.9	(0.2)
7	-0.3	(0.0)	-0.2	(0.0)	6.2	(2.5)	4.4	(1.8)	7.6	(3.0)	5.4	(2.2)
8	-0.2	(0.1)	-0.1	(0.1)	17.9	(14.5)	12.8	(10.3)	19.7	(14.7)	14.0	(10.5)
9	0.0	(0.1)	0.0	(0.1)	45.5	(10.1)	32.5	(7.3)	43.9	(8.9)	31.3	(6.4)
10	0.0	(0.0)	0.0	(0.0)	49.0	(13.2)	35.1	(9.6)	52.7	(14.3)	37.7	(10.3)
11	0.2	(0.1)	0.2	(0.1)	65.8	(6.6)	47.2	(4.8)	70.7	(7.2)	50.6	(5.2)
12	0.1	(0.0)	0.1	(0.0)	66.7	(7.5)	47.8	(5.4)	71.9	(7.8)	51.5	(5.6)
13	0.1	(0.0)	0.1	(0.0)	59.8	(6.1)	42.9	(4.4)	64.8	(5.9)	46.4	(4.2)
14	0.0	(0.1)	0.0	(0.0)	50.8	(2.3)	36.4	(1.7)	54.4	(2.7)	38.9	(2.0)
15	0.0	(0.0)	0.0	(0.0)	48.3	(2.5)	34.6	(1.8)	51.2	(2.9)	36.7	(2.1)
16	0.0	(0.0)	0.0	(0.0)	39.7	(3.2)	28.5	(2.3)	42.3	(3.2)	30.3	(2.3)
17	-0.1	(0.0)	-0.1	(0.0)	28.0	(2.7)	20.0	(1.9)	29.9	(2.6)	21.4	(1.9)
18	-0.2	(0.0)	-0.1	(0.0)	26.9	(2.6)	19.3	(1.9)	28.7	(2.7)	20.6	(1.9)
19	-0.2	(0.0)	-0.1	(0.0)	25.8	(1.6)	18.5	(1.1)	27.1	(1.8)	19.4	(1.3)
20	-0.2	(0.0)	-0.1	(0.0)	20.9	(1.0)	15.0	(0.7)	21.8	(1.2)	15.6	(0.9)
21	-0.1	(0.0)	-0.1	(0.0)	29.0	(5.1)	21.0	(3.8)	29.6	(5.2)	21.3	(3.8)
22	-0.1	(0.0)	-0.1	(0.0)	25.5	(4.3)	18.4	(3.1)	24.7	(4.7)	17.8	(3.4)
23	-0.1	(0.0)	-0.1	(0.0)	22.0	(2.2)	15.9	(1.6)	19.5	(1.9)	14.0	(1.4)
24	-0.2	(0.0)	-0.1	(0.0)	20.8	(2.2)	15.0	(1.6)	18.0	(1.6)	12.9	(1.2)
25	-0.2	(0.0)	-0.2	(0.0)	16.6	(1.7)	11.9	(1.3)	14.5	(1.2)	10.4	(0.9)
26	-0.2	(0.0)	-0.2	(0.0)	16.5	(2.0)	11.8	(1.5)	13.4	(1.5)	9.6	(1.1)
27	-0.1	(0.0)	-0.1	(0.0)	16.7	(1.8)	12.0	(1.3)	12.6	(1.4)	9.0	(1.0)
28	-0.1	(0.0)	-0.1	(0.0)	16.5	(1.3)	11.9	(0.9)	11.5	(1.0)	8.2	(0.7)
29	-0.1	(0.1)	-0.1	(0.1)	17.1	(1.5)	12.3	(1.1)	11.2	(1.2)	8.1	(0.9)
30	-0.2	(0.0)	-0.1	(0.0)	20.8	(2.7)	15.0	(1.9)	13.0	(1.8)	9.3	(1.3)
31	0.0	(0.1)	0.0	(0.1)	27.4	(2.8)	19.7	(2.0)	16.4	(2.1)	11.8	(1.5)
Avg	-0.1		-0.1		28.4		20.4		27.7		19.9	
n	31		29		31		31		31		31	
SD	0.1		0.1		16.6		11.8		19.1		13.6	
Min	-0.4		-0.3		3.1		2.2		4.0		2.9	
Max	0.2		0.2		66.7		47.8		71.9		51.5	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for January, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	-0.1	(0.1)	-0.1	(0.1)	34.9	(3.3)	25.1	(2.4)	22.1	(2.6)	15.8	(1.9)
2	-0.1	(0.0)	-0.1	(0.0)	44.6	(4.1)	32.1	(3.0)	30.7	(3.3)	22.1	(2.4)
3	0.0	(0.0)	0.0	(0.0)	46.3	(2.8)	33.1	(2.1)	33.4	(1.9)	24.0	(1.3)
4	0.0	(0.0)	0.0	(0.0)	48.5	(5.1)	34.9	(3.7)	38.2	(3.2)	27.4	(2.3)
5	0.0	(0.0)	0.0	(0.0)	44.1	(3.5)	31.8	(2.6)	39.4	(2.8)	28.3	(2.0)
6	0.1	(0.0)	0.0	(0.0)	41.4	(3.5)	29.8	(2.5)	39.6	(3.0)	28.4	(2.2)
7	0.3	(0.1)	0.2	(0.1)	51.9	(5.8)	37.3	(4.2)	51.1	(5.2)	36.7	(3.7)
8	0.2	(0.0)	0.1	(0.0)	44.7	(2.7)	31.8	(1.8)	41.0	(4.0)	29.4	(2.9)
9	0.2	(0.1)	0.1	(0.1)	34.6	(8.3)			29.7	(6.7)	21.3	(4.8)
10	0.6	(0.1)	0.4	(0.1)	33.9	(5.0)			30.2	(5.1)	21.6	(3.7)
11	0.6	(0.1)	0.4	(0.1)	33.5	(6.0)	22.9	(3.9)	30.0	(5.8)	21.5	(4.2)
12												
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31	1.3	(0.1)	1.0	(0.1)	102.0	(8.7)	72.2	(6.1)	106.0	(9.5)	75.2	(6.9)
Avg	0.3		0.2		46.7		35.1		41		29.3	
n	12		12		12		10		12		12	
SD	0.4		0.3		17.8		13		21		14.8	
Min	-0.1		-0.1		33.5		22.9		22.1		15.8	
Max	1.3		1.0		102.0		72.2		106.0		75.2	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for February, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	1.5	(0.1)	1.1	(0.1)	84.5	(6.8)	60.5	(4.9)	87.0	(7.4)	62.3	(5.4)
2	1.2	(0.1)	0.9	(0.0)	71.4	(12.3)	51.1	(8.9)	73.9	(13.2)	52.9	(9.5)
3	1.1	(0.1)	0.8	(0.0)	60.8	(6.2)	43.5	(4.5)	61.7	(6.6)	44.2	(4.8)
4	0.9	(0.1)	0.7	(0.1)	65.2	(27.5)	46.2	(20.2)	64.3	(27.8)	46.4	(20.3)
5	0.9	(0.1)	0.7	(0.1)	46.9	(19.7)	33.6	(14.4)	51.2	(19.1)	36.5	(14.0)
6	0.9	(0.0)	0.7	(0.0)	48.4	(4.4)	34.6	(3.2)	52.9	(4.4)	37.8	(3.1)
7	0.9	(0.0)	0.6	(0.0)	52.7	(10.9)	37.8	(7.9)	56.5	(10.6)	40.5	(7.7)
8	0.9	(0.1)	0.6	(0.0)	52.8	(5.6)	37.8	(4.1)	54.2	(5.4)	38.8	(3.9)
9	0.7	(0.0)	0.5	(0.0)	49.9	(3.1)	35.7	(2.2)	50.6	(3.2)	36.2	(2.3)
10	0.7	(0.0)	0.5	(0.0)	51.5	(6.2)	36.9	(4.5)	52.4	(6.6)	37.5	(4.8)
11	0.7	(0.0)	0.5	(0.0)	50.2	(2.9)	36.0	(2.1)	50.5	(3.0)	36.2	(2.2)
12	0.6	(0.0)	0.5	(0.0)	47.3	(2.6)	34.0	(1.9)	47.7	(2.5)	34.3	(1.9)
13	0.6	(0.0)	0.4	(0.0)	38.4	(2.9)	27.6	(2.1)	38.3	(3.0)	27.5	(2.2)
14	0.5	(0.0)	0.3	(0.0)	35.3	(1.5)	25.3	(1.1)	34.3	(1.6)	24.6	(1.2)
15	0.4	(0.0)	0.3	(0.0)	27.5	(2.4)	19.7	(1.8)	26.6	(2.3)	19.0	(1.7)
16	0.4	(0.0)	0.3	(0.0)	25.7	(1.3)	18.4	(0.9)	25.0	(1.0)	17.9	(0.7)
17	0.4	(0.1)	0.3	(0.1)	32.2	(8.1)	22.9	(5.9)	31.9	(8.9)	22.6	(6.4)
18	0.5	(0.0)	0.4	(0.0)	32.5	(4.8)	23.4	(3.5)	30.4	(4.7)	21.9	(3.4)
19	0.4	(0.0)	0.3	(0.0)	26.2	(5.4)	18.9	(3.9)	22.4	(5.1)	16.1	(3.6)
20	0.5	(0.0)	0.4	(0.0)	27.0	(1.8)	19.4	(1.4)	22.2	(1.5)	16.0	(1.1)
21	0.5	(0.0)	0.4	(0.0)	24.1	(2.0)	17.4	(1.4)	20.0	(1.2)	14.4	(0.8)
22	0.5	(0.0)	0.3	(0.0)	22.8	(2.6)	16.4	(1.9)	19.2	(1.7)	13.8	(1.2)
23	0.5	(0.0)	0.3	(0.0)	22.4	(1.8)	16.2	(1.3)	18.5	(1.2)	13.4	(0.9)
24	0.5	(0.0)	0.3	(0.0)	21.6	(2.5)	15.5	(1.8)	16.8	(2.4)	12.1	(1.7)
25	0.4	(0.0)	0.3	(0.0)	22.7	(4.5)	16.3	(3.2)	17.0	(3.6)	12.2	(2.6)
26	0.5	(0.0)	0.3	(0.0)	22.4	(4.3)	16.1	(3.1)	17.4	(4.0)	12.5	(2.9)
27	0.4	(0.0)	0.3	(0.0)	22.2	(2.7)	16.0	(2.0)	16.0	(2.1)	11.5	(1.5)
28	0.4	(0.1)	0.3	(0.1)	26.1	(2.2)	18.7	(1.6)	18.7	(1.2)	13.4	(0.9)
Avg	0.7		0.5		39.7		28.4		38.5		27.6	
n	28		28		28		28		28		28	
SD	0.3		0.2		16.9		12.1		19.5		14	
Min	0.4		0.3		21.6		15.5		16.0		11.5	
Max	1.5		1.1		84.5		60.5		87.0		62.3	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for March, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.6	(0.1)	0.4	(0.0)	28.9	(1.9)	20.8	(1.4)	21.4	(1.9)	15.4	(1.4)
2	0.5	(0.0)	0.4	(0.0)	26.6	(5.2)	19.2	(3.8)	21.7	(2.8)	15.6	(2.1)
3	0.4	(0.0)	0.3	(0.0)	24.2	(1.1)	17.4	(0.8)	22.5	(2.1)	16.2	(1.5)
4	0.4	(0.0)	0.3	(0.0)	26.1	(1.6)	18.8	(1.2)	22.5	(1.5)	16.1	(1.1)
5	0.4	(0.0)	0.3	(0.0)	26.3	(3.0)	18.9	(2.1)	23.2	(2.6)	16.6	(1.9)
6	0.5	(0.0)	0.3	(0.0)	26.0	(3.9)	18.6	(2.8)	23.1	(3.3)	16.6	(2.4)
7	0.5	(0.0)	0.3	(0.0)	27.7	(3.1)	19.9	(2.2)	23.1	(2.5)	16.6	(1.8)
8	0.4	(0.0)	0.3	(0.0)	26.7	(4.6)	19.2	(3.3)	22.0	(4.2)	15.8	(3.0)
9	0.5	(0.1)	0.4	(0.1)	30.7	(3.4)	22.0	(2.5)	23.9	(2.7)	17.1	(2.0)
10	0.6	(0.1)	0.4	(0.1)	33.7	(7.7)	24.2	(5.5)	26.6	(5.1)	19.0	(3.7)
11	0.8	(0.1)	0.5	(0.1)	35.2	(6.7)	25.3	(4.8)	29.9	(5.2)	21.4	(3.7)
12	0.6	(0.1)	0.4	(0.0)	32.4	(8.4)	23.2	(6.1)	29.4	(6.9)	21.1	(5.0)
13	0.6	(0.0)	0.4	(0.0)	29.8	(8.7)	21.3	(6.2)	26.7	(6.6)	19.2	(4.7)
14	0.6	(0.1)	0.4	(0.1)	34.2	(5.4)	24.5	(3.9)	31.7	(4.5)	22.7	(3.2)
15	0.5	(0.1)	0.3	(0.1)	27.7	(8.6)	19.8	(6.2)	27.6	(8.8)	19.8	(6.3)
16	0.7	(0.2)	0.5	(0.1)	25.9	(8.4)	18.5	(6.0)	25.3	(8.1)	18.2	(5.8)
17	1.0	(0.1)	0.7	(0.1)	23.6	(7.9)	16.9	(5.7)	22.3	(8.1)	16.0	(5.9)
18	0.8	(0.2)	0.6	(0.2)	19.1	(4.2)	13.7	(3.0)	18.0	(4.0)	12.9	(2.8)
19	0.8	(0.1)	0.6	(0.1)	18.8	(6.5)	13.5	(4.6)	17.1	(6.0)	12.2	(4.3)
20	0.7	(0.1)	0.5	(0.1)	17.5	(5.6)	12.5	(4.0)	16.1	(5.1)	11.5	(3.6)
21	0.6	(0.0)	0.4	(0.0)	20.0	(4.7)	14.3	(3.4)	18.1	(4.3)	13.0	(3.1)
22	0.6	(0.2)	0.4	(0.1)	23.0	(4.2)	16.5	(3.0)	20.3	(3.1)	14.6	(2.2)
23	0.5	(0.1)	0.3	(0.0)	19.6	(4.0)	14.0	(2.9)	17.2	(3.3)	12.3	(2.4)
24	0.5	(0.1)	0.3	(0.1)	20.4	(5.8)	14.6	(4.1)	17.1	(4.7)	12.2	(3.4)
25	0.6	(0.1)	0.4	(0.1)	19.9	(6.2)	14.2	(4.4)	16.8	(4.9)	12.0	(3.5)
26	0.6	(0.2)	0.4	(0.2)	16.0	(8.0)	11.5	(5.7)	14.0	(6.3)	10.0	(4.5)
27	1.2	(0.8)	0.8	(0.6)	55.8	(55.1)	40.0	(39.6)	11.6	(5.0)	8.3	(3.6)
28	4.4	(1.8)	3.1	(1.3)	66.5	(58.2)	47.6	(41.7)	7.3	(1.8)	5.2	(1.3)
29	0.2	(0.1)	0.1	(0.0)	3.2	(0.7)	2.2	(0.5)	2.7	(0.4)	1.9	(0.3)
30	0.9	(0.6)	0.6	(0.4)	28.3	(25.2)	20.3	(18.1)	21.6	(21.7)	15.4	(15.6)
31	0.6	(0.4)	0.4	(0.3)	19.5	(20.4)	13.9	(14.6)	21.9	(23.7)	15.6	(17.0)
Avg	0.7		0.5		26.9		19.3		20.7		14.9	
n	31		31		31		31		31		31	
SD	0.7		0.5		11.1		8		6.2		4.4	
Min	0.2		0.1		3.2		2.2		2.7		1.9	
Max	4.4		3.1		66.5		47.6		31.7		22.7	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for April, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.3	(0.2)	0.2	(0.1)	18.2	(20.4)	13.1	(14.6)	15.6	(18.2)	11.1	(13.1)
2	0.4	(0.2)	0.3	(0.1)	23.5	(27.3)	16.8	(19.5)	22.3	(25.2)	16.0	(18.1)
3	0.0	(0.0)	0.0	(0.0)	1.4	(0.2)	1.0	(0.1)	1.6	(0.2)	1.1	(0.2)
4	-0.1	(0.0)	-0.1	(0.0)	0.9	(0.1)	0.7	(0.1)	1.1	(0.2)	0.7	(0.1)
5	-0.1	(0.0)	-0.1	(0.0)	0.8	(0.2)	0.6	(0.2)	0.9	(0.2)	0.7	(0.1)
6	-0.1	(0.0)	-0.1	(0.0)	0.9	(0.2)	0.6	(0.2)	0.9	(0.2)	0.6	(0.1)
7	-0.1	(0.0)	-0.1	(0.0)	0.3	(0.2)	0.2	(0.1)	0.1	(0.3)	0.1	(0.2)
8	-0.1	(0.1)	-0.1	(0.0)	0.8	(0.7)	0.6	(0.5)	0.9	(0.8)	0.6	(0.6)
9	0.0	(0.0)	0.0	(0.0)	1.1	(0.2)	0.7	(0.1)	1.4	(0.1)	1.0	(0.1)
10	-0.1	(0.0)	-0.1	(0.0)								
11	-0.2	(0.0)	-0.1	(0.0)	0.9	(0.3)	0.6	(0.2)	1.2	(0.2)	0.9	(0.1)
12	-0.1	(0.0)	-0.1	(0.0)	1.2	(0.4)	0.9	(0.3)	1.5	(0.2)	1.1	(0.2)
13	-0.2	(0.0)	-0.1	(0.0)	1.2	(0.3)	0.8	(0.2)	1.4	(0.2)	1.0	(0.1)
14	-0.2	(0.0)	-0.2	(0.0)	0.7	(0.1)	0.5	(0.1)	0.9	(0.1)	0.6	(0.1)
15	-0.2	(0.0)	-0.1	(0.0)	0.8	(0.2)	0.6	(0.1)	1.1	(0.2)	0.8	(0.1)
16	-0.1	(0.0)	-0.1	(0.0)	1.1	(0.3)	0.8	(0.2)	1.3	(0.1)	0.9	(0.1)
17	-0.1	(0.0)	-0.1	(0.0)	1.2	(0.2)	0.9	(0.2)	1.3	(0.2)	0.9	(0.1)
18	0.0	(0.0)	0.0	(0.0)	1.4	(0.6)	1.0	(0.4)	1.4	(0.5)	1.0	(0.4)
19	0.0	(0.1)	0.0	(0.0)	1.4	(0.8)	1.0	(0.6)	1.3	(0.8)	1.0	(0.6)
20												
21												
22												
23												
24												
25												
26												
27												
28												
29	-0.1	(0.0)	0.0	(0.0)	2.3	(0.3)	1.7	(0.3)	2.0	(0.3)	1.4	(0.2)
30	0.0	(0.0)	0.0	(0.0)	3.1	(0.4)	2.2	(0.3)	2.2	(0.4)	1.6	(0.3)
Avg	-0.1		0		3.2		2.3		3		2.2	
n	21		21		20		20		20		20	
SD	0.1		0.1		6		4.3		5.4		3.9	
Min	-0.2		-0.2		0.3		0.2		0.1		0.1	
Max	0.4		0.3		23.5		16.8		22.3		16.0	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for May, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.1	(0.0)	0.1	(0.0)	6.3	(1.6)	4.5	(1.2)	4.0	(1.0)	2.9	(0.7)
2	0.3	(0.0)	0.2	(0.0)	13.6	(1.5)	9.8	(1.1)	8.6	(1.4)	6.2	(1.0)
3	0.5	(0.0)	0.3	(0.0)	16.5	(2.9)	11.9	(2.1)	11.3	(2.0)	8.2	(1.4)
4	0.4	(0.1)	0.3	(0.1)	16.1	(4.8)	11.5	(3.5)	11.4	(3.6)	8.2	(2.6)
5	0.5	(0.1)	0.4	(0.1)	14.4	(5.4)	10.4	(3.9)	11.3	(4.1)	8.1	(3.0)
6	0.5	(0.0)	0.4	(0.0)	14.4	(6.0)	10.3	(4.3)	10.9	(4.4)	7.8	(3.2)
7	0.4	(0.1)	0.3	(0.1)	15.2	(6.3)	10.9	(4.5)	11.4	(4.3)	8.2	(3.1)
8	0.4	(0.0)	0.3	(0.0)	12.6	(5.6)	9.0	(4.0)	10.2	(4.2)	7.3	(3.0)
9	0.4	(0.0)	0.3	(0.0)	10.8	(5.1)	7.8	(3.7)	8.7	(4.1)	6.2	(2.9)
10	0.4	(0.1)	0.3	(0.0)	9.8	(4.7)	7.0	(3.3)	8.4	(3.4)	6.0	(2.5)
11	0.4	(0.1)	0.3	(0.0)	8.9	(3.3)	6.4	(2.4)	9.1	(3.6)	6.6	(2.6)
12	0.5	(0.0)	0.3	(0.0)	10.6	(4.0)	7.6	(2.9)	9.7	(3.7)	7.0	(2.7)
13	0.5	(0.1)	0.4	(0.0)	10.8	(4.8)	7.8	(3.4)	9.8	(4.4)	7.0	(3.2)
14	0.6	(0.1)	0.4	(0.1)	10.3	(3.8)	7.4	(2.7)	9.8	(3.7)	7.0	(2.7)
15	0.8	(0.1)	0.6	(0.1)	10.3	(2.9)	7.4	(2.0)	9.8	(3.3)	7.0	(2.4)
16	0.7	(0.2)	0.5	(0.1)	9.2	(0.9)	6.6	(0.6)	8.6	(1.2)	6.2	(0.9)
17	0.7	(0.2)	0.5	(0.1)	8.7	(0.8)	6.3	(0.6)	8.1	(0.8)	5.8	(0.6)
18	0.5	(0.1)	0.3	(0.0)	7.7	(0.8)	5.5	(0.6)	7.3	(0.7)	5.3	(0.5)
19	0.5	(0.1)	0.4	(0.1)	7.8	(0.7)	5.6	(0.5)	7.9	(0.8)	5.6	(0.6)
20	0.4	(0.1)	0.3	(0.1)	8.5	(1.7)	6.1	(1.2)	8.9	(2.4)	6.4	(1.7)
21	0.6	(0.1)	0.4	(0.1)	9.3	(1.3)	6.7	(0.9)	9.7	(2.3)	7.0	(1.7)
22	0.6	(0.1)	0.4	(0.1)	10.1	(1.3)	7.2	(1.0)	10.3	(1.8)	7.4	(1.3)
23	0.6	(0.1)	0.4	(0.1)	11.2	(2.1)	8.0	(1.5)	11.2	(2.2)	8.0	(1.5)
24	0.7	(0.1)	0.5	(0.0)	12.6	(2.5)	9.0	(1.8)	12.2	(2.5)	8.7	(1.8)
25	1.0	(0.1)	0.7	(0.1)	12.7	(2.2)	9.1	(1.6)	12.2	(2.3)	8.8	(1.6)
26	1.0	(0.1)	0.7	(0.1)	9.5	(2.9)	6.8	(2.1)	10.0	(3.8)	7.2	(2.7)
27	1.6	(0.3)	1.2	(0.2)	16.1	(8.8)	11.6	(6.3)	16.0	(11.3)	11.6	(8.1)
28	0.8	(0.3)	0.6	(0.2)	13.8	(5.5)	9.9	(4.0)	14.3	(4.4)	10.3	(3.1)
29	0.4	(0.1)	0.3	(0.1)	15.4	(4.1)	11.0	(3.0)	17.7	(6.4)	12.7	(4.6)
30	0.4	(0.0)	0.3	(0.0)	12.9	(1.4)	9.2	(1.0)	17.6	(3.3)	12.6	(2.4)
31	0.3	(0.0)	0.2	(0.0)	9.5	(0.9)	6.8	(0.6)	12.8	(2.1)	9.2	(1.5)
Avg	0.6		0.4		11.5		8.2		10.6		7.6	
n	31		31		31		31		31		31	
SD	0.3		0.2		2.8		2		2.8		2	
Min	0.1		0.1		6.3		4.5		4.0		2.9	
Max	1.6		1.2		16.5		11.9		17.7		12.7	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for June, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.3	(0.1)	0.2	(0.0)	8.0	(3.6)	5.8	(2.6)	6.4	(5.5)	4.6	(4.0)
2												
3												
4												
5	0.7	(0.0)	0.5	(0.0)	43.2	(3.8)	31.0	(2.8)	49.0	(4.6)	35.2	(3.4)
6	0.7	(0.1)	0.5	(0.0)	36.4	(5.2)	26.2	(3.7)	44.4	(3.7)	31.9	(2.7)
7	0.6	(0.1)	0.4	(0.0)	28.1	(6.9)	20.2	(5.0)	35.0	(7.9)	25.1	(5.7)
8	0.4	(0.1)	0.3	(0.0)	19.7	(5.1)	14.1	(3.7)	25.3	(6.2)	18.1	(4.4)
9	0.4	(0.0)	0.3	(0.0)	17.4	(2.4)	12.5	(1.7)	21.7	(3.3)	15.6	(2.4)
10	0.4	(0.0)	0.3	(0.0)	16.0	(3.3)	11.5	(2.4)	20.1	(4.5)	14.4	(3.3)
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
Avg	0.5		0.4		24.1		17.3		28.8		20.7	
n	7		7		7		7		7		7	
SD	0.2		0.1		11.5		8.3		13.8		9.9	
Min	0.3		0.2		8.0		5.8		6.4		4.6	
Max	0.7		0.5		43.2		31.0		49.0		35.2	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for July, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15	0.9	(0.1)	0.7	(0.0)								
16	0.7	(0.1)	0.5	(0.1)								
17	0.6	(0.1)	0.4	(0.1)	7.6	(1.6)	5.4	(1.1)	6.8	(1.3)	4.9	(1.0)
18	0.6	(0.1)	0.4	(0.1)	8.2	(1.3)	5.9	(1.0)	7.4	(1.2)	5.3	(0.9)
19	0.7	(0.1)	0.5	(0.1)	8.5	(1.6)	6.1	(1.1)	7.9	(1.2)	5.7	(0.9)
20	0.4	(0.1)	0.3	(0.1)	6.4	(1.1)	4.6	(0.8)	5.9	(0.9)	4.2	(0.6)
21	1.2	(0.6)	0.9	(0.4)	36.3	(36.0)	27.9	(26.5)				
22	1.5	(0.2)	1.1	(0.1)	32.3	(25.6)	23.2	(18.3)	17.7	(7.3)	12.7	(5.2)
23	1.1	(0.1)	0.8	(0.1)	10.7	(1.4)	7.7	(1.0)	11.4	(1.8)	8.2	(1.3)
24												
25												
26												
27												
28	1.2	(0.0)	0.9	(0.0)	32.3	(13.5)	23.2	(9.7)	26.0	(11.2)	18.7	(8.0)
29	1.2	(0.0)	0.8	(0.0)	31.6	(9.7)	22.7	(7.0)	25.1	(8.2)	18.0	(5.9)
30	1.1	(0.1)	0.8	(0.0)	26.1	(9.2)	18.7	(6.6)	23.4	(7.6)	16.8	(5.4)
31	1.0	(0.0)	0.7	(0.0)	24.1	(9.1)	17.3	(6.5)	21.9	(8.2)	15.7	(5.9)
Avg	0.9		0.7		20.4		14.8		15.3		11	
n	13		13		11		11		10		10	
SD	0.3		0.2		11.5		8.5		7.9		5.7	
Min	0.4		0.3		6.4		4.6		5.9		4.2	
Max	1.5		1.1		36.3		27.9		26.0		18.7	

Table E10. Daily means (SD) of NH_3 concentrations at Site CA1B for August, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.8	(0.1)	0.6	(0.1)	21.9	(9.2)	15.7	(6.6)	19.4	(8.4)	13.9	(6.0)
2	0.8	(0.0)	0.5	(0.0)	18.4	(7.7)	13.2	(5.5)	17.5	(6.8)	12.6	(4.9)
3	0.7	(0.1)	0.5	(0.0)	16.1	(5.9)	11.6	(4.2)	15.5	(5.1)	11.2	(3.7)
4	1.0	(0.1)	0.7	(0.0)	13.5	(5.1)	10.0	(3.8)	13.0	(5.2)	9.4	(3.7)
5	1.0	(0.0)	0.7	(0.0)	14.2	(5.2)	10.2	(3.7)	11.6	(4.3)	8.3	(3.1)
6	0.8	(0.0)	0.6	(0.0)	15.5	(1.2)	11.2	(0.9)	12.7	(1.7)	9.1	(1.2)
7	0.8	(0.0)	0.5	(0.0)	12.1	(3.3)	8.7	(2.4)	10.5	(2.4)	7.6	(1.7)
8	0.8	(0.1)	0.5	(0.0)	8.6	(4.3)	6.2	(3.1)	7.7	(4.0)	5.6	(2.8)
9	0.5	(0.1)	0.4	(0.0)	7.3	(4.4)	5.2	(3.2)	6.1	(3.7)	4.4	(2.7)
10	0.6	(0.1)	0.4	(0.1)	6.4	(4.3)	4.6	(3.1)	5.4	(3.4)	3.8	(2.4)
11	0.4	(0.1)	0.3	(0.1)	4.7	(2.2)	3.4	(1.6)	4.6	(2.2)	3.3	(1.6)
12	0.4	(0.0)	0.3	(0.0)	4.2	(1.9)	3.0	(1.4)	4.3	(2.1)	3.1	(1.5)
13	0.3	(0.1)	0.2	(0.1)	3.5	(1.7)	2.5	(1.2)	3.7	(1.8)	2.7	(1.3)
14	0.3	(0.1)	0.2	(0.0)	3.4	(1.5)	2.5	(1.1)	3.6	(1.6)	2.6	(1.2)
15	0.3	(0.0)	0.2	(0.0)	2.9	(1.4)	2.1	(1.0)	3.2	(1.5)	2.3	(1.1)
16	0.2	(0.0)	0.2	(0.0)								
17	0.3	(0.0)	0.2	(0.0)								
18	0.3	(0.0)	0.2	(0.0)	2.1	(0.8)	1.5	(0.6)	2.3	(0.9)	1.7	(0.7)
19	0.3	(0.1)	0.2	(0.0)	1.8	(0.6)	1.3	(0.4)	2.0	(0.7)	1.5	(0.5)
20	0.3	(0.0)	0.2	(0.0)	2.1	(0.6)	1.5	(0.5)	2.2	(0.7)	1.6	(0.5)
21	0.4	(0.1)	0.3	(0.0)	2.2	(0.5)	1.6	(0.4)	2.2	(0.6)	1.6	(0.4)
22	0.3	(0.0)	0.2	(0.0)	1.9	(0.3)	1.4	(0.2)	1.9	(0.3)	1.4	(0.2)
23	0.4	(0.0)	0.3	(0.0)	2.9	(0.6)	2.1	(0.5)	3.0	(0.6)	2.2	(0.4)
24	0.4	(0.0)	0.3	(0.0)	4.4	(1.3)	3.1	(0.9)	4.3	(1.3)	3.1	(0.9)
25	0.4	(0.1)	0.3	(0.0)	5.2	(1.9)	3.7	(1.4)	4.9	(1.8)	3.5	(1.3)
26	0.5	(0.0)	0.3	(0.0)	6.2	(2.4)	4.4	(1.7)	5.6	(1.8)	4.0	(1.3)
27	0.5	(0.0)	0.4	(0.0)	6.3	(1.9)	4.6	(1.3)	5.3	(1.4)	3.8	(1.0)
28	0.5	(0.0)	0.4	(0.0)	6.0	(2.5)	4.3	(1.8)	4.9	(1.9)	3.5	(1.3)
29	0.6	(0.1)	0.4	(0.1)	5.4	(1.9)	3.9	(1.4)	4.7	(1.4)	3.4	(1.0)
30	0.5	(0.1)	0.4	(0.1)	4.3	(0.9)	3.1	(0.7)	3.9	(1.0)	2.8	(0.7)
31	0.7	(0.0)	0.5	(0.0)	6.0	(1.9)	4.3	(1.4)	5.3	(1.8)	3.8	(1.3)
Avg	0.5		0.4		7.2		5.2		6.6		4.7	
n	31		31		29		29		29		29	
SD	0.2		0.2		5.4		3.9		4.8		3.4	
Min	0.2		0.2		1.8		1.3		1.9		1.4	
Max	1.0		0.7		21.9		15.7		19.4		13.9	

Table E10. Daily means (SD) of NH3 concentrations at Site CA1B for September, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.9	(0.1)	0.6	(0.1)	6.8	(1.8)	4.9	(1.3)	6.0	(1.6)	4.3	(1.2)
2	0.7	(0.1)	0.5	(0.1)	5.7	(0.6)	4.1	(0.5)	5.3	(0.8)	3.8	(0.6)
3	0.6	(0.1)	0.4	(0.0)	5.2	(0.8)	3.7	(0.5)	4.7	(0.8)	3.4	(0.6)
4	0.6	(0.1)	0.4	(0.0)	4.8	(0.7)	3.4	(0.5)	4.8	(0.9)	3.5	(0.6)
5	0.7	(0.1)	0.5	(0.0)	6.9	(1.3)	4.9	(0.9)	6.5	(1.4)	4.7	(1.0)
6	0.7	(0.1)	0.5	(0.0)	6.8	(1.8)	4.9	(1.3)	6.3	(1.7)	4.5	(1.2)
7	0.6	(0.1)	0.4	(0.1)	6.7	(1.0)	4.8	(0.7)	6.6	(1.2)	4.7	(0.8)
8	0.7	(0.1)	0.5	(0.1)	6.5	(1.0)	4.7	(0.7)	6.1	(0.9)	4.4	(0.7)
9	0.8	(0.0)	0.5	(0.0)					6.5	(0.8)		
10	0.8	(0.1)	0.6	(0.1)	7.5	(1.2)	5.3	(0.8)				
11	1.2	(0.2)	0.8	(0.1)	7.8	(1.5)	5.6	(1.1)	7.2	(1.4)	5.2	(1.0)
12	0.9	(0.2)	0.6	(0.1)	7.6	(1.0)	5.5	(0.7)	7.1	(0.9)	5.1	(0.7)
13	0.8	(0.0)	0.6	(0.0)	8.2	(2.7)	5.8	(2.0)	8.0	(2.5)	5.7	(1.8)
14	1.1	(0.1)	0.8	(0.1)	12.4	(4.5)	8.9	(3.2)	11.7	(4.3)	8.4	(3.1)
15	1.0	(0.1)	0.7	(0.1)	13.5	(5.0)	9.7	(3.6)	12.2	(3.8)	8.7	(2.8)
16	0.6	(0.0)	0.4	(0.0)	5.5	(1.6)	3.9	(1.1)	5.9	(2.1)	4.3	(1.5)
17	0.6	(0.0)	0.4	(0.0)	4.2	(1.4)	3.0	(1.0)	3.8	(1.0)	2.7	(0.7)
18	0.5	(0.0)	0.4	(0.0)	2.4	(0.6)	1.7	(0.5)	3.6	(0.7)	2.6	(0.5)
19	0.5	(0.1)	0.3	(0.0)	3.7	(2.0)	2.6	(1.5)	3.4	(0.3)	2.5	(0.2)
20	0.7	(0.2)	0.5	(0.2)	5.2	(0.5)	3.7	(0.4)	3.0	(0.2)	2.1	(0.2)
21	0.5	(0.1)	0.4	(0.1)	3.1	(1.3)	2.3	(0.9)	2.5	(0.2)	1.8	(0.2)
22	0.2	(0.1)	0.1	(0.1)	0.8	(0.4)	0.6	(0.3)	1.0	(0.7)	0.7	(0.5)
23	0.0	(0.0)	0.0	(0.0)	0.3	(0.2)	0.2	(0.1)	0.3	(0.2)	0.2	(0.1)
24	-0.1	(0.0)	0.0	(0.0)	0.2	(0.2)	0.1	(0.1)	0.2	(0.2)	0.1	(0.1)
25	-0.1	(0.0)	0.0	(0.0)	0.2	(0.2)	0.1	(0.1)	0.2	(0.2)	0.2	(0.2)
26	0.1	(0.0)	0.0	(0.0)	0.3	(0.1)	0.2	(0.0)	0.4	(0.1)	0.3	(0.1)
27	0.1	(0.0)	0.0	(0.0)	0.4	(0.1)	0.3	(0.1)	0.5	(0.1)	0.3	(0.1)
28	0.0	(0.0)	0.0	(0.0)	0.4	(0.1)	0.3	(0.1)	0.5	(0.1)	0.4	(0.1)
29	0.0	(0.0)	0.0	(0.0)	0.5	(0.1)	0.4	(0.1)	0.7	(0.1)	0.5	(0.1)
30	-0.1	(0.0)	0.0	(0.0)	0.6	(0.1)	0.4	(0.1)	0.8	(0.1)	0.6	(0.1)
Avg	0.5		0.4		4.6		3.3		4.3		3.1	
n	30		30		29		29		29		28	
SD	0.4		0.3		3.6		2.6		3.3		2.4	
Min	-0.1		0.0		0.2		0.1		0.2		0.1	
Max	1.2		0.8		13.5		9.7		12.2		8.7	

Table E10. Daily means (SD) of NH_3 concentrations at Site CA1B for October, 2009.

Day	Ambient				House 10				House 12			
	Mean (SD)				Mean (SD)				Mean (SD)			
	ppm		mg dsm^{-3}		ppm		mg dsm^{-3}		ppm		mg dsm^{-3}	
1	0.0	(0.0)	0.0	(0.0)	0.8	(0.1)	0.5	(0.1)	1.0	(0.2)	0.7	(0.1)
2	0.0	(0.0)	0.0	(0.0)	0.7	(0.2)	0.5	(0.1)	0.9	(0.3)	0.7	(0.2)
3	-0.1	(0.0)	-0.1	(0.0)	0.7	(0.1)	0.5	(0.1)	1.0	(0.1)	0.7	(0.1)
4	-0.1	(0.0)	0.0	(0.0)	1.0	(0.2)	0.7	(0.2)	1.3	(0.3)	1.0	(0.2)
5	0.0	(0.0)	0.0	(0.0)	1.0	(0.2)	0.7	(0.2)	1.4	(0.2)	1.0	(0.1)
6	0.0	(0.0)	0.0	(0.0)	0.9	(0.2)	0.6	(0.1)	1.2	(0.2)	0.8	(0.1)
7	0.0	(0.0)	0.0	(0.0)								
8	-0.1	(0.0)	-0.1	(0.0)	0.9	(0.2)	0.7	(0.1)	1.2	(0.2)	0.8	(0.2)
9	-0.1	(0.0)	-0.1	(0.0)	1.0	(0.2)	0.7	(0.2)	1.2	(0.3)	0.8	(0.2)
10	-0.1	(0.0)	-0.1	(0.0)	1.1	(0.2)	0.8	(0.2)	1.1	(0.3)	0.8	(0.2)
11	-0.1	(0.0)	-0.1	(0.0)	1.2	(0.1)	0.9	(0.1)	1.2	(0.1)	0.9	(0.1)
12	-0.1	(0.0)	-0.1	(0.0)	1.5	(0.1)	1.1	(0.1)	1.5	(0.2)	1.1	(0.1)
13					1.8	(0.2)	1.3	(0.1)	1.9	(0.3)	1.4	(0.2)
14												
15												
16												
17												
18												
19												
20												
21												
22												
23												
24												
25												
26												
27												
28												
29												
30												
31												
Avg	-0.1		0		1		0.7		1.2		0.9	
n	12		12		12		12		12		12	
SD	0		0		0.3		0.2		0.2		0.2	
Min	-0.1		-0.1		0.7		0.5		0.9		0.7	
Max	0.0		0.0		1.8		1.3		1.9		1.4	

Table E11. NH3 emissions

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for December, 2007.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5																
6																
7																
8																
9																
10																
11																
12																
13																
14																
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																
25																
26																
27																
28																
29	28.8	(7.8)	18.9	(5.1)	1400	(379)	274	(74)	28.2	(6.7)	18.5	(4.4)	1360	(323)	267	(63)
30	30.7	(4.0)	20.1	(2.7)	1500	(196)	285	(38)	28.4	(4.1)	18.6	(2.7)	1370	(198)	261	(39)
31	28.4	(4.4)	18.6	(2.9)	1380	(215)	257	(40)	19.8	(23.6)	13.0	(15.5)				
Avg	29.3		19.2		1430		272		25.5		16.7		1370		264	
n	3		3		3		3		3		3		2		2	
SD	1.0		0.7		49		11		4.0		2.6		4		3	
Min	28.4		18.6		1380		257		19.8		13.0		1360		261	
Max	30.7		20.1		1500		285		28.4		18.6		1370		267	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for January, 2008.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	29.0	(8.8)	19.0	(5.8)	1430	(384)	259	(69)	13.2	(10.5)	8.62	(6.87)				
2	19.1	(19.8)	12.5	(13.0)					9.71	(18.50)	6.37	(12.10)				
3	19.8	(28.2)	13.0	(18.5)					11.6	(21.1)	7.62	(13.80)				
4	12.2	(23.3)	8.02	(15.30)					9.35	(17.30)	6.13	(11.30)				
5	10.6	(21.4)	6.92	(14.10)					8.30	(16.70)	5.44	(11.00)				
6	9.76	(16.90)	6.40	(11.10)	1070	(1850)	7720	(13300)	8.14	(14.00)	5.34	(9.18)				
7	8.34	(12.10)	5.47	(7.94)	691	(1130)	5730	(9280)	7.09	(10.20)	4.65	(6.68)				
8	6.85	(8.79)	4.49	(5.76)	325	(417)	2910	(3740)	6.40	(8.14)	4.20	(5.34)	302	(384)	2150	(2730)
9	6.39	(9.60)	4.19	(6.29)	304	(457)	2650	(3970)	5.77	(8.42)	3.79	(5.52)	273	(398)	2260	(3320)
10	6.49	(9.22)	4.25	(6.05)	309	(440)	2410	(3430)	5.86	(8.23)	3.84	(5.39)	277	(389)	2480	(3480)
11	6.03	(7.97)	3.95	(5.23)	288	(381)	1890	(2500)	5.30	(7.04)	3.48	(4.62)	251	(333)	2200	(2930)
12	5.77	(8.79)	3.78	(5.77)	276	(420)	1480	(2230)	4.95	(7.51)	3.25	(4.93)	235	(356)	1850	(2790)
13	5.45	(9.26)	3.57	(6.07)	261	(443)	1130	(1940)	4.48	(7.70)	2.94	(5.05)	213	(365)	1420	(2450)
14	6.14	(7.72)	4.02	(5.06)	294	(370)	1030	(1290)	4.95	(6.25)	3.25	(4.10)	235	(297)	1270	(1610)
15	6.61	(8.41)	4.33	(5.52)	317	(403)	915	(1160)	5.06	(6.39)	3.32	(4.19)	241	(304)	1060	(1340)
16	6.20	(8.15)	4.07	(5.34)	297	(391)	715	(943)	4.36	(6.28)	2.86	(4.12)	207	(299)	746	(1070)
17	5.92	(7.84)	3.88	(5.14)	284	(376)	573	(759)	4.16	(6.64)	2.73	(4.35)	198	(316)	581	(932)
18	6.16	(8.07)	4.04	(5.29)	296	(388)	508	(672)	4.72	(6.70)	3.09	(4.39)	225	(319)	546	(785)
19	6.16	(7.06)	4.04	(4.63)	296	(339)	438	(506)	4.78	(5.45)	3.13	(3.57)	228	(260)	466	(535)
20	5.38	(6.69)	3.53	(4.38)	259	(321)	334	(414)	4.17	(5.21)	2.73	(3.41)	199	(248)	347	(433)
21	5.37	(6.85)	3.52	(4.49)	258	(329)	292	(373)	3.81	(4.93)	2.50	(3.23)	182	(235)	272	(353)
22	5.43	(6.75)	3.56	(4.43)	261	(325)	262	(326)	3.63	(4.66)	2.38	(3.05)	173	(223)	226	(290)
23	5.85	(7.22)	3.83	(4.73)	282	(347)	252	(311)	3.77	(4.67)	2.47	(3.06)	180	(223)	206	(255)
24	6.26	(7.68)	4.10	(5.04)	301	(370)	242	(297)	3.97	(4.91)	2.60	(3.22)	190	(235)	192	(237)
25	6.74	(6.78)	4.42	(4.45)	325	(327)	236	(239)	4.32	(4.28)	2.83	(2.81)	207	(205)	186	(186)
26	6.36	(5.66)	4.17	(3.71)	307	(273)	203	(181)	4.57	(4.04)	3.00	(2.65)	219	(194)	177	(157)
27	6.34	(5.74)	4.16	(3.76)	306	(277)	185	(168)	4.64	(4.18)	3.04	(2.74)	222	(200)	163	(147)
28	8.72	(8.86)	5.72	(5.81)	421	(427)	234	(237)	6.86	(7.60)	4.50	(4.98)	329	(365)	219	(241)
29	9.48	(11.00)	6.22	(7.18)	458	(529)	236	(272)	8.02	(9.91)	5.26	(6.50)	385	(476)	235	(290)
30	10.3	(10.8)	6.76	(7.08)	498	(521)	238	(250)	9.04	(9.89)	5.93	(6.49)	434	(475)	244	(268)
31	10.8	(11.9)	7.08	(7.80)	521	(575)	232	(256)	8.77	(9.63)	5.75	(6.32)	422	(463)	218	(240)
Avg	8.71		5.71		405		1230		6.25		4.10		251		822	
n	31		31		27		27		31		31		24		24	
SD	5.10		3.35		262		1760		2.43		1.60		72		784	
Min	5.37		3.52		258		185		3.63		2.38		173		163	
Max	29.00		19.00		1430		7720		13.20		8.62		434		2480	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for February, 2008.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1																
2																
3																
4																
5	17.2	(11.2)	11.3	(7.4)	836	(544)	275	(180)	15.6	(10.3)	10.2	(6.8)	752	(499)	278	(185)
6	17.4	(9.5)	11.4	(6.3)	843	(462)	263	(145)	15.1	(8.8)	9.9	(5.8)	730	(423)	255	(148)
7	18.3	(9.2)	12.0	(6.0)	886	(447)	263	(133)	17.0	(9.9)	11.2	(6.5)	822	(479)	271	(158)
8	19.5	(9.3)	12.8	(6.1)	947	(453)	268	(129)	18.0	(9.2)	11.8	(6.0)	867	(445)	272	(140)
9	21.7	(10.0)	14.2	(6.5)	1050	(485)	285	(131)	19.5	(9.1)	12.8	(6.0)	942	(442)	280	(132)
10	24.4	(10.2)	16.0	(6.7)	1190	(494)	307	(129)	22.4	(9.4)	14.7	(6.1)	1080	(453)	307	(129)
11	24.2	(9.7)	15.8	(6.3)	1180	(471)	292	(117)	23.0	(8.7)	15.1	(5.7)	1110	(421)	302	(116)
12	23.6	(8.4)	15.4	(5.5)	1150	(408)	274	(99)	22.1	(6.4)	14.5	(4.2)	1070	(311)	278	(82)
13	23.7	(6.4)	15.5	(4.2)	1150	(314)	265	(73)	21.6	(7.0)	14.2	(4.6)	1050	(341)	261	(85)
14	21.4	(8.0)	14.1	(5.2)	1050	(388)	232	(87)	19.7	(8.6)	12.9	(5.6)	957	(415)	230	(100)
15	21.3	(7.0)	14.0	(4.6)	1040	(339)	224	(73)	20.5	(7.8)	13.5	(5.1)	997	(380)	230	(88)
16	23.5	(5.3)	15.4	(3.4)	1150	(256)	239	(53)	22.2	(5.9)	14.5	(3.9)	1080	(286)	240	(64)
17	25.9	(5.6)	17.0	(3.7)	1270	(273)	256	(55)	24.9	(5.5)	16.3	(3.6)	1210	(267)	261	(58)
18	28.3	(6.0)	18.6	(3.9)	1390	(292)	272	(58)	26.1	(5.4)	17.1	(3.6)	1270	(265)	266	(56)
19	28.4	(4.9)	18.6	(3.2)	1390	(239)	266	(46)	26.0	(4.4)	17.1	(2.9)	1270	(214)	257	(43)
20	28.6	(3.1)	18.7	(2.0)	1400	(151)	262	(29)	28.6	(3.4)	18.7	(2.2)	1390	(165)	275	(33)
21	23.9	(19.4)	15.7	(12.7)	1210	(963)			29.7	(9.0)	19.5	(5.9)	1470	(373)	282	(71)
22																
23																
24	8.19	(0.88)	5.37	(0.58)					8.67	(0.81)	5.69	(0.53)				
25	7.52	(3.70)	4.93	(2.43)					8.82	(2.94)	5.78	(1.93)				
26	7.25	(12.10)	4.75	(7.94)					7.60	(10.20)	4.98	(6.69)				
27	12.4	(22.5)	8.10	(14.80)					11.0	(19.7)	7.18	(12.90)				
28	14.0	(20.9)	9.16	(13.70)					12.6	(18.2)	8.29	(11.90)				
29	13.8	(16.4)	9.05	(10.80)	649	(774)	4760	(5660)	12.8	(15.8)	8.39	(10.40)	602	(744)	4410	(5520)
Avg	19.8		13.0		1100		529		18.8		12.4		1040		498	
n	23		23		18		17		23		23		18		18	
SD	6.4		4.2		202		1060		6.3		4.1		227		950	
Min	7.3		4.8		649		224		7.6		5.0		602		230	
Max	28.6		18.7		1400		4760		29.7		19.5		1470		4410	

Table E11. Daily means (SD) of NH_3 emissions at Site CA1B for March, 2008.

Day	House 10				House 12			
	kg d^{-1}	g $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$	kg d^{-1}	g $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$
1	9.36 (11.50)	6.14 (7.57)	441 (544)	3710 (4570)	7.43 (14.60)	4.87 (9.60)	350 (690)	2950 (5780)
2	9.55 (12.00)	6.26 (7.87)	450 (566)	4050 (5090)	8.44 (13.00)	5.53 (8.53)	398 (614)	3580 (5510)
3	9.56 (9.93)	6.27 (6.51)	452 (469)	3920 (4090)	9.36 (9.72)	6.14 (6.37)	443 (459)	3840 (4010)
4	7.99 (8.64)	5.24 (5.67)	378 (409)	2910 (3160)	7.39 (7.69)	4.84 (5.05)	349 (364)	2690 (2820)
5	7.44 (8.81)	4.88 (5.78)	352 (417)	2260 (2670)	6.80 (7.74)	4.46 (5.08)	322 (367)	2070 (2360)
6	8.16 (9.20)	5.35 (6.03)	387 (436)	2040 (2330)	7.30 (7.79)	4.78 (5.11)	346 (369)	1830 (1980)
7	7.75 (8.19)	5.08 (5.37)	368 (388)	1570 (1670)	6.39 (6.96)	4.19 (4.57)	303 (330)	1300 (1420)
8	4.66 (6.99)	3.06 (4.59)	221 (332)	789 (1210)	3.77 (5.70)	2.47 (3.74)	179 (271)	638 (988)
9	2.08 (2.13)	1.36 (1.40)	99 (101)	279 (287)	1.70 (1.93)	1.11 (1.27)	81 (92)	228 (263)
10	2.93 (2.58)	1.92 (1.69)	139 (123)	328 (289)	2.07 (1.88)	1.36 (1.24)	99 (90)	233 (212)
11	3.97 (4.17)	2.60 (2.74)	188 (198)	374 (391)	2.32 (2.49)	1.52 (1.63)	111 (118)	220 (234)
12	5.09 (5.38)	3.34 (3.53)	242 (256)	410 (433)	2.77 (3.00)	1.81 (1.97)	132 (143)	223 (241)
13	6.25 (5.64)	4.10 (3.70)	297 (268)	435 (395)	3.47 (3.26)	2.28 (2.14)	165 (155)	242 (227)
14	6.34 (5.88)	4.15 (3.86)	301 (280)	384 (357)	3.87 (3.84)	2.54 (2.52)	185 (183)	235 (233)
15	6.68 (6.19)	4.38 (4.06)	318 (295)	356 (329)	3.99 (3.96)	2.61 (2.60)	190 (189)	213 (212)
16	6.45 (6.12)	4.23 (4.01)	307 (292)	305 (291)	3.90 (3.67)	2.56 (2.41)	186 (175)	185 (174)
17	6.40 (4.72)	4.20 (3.09)	305 (225)	271 (201)	4.10 (3.06)	2.69 (2.00)	196 (146)	174 (130)
18	6.49 (4.09)	4.26 (2.68)	310 (195)	247 (156)	3.99 (2.57)	2.62 (1.68)	191 (123)	152 (98)
19	7.56 (6.15)	4.96 (4.03)	361 (293)	261 (210)	4.27 (3.20)	2.80 (2.10)	204 (153)	147 (110)
20	8.45 (8.92)	5.54 (5.85)	404 (426)	265 (280)	4.98 (4.38)	3.27 (2.87)	239 (210)	157 (138)
21	9.44 (9.98)	6.19 (6.55)	452 (478)	272 (289)	5.99 (5.09)	3.93 (3.34)	287 (244)	173 (147)
22	9.22 (8.23)	6.04 (5.40)	441 (394)	245 (220)	6.96 (5.24)	4.56 (3.44)	334 (252)	185 (140)
23	9.56 (7.28)	6.27 (4.78)	458 (349)	235 (180)	7.79 (5.60)	5.11 (3.67)	375 (270)	192 (139)
24								
25	11.5 (8.3)	7.53 (5.46)	551 (400)	244 (178)	9.46 (6.89)	6.21 (4.52)	457 (332)	202 (148)
26	12.9 (9.0)	8.43 (5.88)	618 (431)	256 (179)	10.40 (7.04)	6.82 (4.62)	503 (340)	208 (141)
27								
28	14.7 (8.6)	9.67 (5.61)	709 (412)	260 (152)	13.00 (6.88)	8.55 (4.51)	630 (333)	231 (122)
29	17.0 (7.3)	11.2 (4.8)	820 (353)	283 (122)	14.90 (6.57)	9.78 (4.31)	722 (318)	250 (110)
30	17.2 (8.0)	11.3 (5.3)	830 (386)	272 (127)	15.30 (7.02)	10.00 (4.60)	741 (340)	243 (112)
31	16.9 (8.1)	11.1 (5.3)	814 (389)	253 (122)	15.30 (7.60)	10.00 (4.98)	740 (368)	230 (115)
Avg	8.68	5.69	414	948	6.81	4.46	326	801
n	29	29	29	29	29	29	29	29
SD	3.89	2.55	188	1210	3.88	2.54	188	1110
Min	2.08	1.36	99	235	1.70	1.11	81	147
Max	17.20	11.30	830	4050	15.30	10.00	741	3840

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for April, 2008.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	18.0	(7.9)	11.8	(5.2)	868	(380)	257	(113)	16.1	(7.7)	10.5	(5.0)	779	(372)	230	(111)
2	18.7	(6.2)	12.3	(4.1)	904	(301)	255	(86)	17.5	(6.4)	11.5	(4.2)	850	(311)	240	(88)
3	20.6	(5.2)	13.5	(3.4)	998	(251)	269	(68)	18.5	(5.8)	12.1	(3.8)	898	(279)	242	(76)
4	21.6	(5.6)	14.2	(3.7)	1050	(270)	270	(70)	19.0	(5.2)	12.5	(3.4)	924	(255)	239	(67)
5																
6																
7																
8																
9																
10																
11																
12	30.7	(6.7)	20.1	(4.4)	1490	(327)	293	(64)	26.5	(5.9)	17.3	(3.9)	1290	(290)	253	(57)
13	26.0	(5.3)	17.1	(3.5)	1270	(260)	242	(50)	23.1	(5.6)	15.1	(3.7)	1130	(272)	215	(52)
14	21.3	(3.9)	13.9	(2.6)	1040	(190)	193	(36)	18.2	(3.6)	11.9	(2.4)	890	(178)	166	(33)
15	10.3	(9.8)	6.75	(6.41)					5.78	(6.50)	3.79	(4.3)				
16	10.6	(13.3)	6.97	(8.75)					9.12	(16.60)	5.98	(10.90)				
17	7.35	(7.58)	4.82	(4.97)					3.59	(6.02)	2.35	(3.95)				
18	1.91	(2.22)	1.25	(1.46)					2.26	(2.80)	1.48	(1.84)				
19	0.117	(0.100)	0.077	(0.066)					0.101	(0.084)	0.067	(0.055)				
20	0.062	(0.072)	0.041	(0.047)					0.017	(0.053)	0.011	(0.035)				
21	0.217	(0.237)	0.142	(0.156)					0.133	(0.136)	0.087	(0.089)				
22	0.099	(0.181)	0.065	(0.118)					0.083	(0.145)	0.055	(0.095)	4.02	(7.68)	25.7	(49.1)
23	0.156	(0.285)	0.102	(0.187)	7.31	(13.40)	53.9	(98.0)	0.109	(0.203)	0.071	(0.133)	5.12	(9.56)	38.8	(72.3)
24	0.170	(0.232)	0.112	(0.152)	7.98	(10.90)	67.9	(93.0)	0.107	(0.148)	0.070	(0.097)	5.05	(6.97)	43.7	(60.5)
25	0.356	(0.538)	0.233	(0.353)	16.7	(25.3)	150	(228)	0.248	(0.357)	0.163	(0.234)	11.7	(16.8)	105	(152)
26	0.562	(0.587)	0.369	(0.385)	26.4	(27.6)	228	(239)	0.394	(0.408)	0.258	(0.268)	18.6	(19.2)	158	(164)
27	0.756	(0.665)	0.496	(0.436)	35.6	(31.3)	272	(241)	0.558	(0.494)	0.366	(0.324)	26.3	(23.3)	196	(174)
28	0.587	(0.521)	0.385	(0.341)	27.7	(24.5)	177	(158)	0.438	(0.383)	0.288	(0.251)	20.7	(18.1)	128	(112)
29	0.373	(0.472)	0.244	(0.310)	17.6	(22.3)	92.0	(116.0)	0.251	(0.288)	0.165	(0.189)	11.9	(13.6)	60.0	(68.7)
30	0.476	(0.624)	0.312	(0.409)	22.5	(29.5)	94.3	(122.0)	0.300	(0.393)	0.197	(0.258)	14.2	(18.6)	57.2	(73.8)
Avg	8.31		5.45		518		194		7.06		4.63		430		150	
n	23		23		15		15		23		23		16		16	
SD	10.10		6.60		551		80		8.90		5.84		485		82	
Min	0.06		0.04		7		54		0.02		0.01		4		26	
Max	30.70		20.10		1490		293		26.50		17.30		1290		253	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for May, 2008.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	0.62	(0.78)	0.41	(0.51)	29.50	(37.00)	102.00	(129.00)	0.45	(0.56)	0.30	(0.37)	21.40	(26.50)	71.90	(89.20)
2	0.73	(0.82)	0.48	(0.54)	34.40	(38.70)	97.90	(111.00)	0.52	(0.59)	0.34	(0.38)	24.60	(27.70)	67.90	(76.70)
3	0.91	(1.00)	0.60	(0.66)	43.20	(47.50)	101.00	(112.00)	0.64	(0.70)	0.42	(0.46)	30.10	(33.00)	68.60	(76.00)
4	1.12	(1.01)	0.73	(0.66)	52.90	(47.70)	105.00	(95.40)	0.72	(0.66)	0.47	(0.43)	34.00	(31.20)	65.60	(60.30)
5	1.19	(0.96)	0.78	(0.63)	56.60	(45.50)	95.60	(77.30)	0.82	(0.69)	0.54	(0.45)	39.00	(32.70)	64.10	(54.00)
6	1.49	(1.25)	0.98	(0.82)	70.50	(59.20)	102.00	(86.00)	1.04	(0.88)	0.68	(0.58)	49.40	(41.60)	70.00	(59.00)
7	0.99	(0.98)	0.65	(0.64)	47.10	(46.30)	59.70	(58.70)	0.90	(0.91)	0.59	(0.59)	42.60	(42.90)	52.80	(53.10)
8	1.57	(1.00)	1.03	(0.65)	74.60	(47.30)	83.20	(52.90)	1.45	(0.90)	0.95	(0.59)	68.80	(42.60)	75.20	(46.70)
9	1.59	(1.12)	1.04	(0.74)	75.60	(53.30)	74.70	(52.60)	1.51	(1.04)	0.99	(0.68)	71.60	(49.40)	69.50	(47.90)
10	2.28	(1.37)	1.49	(0.90)	108.00	(65.10)	95.60	(57.40)	2.00	(1.20)	1.31	(0.79)	94.90	(57.10)	82.40	(49.70)
11	2.40	(1.55)	1.58	(1.02)	114.00	(73.80)	90.80	(58.70)	2.02	(1.35)	1.33	(0.88)	96.00	(63.90)	75.00	(49.80)
12	2.42	(1.51)	1.59	(0.99)	115.00	(71.60)	82.90	(51.50)	2.09	(1.40)	1.37	(0.92)	99.30	(66.50)	70.30	(46.80)
13	3.21	(1.89)	2.11	(1.24)	153.00	(90.00)	100.00	(59.00)	3.03	(1.85)	1.99	(1.21)	144.00	(87.90)	93.20	(56.80)
14	3.67	(2.07)	2.41	(1.36)	175.00	(98.80)	105.00	(59.50)	3.62	(2.17)	2.37	(1.42)	172.00	(103.00)	102.00	(61.10)
15																
16																
17																
18																
19																
20	11.00	(5.34)	7.22	(3.50)	527.00	(256.00)	205.00	(99.40)	7.73	(4.07)	5.07	(2.67)	369.00	(194.00)	142.00	(74.90)
21	10.70	(4.70)	7.00	(3.08)	511.00	(225.00)	187.00	(82.70)	7.69	(3.47)	5.04	(2.27)	367.00	(166.00)	133.00	(59.80)
22	11.70	(4.45)	7.65	(2.92)	558.00	(213.00)	193.00	(73.80)	8.91	(3.66)	5.84	(2.40)	426.00	(175.00)	146.00	(59.90)
23	12.70	(4.53)	8.32	(2.97)	608.00	(217.00)	198.00	(70.80)	8.48	(3.02)	5.56	(1.98)	406.00	(145.00)	131.00	(46.60)
24	15.30	(5.00)	10.10	(3.28)	735.00	(240.00)	228.00	(73.80)	10.30	(3.67)	6.76	(2.40)	494.00	(175.00)	152.00	(53.00)
25	20.40	(5.26)	13.40	(3.45)	980.00	(252.00)	289.00	(73.60)	17.70	(4.97)	11.60	(3.26)	846.00	(238.00)	247.00	(68.60)
26	25.50	(7.85)	16.70	(5.14)	1220.00	(377.00)	344.00	(106.00)	22.70	(7.36)	14.90	(4.83)	1090.00	(353.00)	304.00	(99.10)
27	25.90	(6.12)	17.00	(4.02)	1250.00	(294.00)	335.00	(79.20)	23.70	(6.85)	15.50	(4.49)	1140.00	(329.00)	303.00	(88.00)
28	26.90	(7.17)	17.70	(4.70)	1290.00	(345.00)	334.00	(89.10)	25.00	(6.98)	16.40	(4.57)	1200.00	(335.00)	308.00	(86.30)
29	25.70	(6.16)	16.90	(4.04)	1240.00	(296.00)	307.00	(73.70)	24.50	(6.02)	16.10	(3.95)	1180.00	(289.00)	290.00	(71.50)
30	26.90	(5.87)	17.60	(3.85)	1300.00	(283.00)	309.00	(67.30)	25.40	(6.14)	16.60	(4.03)	1220.00	(295.00)	289.00	(69.90)
31	26.30	(5.79)	17.30	(3.79)	1270.00	(279.00)	292.00	(64.20)	24.20	(6.01)	15.90	(3.94)	1170.00	(289.00)	267.00	(66.00)
Avg	10.1		6.6		486.0		174.0		8.7		5.7		419.0		144.0	
n	26		26		26		26		26		26		26		26	
SD	10.2		6.7		490.0		96.8		9.4		6.1		450.0		91.5	
Min	0.6		0.4		29.5		59.7		0.5		0.3		21.4		52.8	
Max	26.9		17.7		1300.0		344.0		25.4		16.6		1220.0		308.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for June, 2008.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	28.40	(6.74)	18.60	(4.42)	1370.00	(326.00)	305.00	(72.70)	25.10	(6.46)	16.40	(4.24)	1210.00	(311.00)	267.00	(68.90)
2	28.00	(6.69)	18.40	(4.39)	1360.00	(324.00)	291.00	(69.50)	25.40	(6.41)	16.60	(4.20)	1220.00	(309.00)	261.00	(65.90)
3	30.40	(7.31)	19.90	(4.79)	1470.00	(354.00)	306.00	(73.50)	27.80	(6.60)	18.20	(4.33)	1340.00	(319.00)	277.00	(65.80)
4	30.10	(6.52)	19.80	(4.27)	1460.00	(316.00)	295.00	(63.70)	27.50	(6.44)	18.00	(4.22)	1330.00	(311.00)	266.00	(62.30)
5	25.50	(6.77)	16.70	(4.44)	1240.00	(329.00)	243.00	(65.40)	23.80	(6.50)	15.60	(4.26)	1150.00	(314.00)	224.00	(62.00)
6	20.50	(7.54)	13.50	(4.94)					21.10	(5.47)	13.80	(3.59)	1010.00	(250.00)	192.00	(47.90)
7	2.22	(3.93)	1.45	(2.57)					3.22	(6.07)	2.11	(3.98)				
8	0.00	(0.00)	0.00	(0.00)					0.00	(0.00)	0.00	(0.00)				
9	0.00	(0.00)	0.00	(0.00)					0.00	(0.00)	0.00	(0.00)				
10	2.71	(3.79)	1.78	(2.49)					6.51	(6.00)	4.27	(3.93)				
11	2.60	(1.26)	1.70	(0.83)					3.14	(1.34)	2.06	(0.88)				
12	3.56	(3.56)	2.33	(2.33)					2.73	(2.80)	1.79	(1.84)				
13	4.00	(3.00)	2.62	(1.96)					3.60	(3.12)	2.36	(2.04)				
14	3.47	(3.40)	2.27	(2.23)					3.25	(3.34)	2.13	(2.19)				
15	3.32	(3.43)	2.18	(2.25)	156.00	(161.00)	1160.00	(1170.00)	3.09	(3.23)	2.03	(2.12)	146.00	(152.00)	1070.00	(1100.00)
16	3.23	(2.62)	2.12	(1.72)	152.00	(123.00)	1300.00	(1050.00)	2.92	(2.52)	1.91	(1.65)	138.00	(119.00)	1170.00	(1010.00)
17	3.09	(2.67)	2.03	(1.75)	146.00	(126.00)	1310.00	(1130.00)	2.75	(2.54)	1.80	(1.67)	130.00	(120.00)	1170.00	(1080.00)
18	2.90	(2.41)	1.90	(1.58)	137.00	(114.00)	1180.00	(984.00)	2.62	(2.19)	1.72	(1.44)	124.00	(104.00)	1070.00	(902.00)
19	2.92	(2.33)	1.91	(1.53)	138.00	(110.00)	1050.00	(847.00)	2.67	(2.08)	1.75	(1.36)	127.00	(98.60)	968.00	(761.00)
20	2.95	(2.03)	1.93	(1.33)	139.00	(96.10)	886.00	(629.00)	2.77	(1.93)	1.81	(1.27)	131.00	(91.60)	840.00	(601.00)
21	2.96	(2.10)	1.94	(1.38)	140.00	(99.20)	730.00	(532.00)	2.69	(1.88)	1.76	(1.23)	127.00	(89.00)	669.00	(478.00)
22	2.41	(1.73)	1.58	(1.14)	114.00	(81.90)	478.00	(349.00)	2.25	(1.68)	1.48	(1.10)	107.00	(79.90)	452.00	(343.00)
23	2.51	(1.81)	1.65	(1.19)	119.00	(85.60)	402.00	(288.00)	2.43	(1.79)	1.59	(1.17)	115.00	(84.80)	393.00	(287.00)
24	3.68	(2.88)	2.41	(1.89)	174.00	(136.00)	488.00	(383.00)	3.10	(2.37)	2.03	(1.56)	147.00	(113.00)	416.00	(319.00)
25	2.81	(2.21)	1.84	(1.45)	133.00	(105.00)	309.00	(245.00)	2.38	(2.02)	1.56	(1.33)	113.00	(96.10)	265.00	(226.00)
26	3.66	(2.90)	2.40	(1.90)	173.00	(138.00)	340.00	(269.00)	2.73	(2.16)	1.79	(1.41)	130.00	(102.00)	256.00	(203.00)
27	3.13	(2.24)	2.05	(1.47)	148.00	(106.00)	249.00	(178.00)	2.92	(2.19)	1.92	(1.43)	139.00	(104.00)	234.00	(175.00)
28	2.53	(1.93)	1.66	(1.27)	120.00	(91.60)	173.00	(132.00)	2.35	(1.85)	1.54	(1.21)	112.00	(87.80)	162.00	(127.00)
29	2.52	(1.69)	1.65	(1.11)	119.00	(80.10)	150.00	(100.00)	2.36	(1.72)	1.55	(1.13)	112.00	(81.60)	142.00	(102.00)
30	2.47	(1.67)	1.62	(1.09)	117.00	(79.20)	130.00	(87.40)	2.26	(1.66)	1.48	(1.09)	108.00	(79.20)	120.00	(87.50)
Avg	7.6		5.0		435.0		561.0		7.2		4.7		421.0		495.0	
n	30		30		21		21		30		30		22		22	
SD	9.9		6.5		531.0		399.0		9.1		6.0		487.0		362.0	
Min	0.0		0.0		114.0		130.0		0.0		0.0		107.0		120.0	
Max	30.4		19.9		1470.0		1310.0		27.8		18.2		1340.0		1170.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for July, 2008.

Day	House 10								House 12							
	kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1	2.41	(1.75)	1.58	(1.15)	114.00	(82.90)	112.00	(81.20)	2.02	(1.52)	1.33	(1.00)	96.30	(72.40)	94.90	(71.00)
2	2.35	(1.54)	1.54	(1.01)	112.00	(73.00)	98.10	(63.80)	2.15	(1.60)	1.41	(1.05)	102.00	(76.40)	90.10	(67.10)
3	2.38	(1.64)	1.56	(1.07)	113.00	(77.80)	89.50	(61.30)	2.36	(1.95)	1.55	(1.28)	112.00	(93.00)	89.20	(73.40)
4	1.96	(1.19)	1.28	(0.78)	93.20	(56.60)	66.60	(40.10)	1.59	(1.12)	1.05	(0.74)	76.10	(53.50)	54.50	(38.00)
5	2.66	(1.69)	1.74	(1.11)	127.00	(80.30)	82.50	(52.20)	2.41	(1.78)	1.58	(1.17)	115.00	(84.90)	75.30	(55.20)
6	3.45	(2.08)	2.26	(1.36)	164.00	(99.10)	98.00	(59.00)	3.01	(2.02)	1.97	(1.32)	144.00	(96.60)	85.90	(57.70)
7	4.55	(2.08)	2.98	(1.37)	217.00	(99.40)	119.00	(54.30)	3.92	(2.07)	2.57	(1.36)	188.00	(99.00)	103.00	(54.50)
8	5.97	(2.82)	3.91	(1.85)	285.00	(135.00)	145.00	(68.10)	5.33	(2.82)	3.49	(1.85)	255.00	(135.00)	130.00	(68.70)
9	6.68	(2.85)	4.38	(1.87)	319.00	(136.00)	150.00	(63.90)	6.16	(2.97)	4.04	(1.95)	296.00	(142.00)	140.00	(67.00)
10	7.11	(3.45)	4.66	(2.26)	340.00	(165.00)	150.00	(72.50)	6.40	(3.48)	4.20	(2.28)	307.00	(167.00)	136.00	(73.80)
11	7.74	(3.63)	5.08	(2.38)	370.00	(174.00)	152.00	(71.20)	6.36	(3.40)	4.17	(2.23)	305.00	(163.00)	126.00	(67.00)
12	10.20	(4.36)	6.71	(2.86)	490.00	(209.00)	189.00	(80.30)	8.76	(4.69)	5.74	(3.07)	421.00	(225.00)	163.00	(87.00)
13	13.50	(4.37)	8.85	(2.87)	647.00	(209.00)	235.00	(75.60)	11.40	(4.54)	7.50	(2.98)	550.00	(218.00)	201.00	(79.30)
14	14.00	(5.13)	9.17	(3.36)	671.00	(246.00)	231.00	(84.40)	12.40	(5.28)	8.13	(3.46)	598.00	(255.00)	206.00	(87.40)
15	15.40	(5.70)	10.10	(3.74)	738.00	(274.00)	240.00	(88.80)	14.90	(6.43)	9.80	(4.22)	721.00	(310.00)	235.00	(101.00)
16	17.50	(5.89)	11.50	(3.86)	840.00	(283.00)	260.00	(87.00)	17.10	(6.25)	11.20	(4.10)	825.00	(302.00)	256.00	(93.10)
17	17.20	(6.48)	11.30	(4.25)	829.00	(312.00)	244.00	(91.90)	17.70	(6.94)	11.60	(4.55)	856.00	(336.00)	253.00	(99.00)
18	17.90	(5.57)	11.70	(3.65)	861.00	(268.00)	242.00	(74.60)	18.40	(6.75)	12.10	(4.43)	894.00	(327.00)	251.00	(91.60)
19	20.50	(5.42)	13.40	(3.56)	988.00	(261.00)	265.00	(69.50)	18.70	(5.56)	12.30	(3.65)	908.00	(270.00)	244.00	(72.10)
20	21.70	(6.72)	14.20	(4.40)	1050.00	(324.00)	269.00	(82.80)	20.50	(7.01)	13.40	(4.60)	995.00	(340.00)	256.00	(87.20)
21	25.20	(6.11)	16.50	(4.01)	1220.00	(295.00)	300.00	(72.70)	23.70	(6.88)	15.60	(4.51)	1150.00	(335.00)	286.00	(82.70)
22	25.80	(5.94)	16.90	(3.90)	1250.00	(288.00)	297.00	(67.80)	24.20	(7.12)	15.90	(4.67)	1180.00	(347.00)	281.00	(82.20)
23	24.30	(5.13)	15.90	(3.37)	1180.00	(249.00)	269.00	(56.50)	23.60	(6.00)	15.50	(3.94)	1150.00	(293.00)	264.00	(67.20)
24	23.70	(5.12)	15.50	(3.35)	1150.00	(248.00)	254.00	(53.70)	22.30	(5.40)	14.60	(3.54)	1090.00	(264.00)	242.00	(57.80)
25	28.30	(5.31)	18.50	(3.48)	1370.00	(258.00)	294.00	(53.80)	25.60	(5.67)	16.80	(3.72)	1260.00	(279.00)	269.00	(58.90)
26	28.40	(5.63)	18.60	(3.69)	1380.00	(274.00)	286.00	(55.50)	25.60	(6.09)	16.80	(3.99)	1260.00	(300.00)	261.00	(61.50)
27	27.50	(4.70)	18.10	(3.08)	1340.00	(229.00)	270.00	(46.00)	23.50	(5.51)	15.40	(3.62)	1160.00	(272.00)	233.00	(54.80)
28	25.40	(5.95)	16.70	(3.90)	1240.00	(290.00)	243.00	(56.60)	23.60	(6.87)	15.50	(4.50)	1170.00	(340.00)	229.00	(66.60)
29	22.70	(5.28)	14.90	(3.46)	1110.00	(258.00)	211.00	(49.40)	21.20	(6.66)	13.90	(4.37)	1050.00	(331.00)	201.00	(63.30)
30	22.40	(3.64)	14.70	(2.39)	1100.00	(178.00)	204.00	(33.30)	20.00	(4.76)	13.10	(3.12)	1000.00	(238.00)	186.00	(44.50)
31	22.90	(5.68)	15.00	(3.72)	1120.00	(278.00)	204.00	(50.20)	19.30	(5.13)	12.60	(3.36)	972.00	(259.00)	177.00	(47.30)
Avg	15.2		10.0		736.0		202.0		14.0		9.2		684.0		188.0	
n	31		31		31		31		31		31		31		31	
SD	9.2		6.0		447.0		71.7		8.5		5.6		421.0		70.7	
Min	2.0		1.3		93.2		66.6		1.6		1.1		76.1		54.5	
Max	28.4		18.6		1380.0		300.0		25.6		16.8		1260.0		286.0	

Table E11. Daily means (SD) of NH_3 emissions at Site CA1B for August, 2008.

Day	House 10								House 12							
	kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1	18.60	(25.70)	12.20	(16.80)					19.60	(23.70)	12.80	(15.50)				
2	50.90	(86.20)	33.40	(56.50)					35.20	(39.50)	23.10	(25.90)				
3	8.78	(1.06)	5.75	(0.70)					8.83	(1.02)	5.79	(0.67)				
4	6.02	(1.45)	3.95	(0.95)					5.52	(1.30)	3.62	(0.85)				
5	3.24	(1.24)	2.12	(0.81)					2.80	(0.93)	1.83	(0.61)				
6	2.41	(2.10)	1.58	(1.38)					1.84	(1.69)	1.21	(1.11)				
7	2.45	(2.89)	1.61	(1.89)					2.24	(2.39)	1.47	(1.57)				
8	2.76	(1.62)	1.81	(1.06)					2.39	(1.33)	1.56	(0.88)				
9	2.10	(0.97)	1.38	(0.63)					1.71	(0.80)	1.12	(0.53)				
10	1.88	(1.81)	1.23	(1.19)					1.65	(1.57)	1.08	(1.03)				
11	1.85	(2.03)	1.21	(1.33)					1.79	(1.72)	1.18	(1.13)				
12	1.83	(1.88)	1.20	(1.23)	85.30	(87.70)	621.00	(631.00)	1.95	(1.88)	1.28	(1.23)	91.20	(87.90)	664.00	(637.00)
13	1.86	(1.72)	1.22	(1.13)	86.80	(80.20)	731.00	(666.00)	2.04	(1.91)	1.34	(1.26)	95.40	(89.50)	804.00	(748.00)
14	1.80	(1.44)	1.18	(0.95)	84.20	(67.50)	756.00	(605.00)	1.90	(1.68)	1.25	(1.10)	89.00	(78.70)	799.00	(707.00)
15	1.67	(1.22)	1.10	(0.80)	78.30	(57.20)	681.00	(502.00)	1.68	(1.32)	1.10	(0.87)	78.90	(62.10)	687.00	(545.00)
16	1.64	(1.17)	1.07	(0.77)	76.60	(55.00)	594.00	(430.00)	1.56	(1.21)	1.02	(0.79)	73.10	(56.70)	568.00	(445.00)
17	1.45	(1.15)	0.95	(0.76)	68.00	(54.10)	442.00	(356.00)	1.38	(1.18)	0.90	(0.78)	64.70	(55.60)	420.00	(362.00)
18																
19																
20																
21	2.10	(1.44)	1.38	(0.95)	98.60	(67.80)	284.00	(198.00)	1.98	(1.59)	1.30	(1.04)	93.10	(74.80)	268.00	(217.00)
22	2.26	(1.47)	1.48	(0.97)	106.00	(69.10)	253.00	(167.00)	2.11	(1.57)	1.38	(1.03)	99.20	(74.00)	236.00	(177.00)
23	2.39	(1.63)	1.56	(1.07)	112.00	(76.50)	224.00	(154.00)	2.03	(1.68)	1.33	(1.10)	95.40	(79.10)	191.00	(158.00)
24	2.68	(1.60)	1.76	(1.05)	126.00	(75.10)	215.00	(129.00)	2.14	(1.62)	1.40	(1.06)	101.00	(76.30)	172.00	(130.00)
25	3.37	(2.25)	2.21	(1.47)	158.00	(106.00)	233.00	(156.00)	2.30	(1.76)	1.51	(1.16)	108.00	(83.00)	159.00	(122.00)
26	2.99	(1.98)	1.96	(1.30)	140.00	(93.10)	179.00	(119.00)	2.24	(1.74)	1.47	(1.14)	106.00	(82.10)	135.00	(104.00)
27	3.62	(2.19)	2.37	(1.43)	170.00	(103.00)	191.00	(116.00)	2.86	(2.06)	1.88	(1.35)	135.00	(97.10)	151.00	(109.00)
28	4.05	(2.22)	2.66	(1.45)	191.00	(104.00)	190.00	(104.00)	3.03	(2.03)	1.99	(1.33)	143.00	(95.70)	142.00	(95.30)
29	4.87	(2.53)	3.19	(1.66)	229.00	(119.00)	203.00	(105.00)	3.55	(2.26)	2.33	(1.48)	167.00	(107.00)	149.00	(95.00)
30																
31																
Avg	5.4		3.5		121.0		387.0		4.5		2.9		103.0		370.0	
n	26		26		15		15		26		26		15		15	
SD	9.7		6.4		46.1		217.0		7.1		4.7		26.2		252.0	
Min	1.5		1.0		68.0		179.0		1.4		0.9		64.7		135.0	
Max	50.9		33.4		229.0		756.0		35.2		23.1		167.0		804.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for November, 2008.

Day	House 10				House 12			
	kg d^{-1}	g d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	kg d^{-1}	g d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1								
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19								
20	20.50 (10.10)	13.40 (6.60)	979.00 (480.00)	321.00 (157.00)	20.50 (10.60)	13.40 (6.93)	975.00 (503.00)	316.00 (162.00)
21	20.40 (12.30)	13.30 (8.10)	972.00 (590.00)	303.00 (184.00)	20.90 (13.90)	13.70 (9.10)	996.00 (661.00)	307.00 (205.00)
22	21.10 (11.50)	13.80 (7.56)	1010.00 (551.00)	299.00 (164.00)	20.60 (11.90)	13.50 (7.84)	980.00 (569.00)	288.00 (168.00)
23	23.30 (11.60)	15.20 (7.58)	1110.00 (553.00)	314.00 (157.00)	22.20 (11.50)	14.60 (7.51)	1060.00 (545.00)	296.00 (153.00)
24	23.50 (11.10)	15.40 (7.26)	1120.00 (530.00)	304.00 (143.00)	21.60 (9.77)	14.20 (6.41)	1030.00 (465.00)	276.00 (125.00)
25	24.10 (8.51)	15.80 (5.58)	1150.00 (407.00)	299.00 (106.00)				
26	24.20 (5.66)	15.80 (3.71)	1160.00 (271.00)	287.00 (67.90)	24.20 (5.85)	15.90 (3.84)	1160.00 (279.00)	284.00 (69.30)
27	23.70 (1.94)	15.50 (1.27)	1130.00 (93.00)	271.00 (22.20)	25.20 (2.08)	16.50 (1.37)	1200.00 (99.30)	285.00 (23.90)
28	22.10 (2.16)	14.50 (1.42)	1060.00 (103.00)	244.00 (24.80)	22.00 (2.77)	14.40 (1.82)	1050.00 (132.00)	240.00 (31.50)
29	22.30 (4.78)	14.60 (3.14)	1070.00 (229.00)	238.00 (50.30)	21.10 (6.63)	13.80 (4.35)	1000.00 (316.00)	222.00 (69.30)
30	24.00 (5.58)	15.70 (3.66)	1150.00 (268.00)	248.00 (57.60)	23.30 (6.16)	15.30 (4.04)	1110.00 (294.00)	237.00 (62.80)
Avg	22.6	14.8	1080.0	284.0	22.2	14.5	1060.0	275.0
n	11	11	11	11	10	10	10	10
SD	1.4	0.9	67.4	28.2	1.5	1.0	73.4	30.0
Min	20.4	13.3	972.0	238.0	20.5	13.4	975.0	222.0
Max	24.2	15.8	1160.0	321.0	25.2	16.5	1200.0	316.0

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for December, 2008.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	24.40	(4.06)	16.00	(2.66)	1170.00	(195.00)	244.00	(40.60)	23.90	(4.00)	15.70	(2.62)	1140.00	(191.00)	236.00	(39.40)
2	26.50	(3.41)	17.40	(2.24)	1270.00	(164.00)	258.00	(32.80)	26.20	(3.79)	17.10	(2.49)	1250.00	(181.00)	251.00	(36.00)
3	27.20	(6.78)	17.80	(4.44)	1310.00	(326.00)	257.00	(63.20)	25.60	(3.64)	16.80	(2.39)	1220.00	(174.00)	239.00	(34.30)
4	16.70	(19.40)	10.90	(12.70)					15.70	(14.90)	10.30	(9.75)				
5	4.62	(0.58)	3.03	(0.38)					4.60	(0.57)	3.02	(0.38)				
6	3.58	(0.34)	2.35	(0.22)					3.42	(0.34)	2.24	(0.23)				
7	3.13	(0.45)	2.05	(0.29)					3.57	(0.66)	2.34	(0.43)				
8	2.92	(3.02)	1.92	(1.98)					2.84	(3.02)	1.86	(1.98)				
9	2.33	(4.83)	1.53	(3.16)					3.03	(5.97)	1.99	(3.91)				
10	2.50	(5.23)	1.64	(3.43)					2.69	(5.59)	1.76	(3.67)				
11	3.27	(6.57)	2.14	(4.31)					3.54	(7.12)	2.32	(4.67)				
12	3.30	(6.64)	2.16	(4.35)					3.55	(7.12)	2.33	(4.67)				
13	2.93	(5.71)	1.92	(3.75)	138.00	(270.00)	1010.00	(1950.00)	3.24	(5.70)	2.12	(3.74)	152.00	(268.00)	1090.00	(1900.00)
14	2.74	(4.39)	1.79	(2.88)	129.00	(208.00)	1090.00	(1750.00)	2.96	(4.38)	1.94	(2.87)	140.00	(206.00)	1160.00	(1720.00)
15	3.03	(4.40)	1.99	(2.89)	143.00	(208.00)	1290.00	(1870.00)	3.26	(4.46)	2.14	(2.93)	154.00	(210.00)	1380.00	(1890.00)
16	3.03	(3.96)	1.98	(2.60)	143.00	(187.00)	1240.00	(1630.00)	3.24	(4.54)	2.12	(2.98)	153.00	(215.00)	1340.00	(1870.00)
17	2.56	(3.14)	1.68	(2.06)	121.00	(149.00)	935.00	(1150.00)	2.63	(4.08)	1.72	(2.68)	124.00	(193.00)	978.00	(1520.00)
18	2.50	(3.13)	1.64	(2.06)	119.00	(149.00)	766.00	(954.00)	2.55	(4.32)	1.67	(2.83)	121.00	(204.00)	797.00	(1340.00)
19	2.67	(3.33)	1.75	(2.18)	127.00	(158.00)	669.00	(838.00)	2.64	(4.27)	1.73	(2.80)	125.00	(202.00)	678.00	(1110.00)
20	2.30	(2.90)	1.51	(1.90)	109.00	(137.00)	466.00	(589.00)	2.20	(3.63)	1.44	(2.38)	104.00	(172.00)	458.00	(756.00)
21	3.80	(4.79)	2.49	(3.14)	180.00	(227.00)	625.00	(785.00)	3.79	(4.96)	2.48	(3.25)	180.00	(235.00)	635.00	(830.00)
22	4.24	(5.33)	2.78	(3.50)	201.00	(253.00)	565.00	(708.00)	3.85	(4.92)	2.53	(3.23)	183.00	(234.00)	536.00	(685.00)
23	4.00	(5.41)	2.63	(3.55)	190.00	(257.00)	450.00	(609.00)	3.36	(4.47)	2.20	(2.93)	160.00	(212.00)	387.00	(516.00)
24	3.87	(4.89)	2.54	(3.21)	184.00	(232.00)	365.00	(462.00)	3.21	(4.01)	2.11	(2.63)	153.00	(190.00)	310.00	(388.00)
25	3.34	(4.15)	2.19	(2.72)	159.00	(197.00)	269.00	(334.00)	2.84	(3.52)	1.86	(2.31)	135.00	(167.00)	234.00	(290.00)
26	3.48	(4.03)	2.28	(2.64)	165.00	(191.00)	241.00	(279.00)	2.73	(3.13)	1.79	(2.05)	130.00	(149.00)	193.00	(222.00)
27	3.93	(3.90)	2.57	(2.56)	187.00	(185.00)	237.00	(235.00)	2.86	(2.84)	1.87	(1.87)	136.00	(135.00)	176.00	(174.00)
28	4.28	(4.16)	2.81	(2.73)	203.00	(198.00)	227.00	(219.00)	2.98	(2.82)	1.96	(1.85)	142.00	(134.00)	161.00	(152.00)
29	4.86	(4.39)	3.19	(2.88)	231.00	(208.00)	229.00	(207.00)	3.15	(3.01)	2.07	(1.98)	150.00	(143.00)	151.00	(144.00)
30	5.70	(5.31)	3.74	(3.48)	271.00	(253.00)	240.00	(222.00)	3.43	(3.49)	2.25	(2.29)	163.00	(166.00)	146.00	(148.00)
31	7.45	(7.20)	4.88	(4.72)	354.00	(342.00)	282.00	(272.00)	4.38	(4.25)	2.87	(2.79)	209.00	(203.00)	168.00	(163.00)
Avg	6.2		4.0		323.0		543.0		5.7		3.8		292.0		532.0	
n	31		31		22		22		31		31		22		22	
SD	7.0		4.6		373.0		351.0		6.8		4.4		363.0		404.0	
Min	2.3		1.5		109.0		227.0		2.2		1.4		104.0		146.0	
Max	27.2		17.8		1310.0		1290.0		26.2		17.1		1250.0		1380.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for January, 2009.

Day	House 10				House 12			
	kg d^{-1}	g d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}	kg d^{-1}	g d^{-1}m^{-2}	mg d^{-1}hd^{-1}	g d^{-1}AU^{-1}
1	10.10 (8.65)	6.64 (5.67)	481.00 (412.00)	347.00 (296.00)	6.28 (5.43)	4.12 (3.56)	300.00 (259.00)	218.00 (188.00)
2	13.80 (10.50)	9.02 (6.91)	654.00 (502.00)	430.00 (329.00)	9.36 (7.20)	6.14 (4.72)	446.00 (344.00)	296.00 (227.00)
3	15.20 (10.70)	9.94 (7.04)	722.00 (511.00)	435.00 (309.00)	11.00 (7.65)	7.19 (5.02)	523.00 (365.00)	319.00 (223.00)
4	15.40 (11.80)	10.10 (7.74)	734.00 (562.00)	407.00 (313.00)	12.20 (9.28)	7.99 (6.09)	582.00 (443.00)	326.00 (248.00)
5	15.20 (13.70)	9.95 (8.99)	723.00 (653.00)	371.00 (335.00)	13.70 (12.50)	8.99 (8.18)	655.00 (596.00)	339.00 (307.00)
6	15.90 (14.30)	10.40 (9.39)	759.00 (683.00)	361.00 (325.00)	15.30 (13.80)	10.10 (9.04)	733.00 (659.00)	352.00 (317.00)
7	16.90 (18.60)	11.10 (12.20)	806.00 (889.00)	357.00 (394.00)	16.20 (18.00)	10.60 (11.80)	774.00 (862.00)	346.00 (386.00)
8	18.80 (16.30)	12.30 (10.70)	895.00 (776.00)	371.00 (322.00)	16.40 (14.60)	10.80 (9.60)	786.00 (700.00)	329.00 (293.00)
9	19.50 (11.90)	12.80 (7.78)	930.00 (566.00)	362.00 (222.00)	15.60 (9.99)	10.20 (6.55)	745.00 (478.00)	292.00 (189.00)
10	18.30 (12.20)	12.00 (7.99)	873.00 (581.00)	319.00 (213.00)	14.90 (9.97)	9.78 (6.53)	714.00 (477.00)	263.00 (176.00)
11	19.50 (11.80)	12.80 (7.74)	931.00 (564.00)	322.00 (196.00)	16.20 (9.68)	10.60 (6.35)	777.00 (463.00)	271.00 (162.00)
12								
13								
14								
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18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
31	5.10 (10.00)	3.34 (6.59)			5.36 (10.60)	3.51 (6.93)		
Avg	15.3	10.0	773.0	371.0	12.7	8.3	640.0	305.0
n	12	12	11	11	12	12	11	11
SD	4.0	2.6	128.0	36.8	3.8	2.5	152.0	39.1
Min	5.1	3.3	481.0	319.0	5.4	3.5	300.0	218.0
Max	19.5	12.8	931.0	435.0	16.4	10.8	786.0	352.0

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for February, 2009.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	4.28	(8.59)	2.80	(5.63)					4.43	(8.92)	2.91	(5.85)				
2	3.37	(7.52)	2.21	(4.93)					3.55	(6.88)	2.33	(4.51)				
3	3.04	(6.14)	2.00	(4.03)					3.23	(4.10)	2.12	(2.69)				
4	13.50	(24.60)	8.87	(16.10)					9.01	(14.70)	5.91	(9.66)				
5	4.80	(9.34)	3.15	(6.13)					2.73	(4.50)	1.79	(2.95)				
6	2.43	(4.61)	1.59	(3.03)					2.67	(5.35)	1.75	(3.51)				
7	2.62	(5.35)	1.72	(3.51)					2.85	(5.80)	1.87	(3.80)				
8	2.72	(5.45)	1.78	(3.58)					2.70	(5.43)	1.77	(3.56)				
9									2.51	(4.96)	1.65	(3.25)				
10	2.66	(5.39)	1.75	(3.54)	126.00	(254.00)	909.00	(1850.00)	2.79	(4.62)	1.83	(3.03)	130.00	(215.00)	936.00	(1560.00)
11	2.76	(5.57)	1.81	(3.65)	130.00	(263.00)	1080.00	(2180.00)	2.95	(4.22)	1.93	(2.77)	138.00	(197.00)	1150.00	(1650.00)
12									3.07	(4.05)	2.02	(2.65)	144.00	(189.00)	1290.00	(1690.00)
13	2.73	(4.84)	1.79	(3.17)	129.00	(229.00)	1130.00	(2010.00)	2.78	(4.19)	1.82	(2.75)	130.00	(196.00)	1140.00	(1710.00)
14	2.59	(3.35)	1.70	(2.20)	123.00	(159.00)	958.00	(1240.00)	2.50	(3.24)	1.64	(2.12)	117.00	(152.00)	916.00	(1200.00)
15	2.45	(3.05)	1.61	(2.00)	116.00	(145.00)	762.00	(946.00)	2.32	(2.88)	1.52	(1.89)	109.00	(135.00)	717.00	(891.00)
16	2.67	(3.28)	1.75	(2.15)	127.00	(156.00)	681.00	(835.00)	2.55	(3.14)	1.67	(2.06)	119.00	(147.00)	646.00	(796.00)
17	3.53	(5.06)	2.32	(3.32)	168.00	(241.00)	723.00	(1010.00)	3.37	(4.81)	2.21	(3.15)	158.00	(226.00)	686.00	(955.00)
18	4.20	(5.53)	2.75	(3.63)	200.00	(263.00)	706.00	(940.00)	3.98	(5.27)	2.61	(3.46)	187.00	(247.00)	667.00	(896.00)
19	4.58	(5.16)	3.01	(3.38)	218.00	(245.00)	632.00	(712.00)	3.85	(4.46)	2.53	(2.92)	181.00	(210.00)	529.00	(614.00)
20	4.49	(5.81)	2.94	(3.81)	214.00	(277.00)	513.00	(662.00)	3.65	(4.79)	2.40	(3.14)	172.00	(225.00)	416.00	(547.00)
21	4.22	(5.12)	2.77	(3.36)	201.00	(244.00)	407.00	(497.00)	3.51	(4.25)	2.30	(2.79)	165.00	(200.00)	336.00	(408.00)
22	4.21	(5.05)	2.76	(3.31)	200.00	(241.00)	344.00	(411.00)	3.43	(4.12)	2.25	(2.70)	161.00	(194.00)	279.00	(335.00)
23	5.19	(5.47)	3.40	(3.59)	248.00	(261.00)	366.00	(384.00)	4.15	(4.41)	2.72	(2.89)	196.00	(208.00)	291.00	(309.00)
24	5.73	(5.27)	3.76	(3.45)	274.00	(251.00)	352.00	(325.00)	4.49	(4.10)	2.95	(2.69)	212.00	(194.00)	274.00	(252.00)
25	6.29	(5.36)	4.12	(3.52)	300.00	(256.00)	340.00	(288.00)	4.72	(3.90)	3.09	(2.56)	223.00	(184.00)	254.00	(209.00)
26	6.69	(5.18)	4.38	(3.40)	319.00	(248.00)	320.00	(250.00)	4.93	(3.89)	3.23	(2.55)	233.00	(184.00)	235.00	(187.00)
27	6.86	(5.24)	4.50	(3.43)	328.00	(250.00)	293.00	(222.00)	4.91	(3.73)	3.22	(2.45)	232.00	(177.00)	209.00	(158.00)
28	9.08	(6.25)	5.96	(4.10)	434.00	(299.00)	348.00	(238.00)	6.05	(4.27)	3.97	(2.80)	287.00	(203.00)	231.00	(163.00)
Avg	4.5		3.0		214.0		603.0		3.7		2.4		173.0		589.0	
n	26		26		18		18		28		28		19		19	
SD	2.4		1.6		86.6		271.0		1.4		0.9		46.6		345.0	
Min	2.4		1.6		116.0		293.0		2.3		1.5		109.0		209.0	
Max	13.5		8.9		434.0		1130.0		9.0		5.9		287.0		1290.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for March, 2009.

Day	House 10								House 12							
	kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1	11.30	(6.72)	7.41	(4.41)	540.00	(322.00)	393.00	(234.00)	7.42	(4.89)	4.87	(3.21)	352.00	(232.00)	258.00	(169.00)
2	12.10	(6.33)	7.92	(4.15)	579.00	(303.00)	385.00	(203.00)	9.06	(4.54)	5.94	(2.98)	430.00	(216.00)	287.00	(145.00)
3	10.40	(7.77)	6.79	(5.09)	496.00	(372.00)	301.00	(226.00)	8.69	(6.06)	5.70	(3.97)	413.00	(288.00)	252.00	(175.00)
4	11.40	(8.89)	7.47	(5.83)	546.00	(426.00)	305.00	(239.00)	9.10	(7.15)	5.97	(4.69)	433.00	(340.00)	242.00	(191.00)
5	11.80	(8.56)	7.73	(5.61)	566.00	(410.00)	292.00	(212.00)	9.62	(7.18)	6.31	(4.71)	458.00	(342.00)	237.00	(177.00)
6	11.70	(8.25)	7.66	(5.41)	561.00	(396.00)	269.00	(190.00)	9.47	(7.11)	6.21	(4.66)	451.00	(338.00)	217.00	(163.00)
7	12.50	(9.06)	8.22	(5.94)	602.00	(435.00)	268.00	(194.00)	9.70	(6.77)	6.36	(4.44)	462.00	(323.00)	207.00	(145.00)
8	13.90	(8.82)	9.12	(5.79)	668.00	(424.00)	278.00	(177.00)	10.20	(6.42)	6.66	(4.21)	484.00	(306.00)	203.00	(129.00)
9	14.90	(10.80)	9.78	(7.05)	718.00	(517.00)	280.00	(203.00)	10.50	(7.71)	6.87	(5.06)	500.00	(368.00)	196.00	(145.00)
10	16.60	(11.90)	10.90	(7.82)	801.00	(574.00)	295.00	(211.00)	12.90	(8.95)	8.48	(5.87)	618.00	(428.00)	228.00	(158.00)
11	18.70	(12.30)	12.20	(8.08)	898.00	(593.00)	312.00	(207.00)	16.10	(10.30)	10.50	(6.73)	768.00	(491.00)	267.00	(171.00)
12	20.40	(11.80)	13.40	(7.72)	983.00	(568.00)	323.00	(187.00)	19.00	(10.40)	12.50	(6.79)	912.00	(496.00)	300.00	(164.00)
13	20.70	(10.90)	13.60	(7.15)	999.00	(526.00)	311.00	(165.00)	18.90	(8.95)	12.40	(5.87)	905.00	(429.00)	283.00	(135.00)
14	22.30	(10.90)	14.70	(7.16)	1080.00	(527.00)	320.00	(156.00)	20.70	(10.30)	13.60	(6.73)	992.00	(492.00)	295.00	(146.00)
15	23.50	(8.26)	15.40	(5.41)	1130.00	(399.00)	321.00	(114.00)	22.80	(8.91)	14.90	(5.84)	1090.00	(427.00)	310.00	(122.00)
16	25.10	(7.42)	16.40	(4.86)	1210.00	(359.00)	328.00	(98.10)	23.90	(7.20)	15.70	(4.72)	1150.00	(346.00)	311.00	(95.00)
17	24.00	(6.84)	15.70	(4.48)	1160.00	(331.00)	300.00	(87.20)	22.80	(5.47)	14.90	(3.59)	1100.00	(263.00)	285.00	(69.80)
18	23.00	(6.52)	15.10	(4.27)	1110.00	(316.00)	277.00	(78.60)	21.60	(5.79)	14.20	(3.80)	1040.00	(279.00)	259.00	(69.40)
19	23.80	(9.11)	15.60	(5.98)	1160.00	(442.00)	277.00	(106.00)	21.40	(7.07)	14.00	(4.63)	1030.00	(341.00)	247.00	(82.10)
20	22.90	(7.22)	15.00	(4.74)	1110.00	(351.00)	256.00	(81.00)	20.90	(7.40)	13.70	(4.85)	1010.00	(357.00)	232.00	(82.70)
21	22.50	(5.80)	14.70	(3.80)	1090.00	(282.00)	243.00	(62.80)	20.00	(5.43)	13.10	(3.56)	965.00	(262.00)	215.00	(58.40)
22	21.30	(5.92)	14.00	(3.88)	1040.00	(288.00)	223.00	(62.90)	19.20	(6.92)	12.60	(4.54)	927.00	(335.00)	200.00	(72.90)
23	19.50	(6.34)	12.80	(4.16)	950.00	(310.00)	198.00	(64.50)	17.30	(6.37)	11.30	(4.17)	837.00	(309.00)	175.00	(64.60)
24	21.30	(7.78)	14.00	(5.10)	1040.00	(380.00)	211.00	(77.10)	18.00	(6.76)	11.80	(4.43)	872.00	(328.00)	177.00	(66.60)
25	23.90	(7.72)	15.70	(5.06)	1170.00	(379.00)	231.00	(74.80)	20.10	(6.72)	13.20	(4.41)	977.00	(327.00)	192.00	(64.70)
26	21.60	(6.05)	14.10	(3.97)	1060.00	(297.00)	203.00	(57.80)	19.70	(5.25)	12.90	(3.44)	960.00	(256.00)	184.00	(49.60)
27	16.20	(16.00)	10.60	(10.50)					16.50	(4.23)	10.80	(2.77)	802.00	(206.00)	150.00	(39.10)
28	12.20	(21.40)	7.98	(14.00)					12.20	(8.14)	8.02	(5.34)				
29	11.80	(3.02)	7.75	(1.98)					10.70	(1.89)	7.05	(1.24)				
30	3.93	(8.83)	2.58	(5.79)					4.94	(10.10)	3.24	(6.64)				
31	3.43	(3.27)	2.25	(2.14)					2.97	(2.96)	1.95	(1.94)				
Avg	17.0		11.2		895.0		285.0		15.0		9.9		775.0		237.0	
n	31		31		26		26		31		31		27		27	
SD	6.0		3.9		243.0		48.0		5.9		3.8		258.0		44.4	
Min	3.4		2.3		496.0		198.0		3.0		2.0		352.0		150.0	
Max	25.1		16.4		1210.0		393.0		23.9		15.7		1150.0		311.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for April, 2009.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	1.19	(1.32)	0.78	(0.86)					1.28	(1.43)	0.84	(0.94)				
2	2.69	(5.01)	1.76	(3.29)					2.58	(2.91)	1.69	(1.91)				
3	1.38	(0.19)	0.90	(0.12)					1.53	(0.22)	1.00	(0.14)				
4	0.95	(0.12)	0.62	(0.08)					1.09	(0.16)	0.71	(0.10)				
5	0.84	(0.19)	0.55	(0.12)					0.97	(0.16)	0.64	(0.11)				
6	0.92	(0.21)	0.60	(0.14)					1.10	(0.46)	0.72	(0.30)				
7	0.47	(0.56)	0.31	(0.37)					0.38	(0.40)	0.25	(0.26)				
8	0.06	(0.21)	0.04	(0.14)					0.05	(0.13)	0.04	(0.09)				
9	0.06	(0.14)	0.04	(0.09)					0.08	(0.14)	0.05	(0.09)				
10																
11	0.06	(0.09)	0.04	(0.06)	2.69	(4.01)	19.50	(29.10)	0.07	(0.14)	0.05	(0.09)	3.34	(6.74)	24.10	(48.90)
12	0.09	(0.15)	0.06	(0.10)	4.14	(6.90)	34.90	(58.30)	0.11	(0.21)	0.07	(0.14)	5.09	(9.74)	42.60	(81.80)
13	0.09	(0.14)	0.06	(0.09)	4.39	(6.48)	39.40	(58.30)	0.10	(0.20)	0.07	(0.13)	4.77	(9.61)	42.80	(86.30)
14	0.07	(0.11)	0.05	(0.07)	3.24	(5.21)	28.30	(45.30)	0.08	(0.16)	0.05	(0.10)	3.71	(7.33)	32.40	(64.00)
15	0.07	(0.14)	0.05	(0.09)	3.44	(6.82)	26.70	(52.70)	0.09	(0.18)	0.06	(0.12)	4.37	(8.38)	33.90	(64.80)
16	0.12	(0.20)	0.08	(0.13)	5.54	(9.46)	36.10	(61.70)	0.14	(0.21)	0.09	(0.14)	6.57	(9.76)	43.10	(64.30)
17	0.19	(0.26)	0.13	(0.17)	9.04	(12.40)	48.20	(66.20)	0.21	(0.26)	0.13	(0.17)	9.72	(12.10)	51.90	(64.80)
18	0.30	(0.29)	0.20	(0.19)	14.10	(13.70)	61.10	(59.90)	0.31	(0.29)	0.20	(0.19)	14.60	(14.00)	63.30	(61.00)
19	0.38	(0.31)	0.25	(0.20)	18.10	(14.70)	64.00	(53.00)	0.35	(0.30)	0.23	(0.20)	16.80	(14.40)	59.50	(52.50)
20																
21																
22																
23																
24																
25																
26																
27																
28																
29	0.84	(0.60)	0.55	(0.39)	40.20	(28.60)	32.30	(22.90)	0.74	(0.57)	0.49	(0.37)	35.50	(27.00)	28.50	(21.60)
30	1.37	(0.84)	0.90	(0.55)	65.30	(40.20)	47.30	(29.10)	0.91	(0.59)	0.60	(0.39)	43.50	(28.40)	31.60	(20.70)
Avg	0.6		0.4		15.5		39.8		0.6		0.4		13.4		41.2	
n	20		20		11		11		20		20		11		11	
SD	0.7		0.4		19.0		13.4		0.6		0.4		13.1		12.1	
Min	0.1		0.0		2.7		19.5		0.1		0.0		3.3		24.1	
Max	2.7		1.8		65.3		64.0		2.6		1.7		43.5		63.3	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for May, 2009.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	2.64	(1.69)	1.73	(1.11)	126.00	(80.80)	83.00	(52.20)	1.49	(1.01)	0.97	(0.66)	71.00	(48.20)	46.90	(31.30)
2	6.07	(4.45)	3.98	(2.92)	290.00	(213.00)	176.00	(127.00)	3.41	(2.77)	2.24	(1.82)	163.00	(133.00)	98.50	(79.20)
3	9.23	(5.10)	6.05	(3.35)	442.00	(244.00)	246.00	(137.00)	5.85	(3.35)	3.84	(2.20)	280.00	(160.00)	156.00	(89.30)
4	11.90	(4.81)	7.79	(3.16)	569.00	(231.00)	294.00	(120.00)	8.00	(3.52)	5.24	(2.31)	383.00	(168.00)	198.00	(87.60)
5	13.20	(5.17)	8.64	(3.39)	631.00	(248.00)	303.00	(120.00)	9.54	(4.40)	6.26	(2.88)	457.00	(211.00)	219.00	(101.00)
6	13.40	(5.67)	8.79	(3.72)	643.00	(272.00)	287.00	(123.00)	9.66	(4.75)	6.34	(3.11)	463.00	(228.00)	207.00	(103.00)
7	13.50	(6.05)	8.84	(3.97)	647.00	(290.00)	270.00	(122.00)	9.90	(4.62)	6.49	(3.03)	475.00	(222.00)	198.00	(93.20)
8	12.30	(5.01)	8.04	(3.29)	589.00	(241.00)	230.00	(95.30)	9.71	(4.28)	6.37	(2.80)	466.00	(205.00)	182.00	(81.00)
9	12.80	(5.33)	8.42	(3.49)	617.00	(256.00)	227.00	(94.80)	9.84	(4.17)	6.45	(2.73)	473.00	(200.00)	174.00	(74.10)
10	13.10	(5.18)	8.61	(3.40)	631.00	(249.00)	219.00	(86.90)	10.90	(3.99)	7.13	(2.61)	522.00	(192.00)	181.00	(66.60)
11	11.70	(4.69)	7.65	(3.08)	562.00	(226.00)	185.00	(74.20)	11.40	(4.18)	7.50	(2.74)	550.00	(201.00)	181.00	(66.20)
12	12.90	(4.27)	8.49	(2.80)	624.00	(206.00)	194.00	(64.10)	11.50	(3.59)	7.51	(2.35)	552.00	(173.00)	172.00	(53.80)
13	15.70	(4.75)	10.30	(3.12)	758.00	(229.00)	225.00	(68.00)	13.30	(4.21)	8.73	(2.76)	642.00	(203.00)	191.00	(60.40)
14	16.40	(4.93)	10.70	(3.23)	789.00	(238.00)	223.00	(67.00)	14.80	(4.85)	9.73	(3.18)	716.00	(234.00)	203.00	(66.10)
15	19.70	(4.99)	12.90	(3.27)	950.00	(241.00)	257.00	(64.80)	17.20	(4.08)	11.30	(2.68)	831.00	(197.00)	225.00	(52.90)
16	22.80	(5.33)	15.00	(3.49)	1100.00	(258.00)	285.00	(65.00)	20.60	(4.71)	13.50	(3.09)	995.00	(228.00)	257.00	(57.60)
17	24.60	(3.37)	16.10	(2.21)	1190.00	(163.00)	295.00	(39.40)	23.00	(3.53)	15.10	(2.32)	1120.00	(171.00)	277.00	(41.10)
18	22.20	(3.77)	14.50	(2.47)	1070.00	(182.00)	256.00	(42.60)	21.60	(3.30)	14.10	(2.16)	1050.00	(160.00)	250.00	(36.90)
19	19.60	(3.85)	12.80	(2.52)	948.00	(186.00)	219.00	(42.90)	19.10	(4.35)	12.50	(2.85)	929.00	(211.00)	214.00	(48.50)
20	18.20	(4.12)	11.90	(2.70)	883.00	(200.00)	196.00	(44.20)	17.90	(3.77)	11.70	(2.47)	869.00	(183.00)	193.00	(40.60)
21	20.50	(4.49)	13.50	(2.94)	997.00	(218.00)	214.00	(46.20)	20.40	(3.94)	13.40	(2.58)	996.00	(193.00)	214.00	(40.90)
22	23.00	(5.59)	15.10	(3.67)	1120.00	(272.00)	233.00	(55.90)	22.50	(5.26)	14.80	(3.45)	1110.00	(258.00)	230.00	(53.10)
23	21.80	(5.58)	14.30	(3.66)	1060.00	(272.00)	215.00	(54.60)	21.60	(4.67)	14.10	(3.06)	1060.00	(230.00)	214.00	(46.10)
24	22.90	(5.02)	15.00	(3.29)	1120.00	(245.00)	220.00	(47.90)	22.20	(3.95)	14.50	(2.59)	1100.00	(195.00)	215.00	(38.00)
25	24.80	(5.43)	16.30	(3.56)	1210.00	(265.00)	232.00	(50.20)	24.00	(4.89)	15.70	(3.21)	1190.00	(242.00)	227.00	(45.70)
26	21.40	(5.64)	14.00	(3.70)	1040.00	(275.00)	195.00	(51.80)	20.70	(4.90)	13.60	(3.21)	1030.00	(243.00)	192.00	(46.10)
27	29.00	(32.60)	19.00	(21.40)					23.90	(19.00)	15.70	(12.40)				
28	18.60	(21.70)	12.20	(14.20)					17.30	(14.10)	11.30	(9.24)				
29	7.17	(0.98)	4.70	(0.64)					8.45	(1.95)	5.54	(1.28)				
30	5.12	(0.88)	3.36	(0.58)					7.96	(1.53)	5.22	(1.00)				
31	3.90	(0.54)	2.56	(0.35)					5.52	(1.10)	3.62	(0.72)				
Avg	15.8		10.4		793.0		230.0		14.3		9.4		710.0		197.0	
n	31		31		26		26		31		31		26		26	
SD	6.7		4.4		282.0		45.7		6.6		4.3		320.0		45.3	
Min	2.6		1.7		126.0		83.0		1.5		1.0		71.0		46.9	
Max	29.0		19.0		1210.0		303.0		24.0		15.7		1190.0		277.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for June, 2009.

Day	House 10				House 12			
	kg d^{-1}	g $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$	kg d^{-1}	g $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$
1	8.55 (8.69)	5.61 (5.70)			10.10 (18.80)	6.63 (12.40)		
2								
3								
4								
5	2.53 (4.90)	1.66 (3.21)	119.00 (231.00)	883.00 (1720.00)	3.01 (4.41)	1.97 (2.89)		
6	2.60 (4.54)	1.71 (2.98)	123.00 (214.00)	1040.00 (1820.00)	3.22 (4.32)	2.11 (2.84)	152.00 (204.00)	1120.00 (1520.00)
7	3.25 (4.42)	2.13 (2.90)	153.00 (209.00)	1380.00 (1880.00)	3.73 (4.96)	2.44 (3.25)	176.00 (235.00)	1500.00 (2010.00)
8	2.62 (3.21)	1.72 (2.10)	124.00 (152.00)	1070.00 (1320.00)	3.08 (3.87)	2.02 (2.54)	146.00 (183.00)	1310.00 (1640.00)
9	2.30 (2.72)	1.51 (1.79)	109.00 (129.00)	835.00 (988.00)	2.70 (3.13)	1.77 (2.05)	128.00 (148.00)	1100.00 (1280.00)
10	2.37 (2.57)	1.55 (1.68)	112.00 (122.00)	720.00 (783.00)	2.79 (2.87)	1.83 (1.88)	132.00 (136.00)	1010.00 (1050.00)
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								
29								
30								
Avg	3.5	2.3	124.0	989.0	4.1	2.7	147.0	1210.0
n	7	7	6	6	7	7	5	5
SD	2.1	1.4	14.4	212.0	2.5	1.6	17.2	174.0
Min	2.3	1.5	109.0	720.0	2.7	1.8	128.0	1010.0
Max	8.6	5.6	153.0	1380.0	10.1	6.6	176.0	1500.0

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for July, 2009.

Day	House 10				House 12			
	kg d^{-1}	g $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$	kg d^{-1}	g $d^{-1}m^{-2}$	mg $d^{-1}hd^{-1}$	g $d^{-1}AU^{-1}$
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17	26.10 (5.35)	17.10 (3.51)	1280.00 (263.00)	258.00 (51.80)	23.40 (4.51)	15.30 (2.96)	1150.00 (223.00)	239.00 (45.10)
18	27.70 (4.46)	18.20 (2.93)	1360.00 (220.00)	267.00 (41.90)	25.10 (3.97)	16.50 (2.60)	1240.00 (196.00)	250.00 (38.30)
19	28.50 (5.23)	18.70 (3.43)	1410.00 (258.00)	268.00 (48.00)	26.40 (4.05)	17.30 (2.65)	1310.00 (201.00)	256.00 (38.00)
20	21.60 (4.06)	14.20 (2.66)	1070.00 (201.00)	199.00 (38.40)	20.00 (3.24)	13.10 (2.13)	999.00 (162.00)	191.00 (32.00)
21	35.90 (22.70)	23.50 (14.90)						
22	29.40 (26.60)	19.30 (17.40)			26.00 (34.50)	17.10 (22.70)		
23	8.24 (1.09)	5.41 (0.72)			8.21 (1.22)	5.39 (0.80)		
24								
25								
26								
27								
28	4.10 (4.81)	2.69 (3.15)			3.26 (3.97)	2.14 (2.61)		
29	3.52 (4.06)	2.31 (2.66)			2.87 (3.72)	1.88 (2.44)		
30	3.52 (3.64)	2.31 (2.39)			3.13 (3.22)	2.05 (2.11)		
31	3.28 (4.00)	2.15 (2.62)	170.00 (207.00)	1280.00 (1540.00)	2.95 (3.29)	1.94 (2.15)	153.00 (171.00)	1110.00 (1230.00)
Avg	17.4	11.4	1060.0	455.0	14.1	9.3	971.0	410.0
n	11	11	5	5	10	10	5	5
SD	12.3	8.0	459.0	413.0	10.3	6.8	422.0	352.0
Min	3.3	2.2	170.0	199.0	2.9	1.9	153.0	191.0
Max	35.9	23.5	1410.0	1280.0	26.4	17.3	1310.0	1110.0

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for August, 2009.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	3.25	(3.66)	2.13	(2.40)	169.00	(190.00)	1450.00	(1610.00)	2.78	(3.24)	1.82	(2.12)	144.00	(168.00)	1210.00	(1400.00)
2	2.85	(2.77)	1.87	(1.81)	148.00	(144.00)	1330.00	(1290.00)	2.68	(2.82)	1.76	(1.85)	140.00	(147.00)	1250.00	(1320.00)
3	2.77	(2.64)	1.82	(1.73)	144.00	(137.00)	1230.00	(1180.00)	2.59	(2.44)	1.70	(1.60)	135.00	(127.00)	1180.00	(1110.00)
4																
5																
6																
7																
8	2.47	(2.09)	1.62	(1.37)	129.00	(109.00)	435.00	(373.00)	2.14	(1.91)	1.41	(1.25)	112.00	(100.00)	394.00	(356.00)
9	2.80	(1.98)	1.84	(1.30)	146.00	(104.00)	407.00	(296.00)	2.24	(1.79)	1.47	(1.17)	117.00	(93.70)	340.00	(280.00)
10	2.85	(1.95)	1.87	(1.28)	149.00	(102.00)	345.00	(244.00)	2.26	(1.58)	1.48	(1.04)	118.00	(82.90)	284.00	(206.00)
11	2.51	(1.43)	1.65	(0.94)	131.00	(74.50)	256.00	(148.00)	2.46	(1.38)	1.61	(0.90)	129.00	(72.30)	261.00	(149.00)
12	2.37	(1.35)	1.56	(0.89)	124.00	(70.70)	207.00	(119.00)	2.40	(1.32)	1.58	(0.87)	126.00	(69.30)	217.00	(121.00)
13	2.26	(1.31)	1.48	(0.86)	118.00	(68.50)	170.00	(99.00)	2.34	(1.26)	1.53	(0.83)	123.00	(66.30)	182.00	(99.00)
14	1.70	(1.01)	1.11	(0.66)	88.90	(52.70)	111.00	(67.00)	1.81	(1.06)	1.18	(0.70)	94.90	(55.90)	122.00	(72.90)
15	1.72	(1.00)	1.13	(0.66)	90.10	(52.40)	99.30	(58.10)	1.81	(1.07)	1.19	(0.70)	95.30	(56.30)	108.00	(64.50)
16																
17																
18	1.65	(0.92)	1.08	(0.61)	86.60	(48.50)	67.90	(37.90)	1.75	(0.94)	1.15	(0.61)	92.20	(49.20)	74.00	(39.40)
19	1.60	(0.93)	1.05	(0.61)	83.90	(48.90)	59.70	(34.60)	1.70	(0.91)	1.11	(0.60)	89.50	(47.90)	65.00	(34.70)
20	1.65	(1.01)	1.08	(0.67)	86.60	(53.30)	56.10	(34.40)	1.72	(0.97)	1.13	(0.64)	90.50	(51.00)	59.80	(33.60)
21	2.24	(1.10)	1.47	(0.72)	117.00	(58.00)	69.60	(34.20)	2.20	(1.07)	1.44	(0.70)	116.00	(56.40)	69.90	(33.60)
22	3.09	(1.31)	2.02	(0.86)	162.00	(68.70)	88.40	(36.90)	3.02	(1.34)	1.98	(0.88)	159.00	(70.80)	88.30	(38.60)
23	3.56	(1.84)	2.33	(1.21)	187.00	(96.80)	94.50	(48.60)	3.54	(1.67)	2.32	(1.10)	187.00	(88.20)	96.00	(44.90)
24	4.81	(2.44)	3.15	(1.60)	253.00	(128.00)	119.00	(60.10)	4.48	(2.19)	2.94	(1.44)	236.00	(115.00)	113.00	(54.90)
25	6.30	(2.92)	4.13	(1.92)	332.00	(154.00)	145.00	(67.50)	5.53	(2.61)	3.62	(1.71)	292.00	(137.00)	130.00	(61.20)
26	6.87	(3.45)	4.51	(2.26)	362.00	(182.00)	149.00	(74.90)	7.16	(3.43)	4.70	(2.25)	378.00	(181.00)	157.00	(75.00)
27	9.48	(3.40)	6.22	(2.23)	499.00	(179.00)	192.00	(68.50)	7.62	(3.00)	5.00	(1.97)	402.00	(159.00)	157.00	(61.50)
28	11.80	(4.08)	7.71	(2.68)	619.00	(215.00)	225.00	(77.90)	9.43	(3.29)	6.18	(2.16)	498.00	(174.00)	183.00	(63.50)
29	12.00	(3.89)	7.88	(2.55)	633.00	(205.00)	217.00	(69.30)	10.00	(3.42)	6.59	(2.24)	531.00	(181.00)	184.00	(61.80)
30	10.80	(3.39)	7.10	(2.22)	571.00	(179.00)	185.00	(57.70)	9.17	(3.22)	6.01	(2.11)	485.00	(170.00)	159.00	(55.60)
31	12.60	(4.02)	8.25	(2.64)	664.00	(212.00)	205.00	(65.00)	10.50	(3.77)	6.88	(2.47)	556.00	(200.00)	173.00	(61.80)
Avg	4.6		3.0		244.0		317.0		4.1		2.7		218.0		290.0	
n	25		25		25		25		25		25		25		25	
SD	3.6		2.4		191.0		391.0		2.9		1.9		154.0		351.0	
Min	1.6		1.1		83.9		56.1		1.7		1.1		89.5		59.8	
Max	12.6		8.3		664.0		1450.0		10.5		6.9		556.0		1250.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for September, 2009.

Day	House 10								House 12							
	kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}		kg d^{-1}		g d^{-1}m^{-2}		mg d^{-1}hd^{-1}		g d^{-1}AU^{-1}	
1	15.70	(4.40)	10.30	(2.89)	828.00	(233.00)	243.00	(67.60)	13.10	(3.97)	8.58	(2.61)	693.00	(210.00)	205.00	(61.50)
2	17.30	(3.75)	11.40	(2.46)	915.00	(199.00)	256.00	(54.00)	15.10	(3.54)	9.93	(2.32)	802.00	(188.00)	226.00	(52.00)
3	16.60	(3.47)	10.90	(2.28)	880.00	(184.00)	236.00	(48.60)	14.60	(3.49)	9.54	(2.29)	772.00	(185.00)	208.00	(49.60)
4	13.30	(3.56)	8.72	(2.33)	704.00	(188.00)	181.00	(48.20)	12.80	(3.77)	8.37	(2.48)	677.00	(200.00)	175.00	(51.60)
5	17.70	(5.54)	11.60	(3.63)	937.00	(293.00)	230.00	(71.00)	16.30	(4.92)	10.70	(3.23)	865.00	(261.00)	215.00	(64.10)
6	17.60	(4.13)	11.50	(2.71)	931.00	(219.00)	221.00	(51.80)	15.50	(3.89)	10.20	(2.55)	823.00	(207.00)	197.00	(49.40)
7	18.10	(5.50)	11.90	(3.60)	962.00	(292.00)	220.00	(65.90)	17.30	(4.75)	11.40	(3.11)	921.00	(252.00)	212.00	(57.40)
8	17.90	(3.93)	11.70	(2.58)	952.00	(209.00)	210.00	(45.20)	16.30	(3.26)	10.70	(2.14)	868.00	(174.00)	193.00	(37.70)
9																
10	23.60	(5.64)	15.40	(3.70)	1250.00	(300.00)	259.00	(60.50)								
11	25.70	(5.75)	16.80	(3.77)	1370.00	(306.00)	275.00	(59.90)	23.50	(5.10)	15.40	(3.35)	1250.00	(273.00)	253.00	(53.60)
12	25.60	(3.82)	16.80	(2.51)	1370.00	(204.00)	267.00	(39.00)	23.70	(3.34)	15.50	(2.19)	1270.00	(179.00)	249.00	(34.40)
13	19.20	(5.82)	12.60	(3.82)	1030.00	(312.00)	196.00	(59.80)	18.90	(4.80)	12.40	(3.15)	1010.00	(257.00)	194.00	(49.70)
14	23.80	(9.98)	15.60	(6.54)					25.80	(13.50)	16.90	(8.88)				
15	23.10	(17.40)	15.20	(11.40)					24.00	(19.70)	15.80	(12.90)				
16	6.19	(6.41)	4.06	(4.21)					8.87	(11.00)	5.82	(7.23)				
17	3.92	(1.93)	2.57	(1.27)					4.19	(1.72)	2.75	(1.13)				
18	2.90	(1.42)	1.90	(0.93)					2.69	(0.46)	1.76	(0.30)				
19	2.23	(0.91)	1.46	(0.60)					2.36	(0.26)	1.55	(0.17)				
20	2.68	(0.35)	1.76	(0.23)					1.84	(0.23)	1.21	(0.15)				
21	1.84	(0.55)	1.21	(0.36)					1.63	(0.22)	1.07	(0.15)				
22	0.50	(0.48)	0.33	(0.31)					0.80	(0.95)	0.52	(0.62)				
23	0.11	(0.17)	0.07	(0.11)					0.10	(0.14)	0.07	(0.09)				
24	0.07	(0.11)	0.05	(0.07)					0.07	(0.10)	0.04	(0.07)				
25	0.07	(0.11)	0.05	(0.07)					0.07	(0.11)	0.05	(0.07)				
26	0.08	(0.08)	0.05	(0.05)					0.09	(0.09)	0.06	(0.06)				
27	0.09	(0.09)	0.06	(0.06)	4.51	(4.87)	33.40	(36.00)	0.10	(0.10)	0.07	(0.07)	5.22	(5.17)	38.40	(38.30)
28	0.07	(0.08)	0.05	(0.05)	3.60	(3.87)	30.60	(33.00)	0.09	(0.11)	0.06	(0.07)	4.65	(5.69)	39.40	(48.20)
29	0.06	(0.07)	0.04	(0.05)	2.92	(3.76)	26.30	(33.80)	0.08	(0.14)	0.05	(0.09)	4.22	(7.25)	37.90	(65.10)
30	0.08	(0.10)	0.05	(0.06)	3.96	(5.07)	34.20	(43.70)	0.10	(0.16)	0.06	(0.10)	5.05	(8.09)	43.80	(70.20)
Avg	10.2		6.7		759.0		182.0		9.3		6.1		665.0		166.0	
n	29		29		16		16		28		28		15		15	
SD	9.6		6.3		470.0		90.5		9.0		5.9		430.0		78.3	
Min	0.1		0.0		2.9		26.3		0.1		0.0		4.2		37.9	
Max	25.7		16.8		1370.0		275.0		25.8		16.9		1270.0		253.0	

Table E11. Daily means (SD) of NH3 emissions at Site CA1B for October, 2009.

Day	House 10								House 12							
	kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$		kg d^{-1}		g $d^{-1}m^{-2}$		mg $d^{-1}hd^{-1}$		g $d^{-1}AU^{-1}$	
1	0.12	(0.13)	0.08	(0.08)	6.09	(6.66)	46.50	(50.80)	0.15	(0.18)	0.10	(0.12)	7.81	(9.27)	59.90	(71.30)
2	0.15	(0.13)	0.10	(0.09)	7.63	(6.89)	48.70	(44.10)	0.19	(0.17)	0.12	(0.11)	9.76	(8.96)	62.90	(58.00)
3	0.15	(0.15)	0.10	(0.10)	7.69	(7.65)	40.30	(40.40)	0.20	(0.20)	0.13	(0.13)	10.50	(10.60)	55.20	(56.00)
4	0.18	(0.19)	0.12	(0.12)	9.12	(9.73)	38.40	(40.80)	0.24	(0.25)	0.16	(0.17)	12.50	(13.20)	53.00	(55.60)
5	0.19	(0.21)	0.13	(0.14)	9.95	(11.10)	34.50	(38.40)	0.25	(0.30)	0.17	(0.20)	13.10	(15.90)	45.70	(54.80)
6	0.22	(0.22)	0.14	(0.14)	11.40	(11.20)	32.10	(31.90)	0.29	(0.32)	0.19	(0.21)	15.30	(16.50)	43.60	(47.20)
7																
8	0.30	(0.26)	0.20	(0.17)	15.80	(13.80)	31.20	(27.30)	0.38	(0.34)	0.25	(0.22)	19.80	(17.50)	39.30	(34.90)
9	0.34	(0.29)	0.22	(0.19)	17.60	(15.40)	29.70	(26.10)	0.38	(0.35)	0.25	(0.23)	20.00	(18.10)	34.00	(30.80)
10	0.40	(0.34)	0.26	(0.22)	20.80	(17.80)	30.30	(25.80)	0.42	(0.36)	0.28	(0.24)	22.00	(18.90)	32.20	(27.60)
11	0.48	(0.45)	0.32	(0.30)	25.30	(23.60)	32.00	(29.70)	0.47	(0.49)	0.31	(0.32)	24.40	(25.40)	31.00	(32.20)
12	0.67	(0.57)	0.44	(0.37)	34.80	(29.80)	38.60	(33.00)	0.60	(0.60)	0.39	(0.39)	31.40	(31.30)	35.00	(34.90)
13																
14																
15																
16																
17																
18																
19																
20																
21																
22																
23																
24																
25																
26																
27																
28																
29																
30																
31																
Avg	0.3		0.2		15.1		36.6		0.3		0.2		17.0		44.7	
n	11		11		11		11		11		11		11		11	
SD	0.2		0.1		8.5		6.3		0.1		0.1		6.9		11.0	
Min	0.1		0.1		6.1		29.7		0.2		0.1		7.8		31.0	
Max	0.7		0.4		34.8		48.7		0.6		0.4		31.4		62.9	

Table E12. Completeness of airflow and emission data

Table E12. Completeness of airflow and emission data at Site CA1B for September, 2007.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	98	98	0	0	0	0	0	0	0	0	0	0
26	100	100	0	0	0	0	0	0	0	0	0	0
27	97	97	0	0	0	0	0	0	0	0	0	0
28	100	100	0	0	0	0	0	74	0	0	0	0
29	100	100	0	0	0	0	0	100	0	0	0	0
30	100	100	0	0	0	0	0	100	0	0	0	0
Avg	20	20	0	0	0	0	0	9	0	0	0	0
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	40	40	0	0	0	0	0	28	0	0	0	0
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	0	0	0	0	0	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for October, 2007.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	0	0	0	0	0	100	0	0	0	0
2	100	100	0	0	0	0	0	100	0	0	0	0
3	100	100	0	0	0	0	0	100	0	0	0	0
4	100	100	0	0	0	0	0	100	0	0	0	0
5	91	91	0	0	0	0	0	91	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	50	50	0	0	0	0	0	0	0	0	0	0
12	33	33	0	0	0	0	0	0	0	0	0	0
13	42	45	0	0	0	0	0	0	0	0	0	0
14	100	100	0	0	0	0	0	0	0	0	0	0
15	100	100	0	0	0	0	0	0	0	0	0	0
16	100	100	0	0	0	0	0	0	0	0	0	0
17	100	100	0	0	0	0	0	0	0	0	0	0
18	100	100	0	0	0	0	0	0	0	0	0	0
19	100	99	0	0	0	0	0	0	0	0	0	0
20	100	47	0	0	0	0	0	0	0	0	0	0
21	100	100	0	0	0	0	0	0	0	0	0	0
22	100	100	0	0	0	0	0	0	0	0	0	0
23	100	100	0	0	0	0	0	0	0	0	0	0
24	100	100	0	0	0	0	0	0	0	0	0	0
25	100	100	0	0	0	0	0	0	0	0	0	0
26	100	100	0	0	0	0	0	0	0	0	0	0
27	100	100	0	0	0	0	0	0	0	0	0	0
28	100	100	0	0	0	0	0	0	0	0	0	0
29	78	77	0	0	0	0	0	0	0	0	0	0
30	50	54	0	0	0	0	0	0	0	0	0	0
31	100	100	0	0	0	0	0	0	0	0	0	0
Avg	76	74	0	0	0	0	0	16	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	38	38	0	0	0	0	0	36	0	0	0	0
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	0	0	0	0	0	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for November, 2007.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	77	0	0	0	0	0	0	0	0	0	0
2	100	100	0	0	0	0	0	0	0	0	0	0
3	100	100	0	0	0	0	0	0	0	0	0	0
4	100	100	0	0	0	0	0	0	0	0	0	0
5	80	80	0	0	0	0	0	0	0	0	0	0
6	80	80	0	0	0	0	0	0	0	0	0	0
7	100	100	0	0	0	0	22	0	0	0	0	0
8	100	100	0	0	0	0	100	0	0	0	0	0
9	95	95	0	0	0	0	95	0	0	0	0	0
10	92	93	0	0	0	0	79	0	0	0	0	0
11	44	50	0	0	0	0	44	0	0	0	0	0
12	100	100	0	0	0	0	100	0	0	0	0	0
13	100	100	0	0	26	27	100	0	0	0	0	0
14	66	66	0	0	62	62	66	0	0	0	0	0
15	100	100	0	0	100	100	100	0	0	0	0	0
16	100	100	0	0	100	100	100	0	0	0	0	0
17	100	80	0	0	100	80	100	0	0	0	0	0
18	100	78	0	0	100	78	100	0	0	0	0	0
19	100	100	0	0	100	100	100	0	0	0	0	0
20	100	100	0	0	70	100	90	31	0	0	0	0
21	100	100	0	0	42	100	97	97	0	0	0	0
22	37	37	0	0	37	34	37	37	0	0	0	0
23	64	64	0	0	63	61	64	64	0	0	0	0
24	100	100	0	0	100	100	100	100	0	0	0	0
25	100	100	0	0	100	100	100	100	0	0	0	0
26	100	100	0	0	100	100	100	100	0	0	0	0
27	100	100	0	0	100	100	100	100	0	0	0	0
28	100	100	0	0	100	100	100	100	0	0	0	0
29	100	100	0	0	100	100	100	100	0	0	0	0
30	100	100	0	0	100	100	100	100	0	0	0	0
Avg	92	90	0	0	50	51	70	31	0	0	0	0
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	17	17	0	0	45	46	40	44	0	0	0	0
Min	37	37	0	0	0	0	0	0	0	0	0	0
Max	100	100	0	0	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for December, 2007.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	0	0	100	100	67	68	0	0	0	0
2	100	100	0	0	100	100	100	100	0	0	0	0
3	100	100	0	0	100	100	100	100	0	0	0	0
4	100	100	0	0	100	100	100	100	0	0	0	0
5	100	100	0	0	100	100	100	100	0	0	0	0
6	100	100	0	0	100	100	100	100	0	0	0	0
7	100	100	0	0	100	100	100	100	0	0	0	0
8	100	100	0	0	100	100	100	100	0	0	0	0
9	100	100	0	0	100	100	100	100	0	0	0	0
10	76	76	0	0	75	76	60	59	0	0	10	12
11	36	36	0	0	36	34	0	0	0	0	36	36
12	100	100	0	0	100	100	0	0	0	0	100	100
13	100	100	0	0	100	100	0	0	0	0	95	95
14	100	100	0	0	100	100	0	0	0	0	98	99
15	100	100	0	0	100	100	0	0	0	0	100	100
16	100	100	0	0	100	100	0	0	0	0	88	88
17	100	100	0	0	100	100	0	0	0	0	100	100
18	100	100	0	0	100	100	0	0	0	0	100	100
19	100	100	0	0	100	100	43	41	0	0	51	51
20	100	100	0	0	100	100	100	100	0	0	0	0
21	100	100	0	0	100	100	100	100	0	0	0	0
22	100	100	0	0	100	100	96	96	0	0	0	0
23	100	100	0	0	59	59	95	95	0	0	0	0
24	100	100	0	0	100	100	100	100	0	0	0	0
25	100	100	0	0	100	100	94	94	0	0	0	0
26	100	100	0	0	100	100	100	100	0	0	0	0
27	100	100	0	0	100	100	79	79	0	0	0	0
28	99	99	18	18	99	99	89	89	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	54	54	0	0	0	0
31	100	100	100	100	100	100	0	0	0	0	0	0
Avg	97	97	10	10	96	96	64	64	0	0	25	25
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	12	12	30	30	14	14	43	43	0	0	41	41
Min	36	36	0	0	36	34	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	100	100

Table E12. Completeness of airflow and emission data at Site CA1B for January, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	0	0	0	0	0	0
2	100	100	100	100	100	100	0	0	0	0	0	0
3	100	100	100	100	100	100	0	0	0	0	0	0
4	100	100	100	100	100	100	0	0	0	0	0	0
5	100	100	100	100	100	100	40	40	0	0	0	0
6	100	100	100	100	100	100	100	100	0	0	0	0
7	100	100	100	100	100	100	100	100	0	0	0	0
8	100	100	100	100	100	100	100	100	0	0	0	0
9	84	85	84	77	84	77	70	78	0	0	0	0
10	100	100	100	100	100	100	100	100	0	0	0	0
11	100	100	100	100	100	100	100	100	0	0	0	0
12	100	100	100	100	100	100	100	100	0	0	0	0
13	100	100	100	100	100	100	100	100	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	100	100	100	100	100	100	100	100	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	100	0	0	0	0
20	100	100	100	100	100	100	100	100	0	0	0	0
21	100	100	100	100	100	100	100	100	0	0	0	0
22	100	100	100	100	100	100	100	100	0	0	0	0
23	100	100	100	100	100	100	100	100	0	0	0	0
24	100	100	100	100	100	100	100	100	0	0	0	0
25	99	99	99	99	99	99	92	93	0	0	0	0
26	100	100	100	100	100	100	100	100	0	0	0	0
27	99	99	99	99	99	99	95	95	0	0	0	0
28	100	100	100	100	100	100	55	55	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
31	100	100	100	100	100	100	100	100	0	0	0	0
Avg	99	99	99	99	99	99	82	83	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	3	3	3	4	3	4	35	35	0	0	0	0
Min	84	85	84	77	84	77	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for February, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	74	74	74	74	52	51	41	39	0	0
2	9	9	0	0	0	0	0	0	9	9	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	58	58	14	14	15	15	0	0	58	58	0	0
5	100	100	100	100	100	100	0	0	100	100	0	0
6	100	100	100	100	100	100	0	0	100	100	0	0
7	100	100	100	100	100	100	0	0	100	100	0	0
8	100	100	100	100	100	100	0	0	97	97	0	0
9	100	100	100	100	100	100	0	0	100	100	0	0
10	100	100	100	100	100	100	0	0	100	100	0	0
11	98	99	98	99	98	99	0	0	98	99	0	0
12	100	100	100	100	100	100	0	0	100	100	0	0
13	100	100	100	100	100	100	0	0	100	100	0	0
14	97	97	97	97	97	97	0	0	97	97	0	0
15	100	100	100	100	100	100	0	0	100	100	0	0
16	100	100	100	100	100	100	0	0	100	100	0	0
17	100	100	100	100	100	100	0	0	100	100	0	0
18	100	100	100	100	100	100	0	0	87	100	0	0
19	100	100	100	100	100	100	0	0	0	57	0	0
20	100	100	100	100	100	100	0	0	0	0	0	0
21	96	96	96	96	96	96	0	0	0	0	0	0
22	88	88	50	52	88	88	0	0	0	0	0	0
23	99	99	39	38	99	99	0	0	0	0	0	0
24	100	100	100	100	100	100	0	0	0	0	0	0
25	99	99	99	99	99	99	1	0	0	0	0	0
26	94	94	94	94	94	94	0	0	0	0	0	0
27	100	100	100	100	100	100	0	0	0	0	0	0
28	100	100	100	100	100	100	0	0	0	0	0	0
29	97	97	97	97	97	97	47	47	0	0	0	0
Avg	91	91	85	85	88	88	3	3	51	54	0	0
n	29	29	29	29	29	29	29	29	29	29	29	29
SD	25	25	31	31	29	29	13	13	47	47	0	0
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	52	51	100	100	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for March, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	100	100	0	0	0	0
2	100	100	100	100	100	100	100	100	0	0	0	0
3	100	100	100	100	100	100	100	100	0	0	0	0
4	100	100	100	100	100	100	100	100	0	0	0	0
5	100	100	100	100	100	100	100	100	0	0	0	0
6	100	100	100	100	100	100	100	100	0	0	0	0
7	100	100	100	100	100	100	100	100	0	0	0	0
8	99	99	99	99	99	99	95	97	0	0	0	0
9	96	96	96	96	96	96	96	96	0	0	0	0
10	100	100	100	100	100	100	100	100	0	0	0	0
11	100	100	100	100	100	100	100	100	0	0	0	0
12	100	100	100	100	100	100	100	100	0	0	0	0
13	100	100	100	100	100	100	100	100	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	100	100	100	100	100	100	100	100	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	100	0	0	0	0
20	100	100	100	100	100	100	100	100	0	0	0	0
21	100	100	100	100	100	100	100	100	0	0	0	0
22	100	100	100	100	100	100	100	100	0	0	0	0
23	100	100	100	100	100	100	79	69	0	0	0	0
24	51	51	51	49	51	51	0	0	0	0	0	0
25	94	94	93	93	93	94	39	39	0	0	0	0
26	100	100	100	98	100	98	100	100	0	0	0	0
27	52	52	43	51	43	52	52	52	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
31	100	100	100	100	100	100	100	100	0	0	0	0
Avg	97	97	96	96	96	96	92	92	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	12	12	13	12	13	12	22	22	0	0	0	0
Min	51	51	43	49	43	51	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for April, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM$_{10}$		PM$_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	100	100	0	0	0	0
2	100	100	100	100	100	100	100	100	0	0	0	0
3	100	100	100	100	100	100	100	100	0	0	0	0
4	100	100	100	79	100	79	95	96	0	0	0	0
5	94	94	63	63	63	63	94	94	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0
11	53	53	5	5	49	49	49	51	0	0	0	0
12	100	100	100	100	100	100	100	100	0	0	0	0
13	100	100	100	100	100	100	49	49	0	0	0	0
14	100	100	100	100	100	100	0	0	0	0	0	0
15	100	100	100	100	100	100	0	0	0	0	0	0
16	100	100	100	100	100	100	0	0	0	0	0	0
17	100	100	100	100	100	100	0	0	0	0	0	0
18	100	100	100	100	100	100	23	28	0	0	0	0
19	100	100	100	100	100	100	98	98	0	0	0	0
20	99	99	99	99	99	99	99	99	0	0	0	0
21	100	100	100	100	100	100	100	100	0	0	0	0
22	100	100	100	100	100	100	100	100	0	0	0	0
23	100	100	100	100	100	100	100	100	0	0	0	0
24	100	100	100	100	100	100	100	100	0	0	0	0
25	100	100	100	100	100	100	100	100	0	0	0	0
26	100	100	100	100	100	100	100	100	0	0	0	0
27	100	100	100	100	100	100	100	100	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
Avg	82	82	79	78	80	80	64	64	0	0	0	0
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	37	37	40	39	38	37	45	45	0	0	0	0
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for May, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	100	100	100	100	100	100	100	100	0	0	0	0
2	100	100	100	100	100	100	95	94	0	0	0	0
3	100	100	100	100	100	100	100	100	0	0	0	0
4	100	100	100	100	100	100	100	100	0	0	0	0
5	100	100	100	100	100	100	100	100	0	0	0	0
6	100	100	100	100	100	100	100	100	0	0	0	0
7	100	100	78	77	78	79	91	89	0	0	0	0
8	100	100	100	100	100	100	100	100	0	0	0	0
9	100	100	100	100	100	100	100	100	0	0	0	0
10	100	100	100	100	100	100	100	100	0	0	0	0
11	100	100	100	100	100	100	100	100	0	0	0	0
12	100	100	100	100	100	100	100	100	0	0	0	0
13	100	100	100	100	100	100	100	100	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	93	91	71	68	71	68	63	61	0	0	27	26
16	14	14	0	0	0	0	0	0	0	0	14	14
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	53	53	52	50	52	50	0	0	0	0	50	47
20	100	100	100	100	100	100	0	0	0	0	100	100
21	100	100	100	100	100	100	0	0	0	0	96	96
22	100	100	100	100	100	100	0	0	0	0	87	87
23	100	100	100	100	100	100	0	0	0	0	99	100
24	100	100	100	100	100	100	0	0	0	0	100	100
25	100	100	100	100	100	100	0	0	0	0	100	100
26	100	100	100	100	100	100	0	0	0	0	100	7
27	100	100	100	100	100	100	0	0	0	0	100	0
28	100	100	100	100	100	100	48	46	0	0	45	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
31	100	100	100	100	100	100	100	100	0	0	0	0
Avg	89	89	87	87	87	87	58	58	0	0	30	22
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	29	29	30	30	30	30	47	47	0	0	42	38
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	100	100

Table E12. Completeness of airflow and emission data at Site CA1B for June, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM$_{10}$		PM$_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	100	100	0	0	0	0
2	100	100	100	100	100	100	97	97	0	0	0	0
3	100	100	100	100	100	100	100	100	0	0	0	0
4	100	100	100	100	100	100	95	35	0	0	0	0
5	100	100	100	100	100	100	48	47	0	0	0	0
6	100	100	100	100	100	100	0	0	0	0	0	0
7	100	100	100	100	100	100	0	0	0	0	0	0
8	100	100	100	100	100	100	0	0	0	0	0	0
9	100	100	100	100	100	100	0	0	0	0	0	0
10	100	100	100	100	100	100	0	0	0	0	0	0
11	100	100	100	100	100	100	0	0	0	0	0	0
12	100	100	100	100	100	100	51	51	0	0	0	0
13	100	100	100	100	100	100	100	100	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	100	100	100	100	100	100	100	100	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	96	0	0	0	0
20	100	100	100	100	100	100	100	100	0	0	0	0
21	100	100	100	100	100	100	100	100	0	0	0	0
22	100	100	100	100	100	100	100	100	0	0	0	0
23	100	100	100	100	100	100	100	100	0	0	0	0
24	99	99	99	99	99	99	84	88	0	0	0	0
25	100	100	100	100	100	100	100	100	0	0	0	0
26	100	100	100	100	100	100	96	93	0	0	0	0
27	100	100	100	100	100	100	100	100	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
Avg	100	100	100	100	100	100	76	74	0	0	0	0
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	0	0	0	0	0	0	40	40	0	0	0	0
Min	99	99	99	99	99	99	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for July, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	95	87	0	0	0	0
2	100	100	100	100	100	100	100	100	0	0	0	0
3	100	100	100	100	100	100	90	90	0	0	0	0
4	100	100	100	100	100	100	100	100	0	0	0	0
5	100	100	100	100	100	100	100	100	0	0	0	0
6	100	100	100	100	100	100	100	100	0	0	0	0
7	100	100	100	100	100	100	100	100	0	0	0	0
8	100	100	100	100	100	100	100	100	0	0	0	0
9	100	100	100	100	100	100	50	50	44	40	0	0
10	100	100	100	100	100	100	0	0	100	100	0	0
11	100	100	100	100	100	100	0	0	100	100	0	0
12	100	100	100	100	100	100	0	0	100	100	0	0
13	100	100	100	100	100	100	0	0	100	100	0	0
14	100	100	100	100	100	100	0	0	100	100	0	0
15	100	100	100	100	100	100	0	0	100	100	0	0
16	100	100	100	100	100	100	0	0	100	100	0	0
17	100	100	100	100	100	100	0	0	100	100	0	0
18	100	100	100	100	100	100	0	0	94	93	0	0
19	100	100	100	100	100	100	0	0	100	100	0	0
20	100	100	100	100	100	100	0	0	100	100	0	0
21	100	100	100	100	100	100	0	0	100	100	0	0
22	100	100	100	100	100	100	0	0	100	100	0	0
23	100	100	100	100	100	100	0	0	100	100	0	0
24	100	100	100	100	100	100	0	0	100	100	0	0
25	99	99	99	99	99	99	41	42	49	46	0	0
26	100	100	100	100	100	100	100	100	0	0	0	0
27	100	100	100	100	100	100	100	100	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	47	47	0	0	0	0
30	100	100	100	100	100	100	0	0	0	0	0	0
31	100	100	100	100	100	100	0	0	0	0	0	0
Avg	100	100	100	100	100	100	40	39	51	51	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	0	0	0	0	0	0	46	46	48	48	0	0
Min	99	99	99	99	99	99	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	100	100	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for August, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	99	99	99	99	99	99	0	0	0	0	0	0
2	100	100	100	100	100	100	0	0	0	0	0	0
3	100	100	100	100	100	100	0	0	0	0	0	0
4	100	100	100	100	100	100	0	0	0	0	0	0
5	100	100	100	100	100	100	0	0	0	0	0	0
6	100	100	100	100	100	100	0	0	0	0	0	0
7	100	100	100	100	100	100	0	0	0	0	0	0
8	100	100	100	100	100	100	0	0	0	0	0	0
9	100	100	100	100	100	100	0	0	0	0	0	0
10	100	100	100	100	100	100	0	0	0	0	0	0
11	93	93	93	93	93	93	40	40	0	0	0	0
12	100	100	100	100	100	100	100	100	0	0	0	0
13	100	100	100	100	100	100	100	100	0	0	0	0
14	97	97	97	97	97	97	97	97	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	100	100	100	100	100	100	100	100	0	0	0	0
18	94	94	38	36	94	71	94	94	0	0	0	0
19	100	100	0	0	100	100	100	100	0	0	0	0
20	100	100	44	44	100	100	100	100	0	0	0	0
21	100	100	100	100	100	100	97	94	0	0	0	0
22	100	100	100	100	100	100	100	100	0	0	0	0
23	100	100	100	100	100	100	100	100	0	0	0	0
24	100	100	100	100	100	100	100	100	0	0	0	0
25	100	100	100	100	100	100	100	100	0	0	0	0
26	100	100	100	100	100	100	100	100	0	0	0	0
27	100	100	100	100	100	100	100	100	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	95	93	0	0	0	0
30	100	100	19	19	100	100	100	100	0	0	0	0
31	100	100	0	0	100	100	100	100	0	0	0	0
Avg	99	99	87	87	99	99	65	65	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	2	2	30	30	2	5	46	46	0	0	0	0
Min	93	93	0	0	93	71	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for September, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	0	0	100	100	100	100	0	0	0	0
2	98	98	0	0	98	98	98	98	0	0	0	0
3	100	100	0	0	100	100	100	100	0	0	0	0
4	100	100	0	0	100	100	100	100	0	0	0	0
5	100	100	0	0	100	100	100	100	0	0	0	0
6	100	100	0	0	100	100	100	100	0	0	0	0
7	100	100	0	0	100	100	100	100	0	0	0	0
8	100	100	0	0	100	100	100	100	0	0	0	0
9	100	100	0	0	100	100	100	100	0	0	0	0
10	100	100	0	0	100	100	100	100	0	0	0	0
11	100	100	0	0	100	100	91	91	0	0	0	0
12	100	100	0	0	100	100	100	100	0	0	0	0
13	100	100	0	0	100	100	100	100	0	0	0	0
14	100	100	0	0	100	100	100	100	0	0	0	0
15	100	100	0	0	100	100	100	100	0	0	0	0
16	100	100	0	0	100	100	100	100	0	0	0	0
17	100	100	0	0	100	100	100	100	0	0	0	0
18	100	100	0	0	100	100	100	100	0	0	0	0
19	100	100	0	0	100	100	100	100	0	0	0	0
20	100	100	0	0	100	100	100	100	0	0	0	0
21	100	100	0	0	100	100	100	100	0	0	0	0
22	100	100	0	0	100	100	97	50	0	0	0	0
23	100	100	0	0	100	100	97	0	0	0	0	0
24	97	97	0	0	97	97	97	37	0	0	0	0
25	100	100	0	0	100	100	58	54	0	0	0	0
26	100	100	0	0	96	98	0	0	0	0	0	0
27	100	100	0	0	0	0	0	0	0	0	0	0
28	100	100	0	0	0	0	0	0	0	0	0	0
29	95	95	0	0	0	0	0	0	0	0	0	0
30	100	100	0	0	0	0	0	0	0	0	0	0
Avg	100	100	0	0	86	86	81	74	0	0	0	0
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	1	1	0	0	34	34	37	40	0	0	0	0
Min	95	95	0	0	0	0	0	0	0	0	0	0
Max	100	100	0	0	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for October, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	0	0	0	0	0	0	0	0	0	0
2	100	100	0	0	0	0	0	0	0	0	0	0
3	100	100	0	0	0	0	0	0	0	0	0	0
4	100	100	0	0	0	0	0	0	0	0	0	0
5	100	100	0	0	0	0	0	0	0	0	0	0
6	100	100	0	0	0	0	0	0	0	0	0	0
7	100	100	0	0	0	0	0	0	0	0	0	0
8	100	100	0	0	0	0	0	0	0	0	0	0
9	100	100	0	0	0	0	0	0	0	0	0	0
10	100	100	0	0	0	0	0	0	0	0	0	0
11	100	100	0	0	0	0	0	0	0	0	0	0
12	100	100	0	0	0	0	0	0	0	0	0	0
13	100	100	0	0	0	0	0	0	0	0	0	0
14	100	100	0	0	0	0	0	0	0	0	0	0
15	100	100	0	0	0	0	0	0	0	0	0	0
16	100	100	0	0	0	0	37	38	0	0	0	0
17	100	100	0	0	0	0	99	99	0	0	0	0
18	100	100	0	0	0	0	100	100	0	0	0	0
19	100	100	0	0	0	0	100	100	0	0	0	0
20	100	100	0	0	0	0	100	100	0	0	0	0
21	100	100	0	0	0	0	100	100	0	0	0	0
22	100	100	0	0	0	0	79	85	0	0	0	0
23	100	100	0	0	0	0	100	100	0	0	0	0
24	100	100	0	0	0	0	100	100	0	0	0	0
25	100	100	0	0	0	0	100	100	0	0	0	0
26	100	100	0	0	0	0	100	100	0	0	0	0
27	100	100	0	0	0	0	100	100	0	0	0	0
28	100	100	0	0	0	0	100	100	0	0	0	0
29	98	99	0	0	0	0	95	92	0	0	0	0
30	100	100	0	0	0	0	100	100	0	0	0	0
31	100	100	0	0	0	0	100	100	0	0	0	0
Avg	100	100	0	0	0	0	49	49	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	0	0	0	0	0	0	49	49	0	0	0	0
Min	98	99	0	0	0	0	0	0	0	0	0	0
Max	100	100	0	0	0	0	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for November, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	100	100	0	0	0	0	100	100	0	0	0	0
2	100	100	0	0	0	0	100	100	0	0	0	0
3	100	100	0	0	0	0	100	100	0	0	0	0
4	100	100	0	0	0	0	100	100	0	0	0	0
5	100	100	0	0	0	0	100	100	0	0	0	0
6	100	100	0	0	0	0	100	100	0	0	0	0
7	64	64	0	0	0	0	53	59	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0
10	52	52	0	0	0	0	52	52	0	0	0	0
11	100	100	0	0	0	0	100	100	0	0	0	0
12	100	100	0	0	0	0	100	100	0	0	0	0
13	100	100	0	0	0	0	100	100	0	0	0	0
14	100	100	0	0	0	0	100	100	0	0	0	0
15	100	100	0	0	0	0	100	100	0	0	0	0
16	100	100	0	0	0	0	100	100	0	0	0	0
17	99	100	0	0	0	0	58	59	0	0	34	0
18	100	100	0	0	0	0	0	0	0	0	100	52
19	100	100	0	0	0	0	0	0	0	0	100	100
20	97	97	94	95	95	95	0	0	0	0	94	76
21	100	100	100	100	100	100	0	0	0	0	100	100
22	100	100	100	100	100	100	0	0	0	0	100	100
23	100	100	100	100	100	100	0	0	0	0	100	100
24	100	100	83	100	83	100	29	29	0	0	65	65
25	99	99	99	74	99	74	99	99	0	0	0	0
26	88	100	88	100	88	100	88	100	0	0	0	0
27	100	100	100	100	100	100	100	100	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
Avg	90	90	36	36	36	36	66	67	0	0	23	20
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	26	26	47	47	47	47	44	44	0	0	40	37
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	100	100

Table E12. Completeness of airflow and emission data at Site CA1B for December, 2008.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	100	100	0	0	0	0
2	97	100	97	100	97	100	92	95	0	0	0	0
3	97	97	97	97	97	97	56	56	0	0	0	0
4	97	99	97	99	97	99	0	0	0	0	0	0
5	89	100	89	100	89	100	0	0	0	0	0	0
6	100	100	100	100	100	100	0	0	0	0	0	0
7	100	100	100	100	100	100	0	0	0	0	0	0
8	97	100	97	100	97	100	0	0	0	0	0	0
9	100	100	100	100	100	100	0	0	0	0	0	0
10	100	100	100	100	100	100	0	0	0	0	0	0
11	100	100	100	100	100	100	0	0	0	0	0	0
12	100	100	100	100	100	100	31	30	0	0	0	0
13	100	100	100	100	100	100	79	92	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	100	100	100	100	100	100	97	92	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	100	0	0	0	0
20	100	100	100	100	100	100	100	100	0	0	0	0
21	94	100	94	100	94	100	94	100	0	0	0	0
22	76	100	76	100	76	100	76	100	0	0	0	0
23	100	100	100	100	100	100	100	100	0	0	0	0
24	100	100	100	100	100	100	100	100	0	0	0	0
25	88	100	88	100	88	100	88	100	0	0	0	0
26	100	100	100	100	100	100	94	95	0	0	0	0
27	100	100	100	100	100	100	100	100	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
31	100	100	100	100	100	100	100	100	0	0	0	0
Avg	98	100	98	100	98	100	68	70	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	5	1	5	1	5	1	43	43	0	0	0	0
Min	76	97	76	97	76	97	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for January, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	100	100	0	0	0	0
2	100	100	100	100	100	100	100	100	0	0	0	0
3	100	100	100	100	100	100	100	100	0	0	0	0
4	100	100	100	100	100	100	100	5	0	0	0	0
5	100	100	100	100	100	100	52	0	38	38	0	0
6	100	100	100	100	100	100	0	0	100	100	0	0
7	100	100	100	100	100	100	0	0	100	100	0	0
8	100	100	100	100	100	100	0	0	100	100	0	0
9	100	100	100	100	100	100	0	0	100	100	0	0
10	100	100	100	100	100	100	0	0	100	100	0	0
11	100	100	100	100	100	100	0	0	100	100	0	0
12	100	100	70	72	100	100	0	0	100	100	0	0
13	100	100	0	0	100	100	0	0	100	100	0	0
14	100	100	0	0	100	100	0	0	100	100	0	0
15	100	100	0	0	100	100	0	0	92	96	0	0
16	100	100	0	0	100	100	0	0	100	100	0	0
17	100	100	0	0	100	100	0	0	100	100	0	0
18	100	100	0	0	100	100	0	0	100	100	0	0
19	100	100	0	0	100	100	0	0	100	100	0	0
20	100	100	0	0	100	100	39	39	54	53	0	0
21	100	100	0	0	100	100	100	100	0	0	0	0
22	81	100	0	0	81	100	81	100	0	0	0	0
23	100	100	0	0	100	100	100	100	0	0	0	0
24	89	100	0	0	89	100	89	100	0	0	0	0
25	100	100	0	0	100	100	100	100	0	0	0	0
26	99	99	0	0	99	99	51	51	0	0	0	0
27	100	100	0	0	100	100	0	0	0	0	0	0
28	100	100	0	0	100	100	0	0	0	0	0	0
29	100	100	0	0	100	100	0	0	0	0	0	0
30	100	100	8	8	100	100	0	0	0	0	0	0
31	85	85	85	85	85	85	0	0	0	0	0	0
Avg	99	100	41	41	99	100	33	29	48	48	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	5	3	48	48	5	3	43	43	48	48	0	0
Min	81	85	0	0	81	85	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	100	100	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for February, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	100	100	100	100	100	100	0	0	0	0	0	0
2	100	100	100	100	100	100	0	0	0	0	0	0
3	100	100	100	100	100	100	0	0	0	0	0	0
4	95	95	95	95	95	95	0	0	0	0	0	0
5	96	96	96	96	96	96	23	22	0	0	0	0
6	100	100	100	100	100	100	100	100	0	0	0	0
7	100	100	100	100	100	100	100	100	0	0	0	0
8	84	100	84	100	84	100	84	100	0	0	0	0
9	49	100	49	100	49	100	49	100	0	0	0	0
10	100	100	100	100	100	100	100	100	0	0	0	0
11	80	100	80	100	80	100	76	96	0	0	0	0
12	57	100	57	100	57	100	57	100	0	0	0	0
13	93	100	93	100	93	100	93	100	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	95	95	95	95	95	95	95	95	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	100	0	0	0	0
20	97	97	97	97	97	97	48	92	0	0	0	0
21	100	100	100	100	100	100	0	100	0	0	0	0
22	100	100	100	100	100	100	0	100	0	0	0	0
23	100	100	100	100	100	100	0	91	0	0	0	0
24	100	100	100	100	100	100	0	100	0	0	0	0
25	100	100	100	100	100	100	0	100	0	0	0	0
26	100	100	100	100	100	100	0	100	0	0	0	0
27	100	100	100	100	100	100	0	100	0	0	0	0
28	100	100	100	100	100	100	0	100	0	0	0	0
Avg	95	99	95	99	95	99	47	82	0	0	0	0
n	28	28	28	28	28	28	28	28	28	28	28	28
SD	12	2	12	2	12	2	45	36	0	0	0	0
Min	49	95	49	95	49	95	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for March, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	100	100	100	100	100	100	0	100	0	0	0	0
2	100	100	100	100	100	100	0	97	0	0	0	0
3	100	100	100	100	100	100	0	95	0	0	0	0
4	100	100	100	100	100	100	0	100	0	0	0	0
5	100	100	100	100	100	100	0	100	0	0	0	0
6	100	100	100	100	100	100	0	100	0	0	0	0
7	100	100	100	100	100	100	0	100	0	0	0	0
8	100	100	100	100	100	100	0	100	0	0	0	0
9	100	100	100	100	100	100	0	100	0	0	0	0
10	100	100	100	100	100	100	0	100	0	0	0	0
11	100	100	100	100	100	100	0	97	0	0	0	0
12	100	100	100	100	100	100	0	45	0	0	0	0
13	100	100	100	100	100	100	0	100	0	0	0	0
14	100	100	100	100	100	100	0	100	0	0	0	0
15	100	100	100	100	100	100	0	100	0	0	0	0
16	100	100	100	100	100	100	0	100	0	0	0	0
17	100	100	100	100	100	100	0	100	0	0	0	0
18	100	100	100	100	100	100	0	100	0	0	0	0
19	100	100	100	100	100	100	0	100	0	0	0	0
20	100	100	100	100	100	100	0	94	0	0	0	0
21	100	100	100	100	100	100	0	100	0	0	0	0
22	80	100	80	100	80	100	0	100	0	0	0	0
23	100	100	100	100	100	100	0	100	0	0	0	0
24	100	100	100	100	100	100	0	100	0	0	0	0
25	100	100	100	100	100	100	0	100	0	0	0	0
26	100	100	100	100	100	100	0	40	0	0	0	0
27	100	100	100	100	100	100	0	0	0	0	0	0
28	100	100	100	100	100	100	0	0	0	0	0	0
29	100	100	100	100	100	100	0	0	0	0	0	0
30	100	100	100	100	100	100	0	0	0	0	0	0
31	100	100	100	100	100	100	0	0	0	0	0	0
Avg	99	100	99	100	99	100	0	80	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	4	0	4	0	4	0	0	38	0	0	0	0
Min	80	100	80	100	80	100	0	0	0	0	0	0
Max	100	100	100	100	100	100	0	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for April, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	0	0	0	0	0	0
2	100	100	100	100	100	100	0	0	0	0	0	0
3	100	100	100	100	100	100	0	0	0	0	0	0
4	100	100	100	100	100	100	0	0	0	0	0	0
5	100	100	100	100	100	100	0	0	0	0	0	0
6	100	100	100	100	100	100	0	0	0	0	0	0
7	100	100	100	100	100	100	0	0	0	0	0	0
8	100	100	100	100	100	100	0	0	0	0	0	0
9	100	100	100	100	100	100	0	0	0	0	0	38
10	85	85	65	64	75	73	0	0	0	0	0	69
11	100	100	100	100	100	100	0	0	0	0	0	100
12	100	100	100	100	100	100	0	0	0	0	0	100
13	100	100	100	100	100	100	0	0	0	0	0	100
14	100	100	100	100	100	100	0	0	0	0	0	100
15	100	100	100	100	100	100	0	0	0	0	0	100
16	100	100	100	100	100	100	0	0	0	0	0	100
17	100	100	100	100	100	100	0	0	0	0	0	100
18	100	100	100	100	100	100	0	0	0	0	0	100
19	100	100	100	100	100	100	0	0	0	0	0	100
20	100	100	33	33	33	33	0	47	0	0	0	48
21	100	100	0	0	0	0	0	100	0	0	0	0
22	100	100	0	0	0	0	0	97	0	0	0	0
23	100	100	0	0	0	0	0	100	0	0	0	0
24	100	100	0	0	0	0	0	100	0	0	0	0
25	100	100	0	0	0	0	0	100	0	0	0	0
26	100	100	0	0	0	0	0	100	0	0	0	0
27	100	100	0	0	0	0	0	100	0	0	0	0
28	100	100	6	6	6	6	0	84	0	0	0	0
29	100	100	100	100	100	100	0	100	0	0	0	0
30	100	100	100	100	100	100	0	85	0	0	0	0
Avg	100	100	70	70	71	70	0	34	0	0	0	35
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	3	3	44	44	44	44	0	45	0	0	0	45
Min	85	85	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	0	100	0	0	0	100

Table E12. Completeness of airflow and emission data at Site CA1B for May, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	0	0	0	0	0	0
2	100	100	100	100	100	100	0	0	0	0	0	0
3	100	100	100	100	100	100	0	0	0	0	0	0
4	100	100	100	100	100	100	0	43	0	0	0	0
5	100	100	100	100	100	100	0	100	0	0	0	0
6	100	100	100	100	100	100	0	100	0	0	0	0
7	100	100	100	100	100	100	0	100	0	0	0	0
8	100	100	100	100	100	100	0	100	0	0	0	0
9	100	100	100	100	100	100	0	100	0	0	0	0
10	100	100	100	100	100	100	0	98	0	0	0	0
11	100	100	100	100	100	100	34	82	0	0	0	0
12	100	100	100	100	100	100	99	100	0	0	0	0
13	100	100	100	100	100	100	99	100	0	0	0	0
14	100	100	100	100	100	100	100	100	0	0	0	0
15	100	100	100	100	100	100	100	100	0	0	0	0
16	100	100	100	100	100	100	100	100	0	0	0	0
17	100	100	100	100	100	100	100	100	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	100	0	0	0	0
20	100	100	100	100	100	100	100	95	0	0	0	0
21	100	100	100	100	100	100	100	99	0	0	0	0
22	100	100	100	100	100	100	95	48	0	0	0	0
23	100	100	100	100	100	100	100	0	0	0	0	0
24	100	100	100	100	100	100	32	0	0	0	0	0
25	100	100	100	100	100	100	91	0	0	0	0	0
26	100	100	100	76	100	77	47	0	0	0	0	0
27	99	99	99	99	99	99	0	0	0	0	0	0
28	100	100	100	100	100	100	0	0	0	0	0	0
29	100	100	100	100	100	100	0	0	0	0	0	0
30	100	100	100	100	100	100	0	0	0	0	0	0
31	100	100	100	100	100	100	0	0	0	0	0	0
Avg	100	100	100	99	100	99	45	57	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	0	0	0	4	0	4	47	47	0	0	0	0
Min	99	99	99	76	99	77	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for June, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM$_{10}$		PM$_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	0	0	0	0	0	0
2	48	48	3	3	3	3	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0
4	48	48	10	10	10	10	28	0	0	0	0	0
5	99	99	99	99	99	99	58	46	0	0	0	0
6	100	100	100	100	100	100	99	100	0	0	0	0
7	100	100	100	100	100	100	100	97	0	0	0	0
8	100	100	100	100	100	100	100	100	0	0	0	0
9	100	100	100	100	100	100	100	100	0	0	0	0
10	100	100	100	100	100	100	99	100	0	0	0	0
11	100	100	14	14	100	100	97	97	0	0	0	0
12	100	100	0	0	100	100	100	100	0	0	0	0
13	100	100	0	0	100	100	100	100	0	0	0	0
14	100	100	0	0	100	100	100	100	0	0	0	0
15	100	100	0	0	100	100	100	100	0	0	0	0
16	100	100	0	0	100	100	100	100	0	0	0	0
17	100	100	0	0	100	100	97	100	0	0	0	0
18	100	100	0	0	100	100	100	100	0	0	0	0
19	100	100	0	0	100	100	100	99	0	0	0	0
20	100	100	0	0	100	100	97	99	0	0	0	0
21	100	100	0	0	100	100	77	99	0	0	0	0
22	100	100	0	0	100	100	99	100	0	0	0	0
23	100	100	0	0	100	100	98	93	0	0	0	0
24	100	100	0	0	100	100	98	99	0	0	0	0
25	91	91	0	0	91	91	56	56	0	0	28	27
26	96	96	0	0	96	96	0	0	0	0	91	95
27	100	100	0	0	100	100	0	0	0	0	100	100
28	100	100	0	0	100	100	0	0	0	0	100	100
29	100	100	0	0	100	100	0	0	0	0	99	100
30	100	100	0	0	100	100	0	0	0	0	100	100
Avg	93	93	24	24	90	90	67	66	0	0	17	17
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	22	22	42	42	29	29	43	45	0	0	36	37
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	100	100

Table E12. Completeness of airflow and emission data at Site CA1B for July, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	100	100	0	0	100	100	0	0	0	0	93	100
2	100	100	0	0	100	100	0	0	0	0	100	100
3	100	100	0	0	100	100	0	0	0	0	100	100
4	100	100	0	0	100	100	0	0	0	0	57	100
5	100	100	0	0	100	100	0	0	0	0	50	100
6	100	100	0	0	100	100	0	0	0	0	100	100
7	100	100	0	0	100	100	0	0	0	0	100	100
8	100	100	0	0	100	100	38	42	0	0	48	50
9	100	100	0	0	100	100	100	100	0	0	0	0
10	100	100	0	0	100	100	100	100	0	0	0	0
11	100	100	0	0	100	100	100	100	0	0	0	0
12	100	100	0	0	100	100	100	100	0	0	0	0
13	100	100	0	0	100	100	97	1	0	0	0	0
14	100	100	28	28	100	100	100	0	0	0	0	0
15	100	100	60	59	60	59	41	0	0	0	0	0
16	100	100	58	59	58	59	96	0	0	0	0	0
17	100	100	100	100	100	100	98	0	0	0	0	0
18	100	100	100	100	100	100	98	0	0	0	0	0
19	100	100	100	100	100	100	81	0	0	0	0	0
20	99	99	99	99	99	99	64	0	0	0	0	0
21	91	83	91	64	91	64	0	0	0	0	0	0
22	100	100	100	100	100	100	0	0	0	0	0	0
23	100	100	100	100	100	100	0	0	0	0	0	0
24	53	53	24	24	24	24	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	38	38	0	0	0	0	38	0	0	0	0	0
28	100	100	99	99	100	100	99	0	0	0	0	0
29	100	100	100	100	100	100	100	0	0	0	0	0
30	100	100	100	100	100	100	100	0	0	0	0	0
31	100	100	100	100	100	100	100	0	0	0	0	0
Avg	90	89	41	40	85	84	50	14	0	0	21	24
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	27	27	46	45	32	32	46	34	0	0	37	42
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	100	100

Table E12. Completeness of airflow and emission data at Site CA1B for August, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**	**H10**	**H12**
1	100	100	100	100	100	100	100	0	0	0	0	0
2	100	100	100	100	100	100	100	0	0	0	0	0
3	100	100	100	100	100	100	94	0	0	0	0	0
4	38	38	38	37	38	37	38	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0
7	49	49	49	49	49	49	0	0	0	0	0	0
8	100	100	100	100	100	100	0	0	0	0	0	0
9	100	100	100	100	100	100	0	0	0	0	0	0
10	100	100	100	100	100	100	0	0	0	0	0	0
11	100	100	100	100	100	100	0	0	0	0	0	0
12	100	100	100	100	100	100	0	0	0	0	0	0
13	100	100	100	100	100	100	0	0	0	0	0	0
14	100	100	100	100	100	100	0	0	0	0	0	0
15	100	100	100	100	100	100	0	0	0	0	0	0
16	93	93	64	51	64	51	30	26	0	0	0	0
17	99	99	50	52	50	52	95	82	0	0	0	0
18	100	100	100	100	100	100	100	100	0	0	0	0
19	100	100	100	100	100	100	100	100	0	0	0	0
20	100	100	100	100	100	100	100	100	0	0	0	0
21	100	100	100	100	100	100	100	100	0	0	0	0
22	100	100	100	100	100	100	100	100	0	0	0	0
23	100	100	100	100	100	100	100	100	0	0	0	0
24	100	100	100	100	100	100	100	100	0	0	0	0
25	100	100	100	100	100	100	100	100	0	0	0	0
26	99	99	79	99	79	99	95	92	0	0	0	0
27	99	99	99	99	99	99	99	97	0	0	0	0
28	100	100	100	100	100	100	100	100	0	0	0	0
29	100	100	100	100	100	100	100	100	0	0	0	0
30	100	100	100	100	100	100	100	100	0	0	0	0
31	100	100	100	100	100	100	100	100	0	0	0	0
Avg	90	90	86	87	86	87	60	48	0	0	0	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	27	27	28	29	28	29	47	49	0	0	0	0
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	0	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for September, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	100	100	0	0	0	0
2	100	100	100	100	100	100	100	100	0	0	0	0
3	100	100	100	100	100	100	100	99	0	0	0	0
4	100	100	100	100	100	100	96	93	0	0	0	0
5	100	100	100	100	100	100	100	100	0	0	0	0
6	100	100	100	100	100	100	100	100	0	0	0	0
7	100	100	100	100	100	100	100	100	0	0	0	0
8	100	100	100	100	100	100	100	100	0	0	0	0
9	98	98	64	75	64	75	98	80	0	0	0	0
10	94	79	75	69	75	69	94	44	0	0	0	0
11	100	100	100	100	100	100	100	0	0	0	0	0
12	100	100	100	100	100	100	100	0	0	0	0	0
13	100	100	79	78	79	75	56	0	0	0	0	0
14	94	87	94	87	94	87	0	0	0	0	0	0
15	100	100	100	100	100	100	0	0	0	0	0	0
16	100	100	100	100	100	100	0	0	0	0	0	0
17	100	100	100	100	100	100	0	0	0	0	0	0
18	100	100	100	100	100	100	0	0	0	0	0	0
19	100	100	100	100	100	100	0	0	0	0	0	0
20	100	100	100	100	100	100	0	0	0	0	0	0
21	100	100	100	100	100	100	0	0	0	0	0	0
22	100	100	100	100	100	100	0	0	0	0	0	0
23	100	100	100	100	100	100	0	0	0	0	0	0
24	100	100	100	100	100	100	0	0	0	0	0	0
25	100	100	100	100	100	100	0	0	0	0	0	0
26	99	99	99	99	99	99	0	0	34	0	0	0
27	100	100	100	100	100	100	0	0	100	0	0	0
28	100	100	100	100	100	100	0	0	100	0	0	0
29	100	100	100	100	100	100	0	0	100	0	0	0
30	100	100	100	100	100	100	0	0	100	0	0	0
Avg	100	99	97	97	97	97	41	31	14	0	0	0
n	30	30	30	30	30	30	30	30	30	30	30	30
SD	2	4	9	8	8	8	48	44	34	0	0	0
Min	94	79	64	69	64	69	0	0	0	0	0	0
Max	100	100	100	100	100	100	100	100	100	0	0	0

Table E12. Completeness of airflow and emission data at Site CA1B for October, 2009.

Day	Airflow		Ammonia		Hydrogen Sulfide		PM_{10}		$PM_{2.5}$		TSP	
	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12	H10	H12
1	100	100	100	100	100	100	0	0	100	0	0	0
2	100	100	100	100	100	100	0	0	100	0	0	0
3	100	100	100	100	100	100	0	0	100	0	0	0
4	100	100	100	100	100	100	0	0	100	0	0	0
5	100	100	100	100	100	100	0	0	100	0	0	0
6	100	100	100	100	100	100	0	0	100	0	0	0
7	99	99	50	49	50	50	0	0	48	0	44	0
8	100	100	100	100	100	100	0	0	0	0	100	0
9	100	100	100	100	100	100	0	0	0	0	100	0
10	100	100	100	100	100	100	0	0	0	0	100	0
11	100	100	100	100	100	100	0	0	0	0	100	0
12	100	100	100	100	100	100	0	0	0	0	100	0
13	83	83	74	74	74	74	0	0	0	0	79	0
14	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0
20	50	50	1	1	1	1	0	0	0	0	42	0
21	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0
28	0	0	0	0	0	0	0	0	0	0	0	0
29	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0
Avg	43	43	40	40	40	40	0	0	21	0	21	0
n	31	31	31	31	31	31	31	31	31	31	31	31
SD	48	48	47	47	47	47	0	0	40	0	38	0
Min	0	0	0	0	0	0	0	0	0	0	0	0
Max	100	100	100	100	100	100	0	0	100	0	100	0

APPENDIX F. BIOMATERIALS CHARACTERISTICS.

Table F1. New litter (ricehulls) characteristics (mean ± SD).

House	Date	n	Date	Percent (wet weight basis)	
				TKN	Solids
10	1/5/08	3	1/5/08	0.52 ± 0.02	91.0 ± 0.52
12	1/5/08	3	1/5/08	0.41 ± 0.01	92.1 ± 0.76
10	6/12/08	2	6/12/08	0.39 ± 0.07	92.8 ± 0.42
12	6/12/08	2	6/12/08	0.61 ± 0.30	93.3 ± 0.35

Table F2. Floor litter characteristics (mean ± SD).

House	Date	n	Percent (wet weight basis)		
			Sulfur	Solids	Ammonia
10	4/4/08	16	N/A	74.4 ± 6.80	0.40 ± 0.09
10	6/19/08	16	N/A	88.6 ± 1.33	0.18 ± 0.09
10	6/26/08	16	N/A	87.4 ± 2.01	0.15 ± 0.08
10	7/3/08	16	N/A	83.8 ± 2.71	0.21 ± 0.07
10	7/9/08	16	N/A	80.0 ± 7.23	0.30 ± 0.13
10	7/18/08	16	N/A	74.8 ± 5.65	0.33 ± 0.06
10	7/25/08	16	N/A	74.6 ± 5.16	0.40 ± 0.13
10	11/20/08	16	N/A	65.3 ± 9.95	0.40 ± 0.08
10	1/15/09	16	N/A	56.8 ± 9.10	0.40 ± 0.10
10	2/17/09	16	N/A	82.6 ± 3.63	0.20 ± 0.11
10	2/25/09	16	N/A	82.3 ± 3.05	0.21 ± 0.09
10	3/3/09	16	N/A	74.2 ± 10.1	0.24 ± 0.06
10	3/12/09	16	0.26 ± 0.05	60.0 ± 11.8	0.39 ± 0.10
10	3/20/09	16	0.24 ± 0.04	64.2 ± 11.3	0.34 ± 0.07
10	3/26/09	16	N/A	60.5 ± 12.0	0.41 ± 0.08
10	8/27/09	12	0.24 ± 0.04	73.4 ± 9.52	0.34 ± 0.09
12	4/4/08	16	N/A	70.9 ± 5.28	0.36 ± 0.06
12	6/19/08	16	N/A	86.5 ± 15.1	0.16 ± 0.09
12	6/26/08	16	N/A	87.5 ± 2.59	0.16 ± 0.08
12	7/3/08	16	N/A	86.7 ± 1.25	0.22 ± 0.05
12	7/9/08	16	N/A	81.4 ± 3.78	0.22 ± 0.03
12	7/18/08	16	N/A	73.1 ± 7.79	0.32 ± 0.07
12	7/25/08	16	N/A	70.1 ± 10.7	0.62 ± 0.38
12	11/20/08	16	N/A	69.0 ± 7.90	0.38 ± 0.10
12	1/15/09	16	N/A	57.1 ± 11.1	0.39 ± 0.13
12	2/17/09	16	N/A	83.5 ± 3.58	0.20 ± 0.13
12	2/25/09	16	N/A	82.4 ± 3.97	0.21 ± 0.09
12	3/3/09	16	N/A	73.1 ± 10.8	0.22 ± 0.06
12	3/12/09	16	0.25 ± 0.04	60.4 ± 10.8	0.39 ± 0.11
12	3/20/09	16	0.25 ± 0.04	69.0 ± 13.2	0.34 ± 0.08
12	3/26/09	16	N/A	64.2 ± 14.1	0.47 ± 0.16
12	8/27/09	20	0.25 ± 0.04	73.1 ± 10.8	0.34 ± 0.15

Table F3. Decaked litter characteristics (mean ± SD).

House	Date	n	Percent (wet weight basis)		
			TKN	Solids	Ash
10	01/02/08	12	2.38 ± 0.11	53.6 ± 5.05	N/A
10	02/27/08	12	2.19 ± 0.24	55.3 ± 5.77	N/A
10	06/07/08	12	2.84 ± 0.26	67.3 ± 3.54	N/A
10	08/01/08	12	2.55 ± 0.32	71.7 ± 5.86	N/A
10	12/03/08	12	1.89 ± 0.23	53.1 ± 8.57	12.7 ± 1.99
10	01/26/09	12	1.89 ± 0.22	54.1 ± 3.88	13.3 ± 1.71
10	05/27/09	12	2.41 ± 0.32	54.3 ± 6.44	13.7 ± 1.30
10	07/21/09	12	2.48 ± 0.16	55.9 ± 5.86	12.7 ± 1.77
12	01/02/08	12	2.47 ± 0.17	62.0 ± 6.20	N/A
12	02/27/08	12	2.09 ± 0.31	56.9 ± 6.22	N/A
12	06/07/08	12	2.82 ± 0.43	68.5 ± 5.29	N/A
12	08/01/08	12	2.50 ± 0.53	70.5 ± 7.90	N/A
12	12/03/08	12	1.78 ± 0.20	49.2 ± 4.30	12.6 ± 1.59
12	01/26/09	12	1.82 ± 0.26	51.9 ± 6.60	14.3 ± 2.95
12	05/27/09	12	2.56 ± 0.24	60.7 ± 7.87	15.2 ± 1.31
12	07/21/09	12	2.36 ± 0.20	52.5 ± 4.25	11.6 ± 1.49

Table F4. Loadout litter characteristics (mean ± SD).

House	Date	n	Percent (wet weight basis)	
			TKN	Solids
10	04/15/08	12	2.38 ± 0.33	71.1 ± 7.30
10	09/25/08	12	2.52 ± 0.50	66.6 ± 6.91
10	03/26/09	12	1.74 ± 0.18	59.7 ± 7.76
10	09/13/09	12	2.25 ± 0.26	-
12	04/15/08	12	2.88 ± 0.58	72.5 ± 4.14
12	09/25/08	12	2.47 ± 0.37	71.1 ± 5.26
12	03/26/09	12	2.08 ± 0.34	62.7 ± 6.13
12	09/13/09	12	2.15 ± 0.39	-

FINAL PROJECT REPORT
On Southeastern Broiler Gaseous and Particulate Matter Emissions Monitoring

FINAL PROJECT REPORT

on

Southeastern Broiler Gaseous and Particulate Matter Emissions Monitoring

Submitted to

Tyson Foods Inc.

by

Iowa State University

and

University of Kentucky

Key Project Personnel:

Dr. Robert T. Burns, Iowa State University
Dr. Hongwei Xin, Iowa State University
Dr. Richard S. Gates, University of Illinois (formerly University of Kentucky)
Dr. Hong Li, Iowa State University
Ms. Lara B. Moody, Iowa State University
Dr. Douglas G. Overhults, University of Kentucky
Mr. John W. Earnest, University of Kentucky
Dr. Steve J. Hoff, Iowa State University
Dr. Steven Trabue, USDA-ARS

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Executive Summary

This report describes the measurement methodologies and results of gaseous and particulate matter (PM) emissions (ammonia, carbon dioxide, hydrogen sulfide, non-methane hydrocarbon or NMHC, total suspended particulate or TSP, PM_{10}, and $PM_{2.5}$) from two typical Tyson broiler production houses located on two separate farm sites in western Kentucky. Each broiler house was 43 ft x 510 ft (13 m x 155 m), with an initial, nominal placement of 25,800 (winter) to 24,400 (summer) Cobb-Cobb straight-run broilers per flock. The broilers were grown on new or built-up litter to an average age of 52 d (50 - 54 d), with flock downtime (i.e., empty house) ranging from 9 to 41 d.

Two state-of-the-art environmentally-controlled mobile air emissions monitoring units, one for each site, were used for the year-round, continuous measurements. The instruments used to measure the concentrations of the aerial constituents in the background and exhaust air of the broiler houses included a photoacoustic multi-gas analyzer for ammonia (NH_3) and carbon dioxide (CO_2), a UV pulsed-fluorescence analyzer for H_2S, a dual-channel methane/NMHC/total hydrocarbon analyzer with a dual flame ionization detector (FID) for NMHC, and tapered element oscillating microbalances (TEOMs) for TSP, PM_{10} and $PM_{2.5}$. Building ventilation rate (VR) was measured by precisely monitoring building static pressure and operation time (1 s sampling interval) of all exhaust fans. The performance of each fan was carefully calibrated *in-situ* with a state-of-the-art ventilation fan calibration device, known as the Fan Assessment Numeration System or FANS. The emission rate (ER) was then determined based on the measured concentration difference between exhaust air and incoming air and the corresponding VR, with corrections for air temperature, air density, and barometric pressure effects. Operation and maintenance of the monitoring instruments and collection and management of the data followed the protocols as set forth in an EPA-approved Category I Quality Assurance Project Plan (QAPP). A particularly noteworthy aspect of the QAPP was the component error analysis that revealed the uncertainty of the measured air emission values to be less than 10% under the monitoring conditions.

The gaseous and PM emissions were monitored quasi-continuously at 2 to 6 min intervals over a 13-month time period, covering nearly six consecutive flocks per house. Consequently, the amount of emission data collected for each constituent, expressed in house-day, was 718 for NH_3, 616 for H_2S, 471 for NMHC, 602 for TSP, 596 for PM_{10}, 578 for $PM_{2.5}$, and 714 for CO_2.

The gaseous and PM emissions from the broiler houses were expressed in various units to meet different purposes of the data application, as follows: 1) annual total emission per house, 2) annual average emission per 1,000 birds or per bird marketed, 3) annual average emission per animal unit (AU = 500 kg or 1100 lb live body weight) marketed and 4) daily mean emission per house. All values included emissions during the period between flocks or downtime. In addition, regression equations were developed to relate gaseous and PM ER to broiler age. The respective emission values (mean ± standard deviation) were:

1) Annual total emission per house (mean ± S.E.): 5.1 ± 0.19 US tons (4,620 ± 171 kg) NH_3, 42.3 ± 2.1 lb (19.2 ± 0.92 kg) H_2S, 510 lb ± 59.6 (231 ± 27 kg) NMHC, 1,731 ± 58.6 lb (785 ± 26.6 kg) TSP, 727 ± 93.4 lb (330 ± 42.3 kg) PM_{10}, 71.7 ± 4.4 lb (32.5 ± 2.0 kg) $PM_{2.5}$, and 718 ± 21.6 US ton (651 ± 9.8 metric ton) CO_2.

2) Annual average emission per 1,000 birds marketed (mean ± S.E.): 78.1 ± 3.1 lb NH_3, 0.32 ± 0.01 lb H_2S, 3.9 ± 0.45 lb NMHC, 13.2 ± 0.46 lb TSP, 5.56 ± 0.71 lb PM_{10}, 0.55 ± 0.04 lb $PM_{2.5}$, and 5.49 ± 0.16 US ton CO_2. Expressed on a per-bird-marketed basis, the annual average emissions were: 35.4 ± 1.32 g NH_3, 0.147 ± 0.01 g H_2S, 1.77 ± 0.21 g NMHC, 6.01 ± 0.21 g TSP, 2.52 ± 0.33 g PM_{10}, 0.25 ± 0.01 g $PM_{2.5}$, and 4.98 ± 0.15 kg CO_2.

3) Annual average emission per 500 kg AU marketed (mean ± S.E.): 6.25 ± 0.23 kg of NH_3, 26.0 ± 1.26 g of H_2S, 0.29 ± 0.03 g NMHC, 1.06 ± 0.04 kg TSP, 0.45 ± 0.06 kg PM_{10}, 0.044 ± 0.003 kg $PM_{2.5}$, and 881 ± 26.5 kg CO_2.

4) Daily mean emission per house (mean ± S.D.): 31.4 ± 14.9 lb (14.2 ± 6.8 kg) NH_3, 0.14 ± 0.09 lb (65.7 ± 42 g) H_2S, 1.68 ± 0.94 lb (0.8 ± 0.4 kg) NMHC, 6.13 ± 4.13 lb (2.78 ± 1.87 kg) TSP, 2.57 ± 1.88 lb (1.16 ± 0.85 kg) PM_{10}, 0.25 ± 0.22 lb (0.11 and 0.10 kg) $PM_{2.5}$, 2.55 ± 1.32 us-ton (2.31 ± 1.2 mton) CO_2. For the downtime between flocks, the daily mean emission per house were: 18.5 ± 17.8 lb (8.39 ± 8.1 kg) NH_3, 0.020 ± 0.028 lb (9.0 ± 12.5 g) H_2S, 0.45 ± 0.64 lb (0.2 ± 0.3 kg) NMHC, 0.12 ± 0.19 lb (0.05 ± 0.086 kg) TSP, 0.052 ± 0.085 lb (0.024 ± 0.039 kg) PM_{10}, 0.03 ± 0.06 lb (0.014 ± 0.027 kg) $PM_{2.5}$, 0.21 ± 0.20 US-ton (0.19 ± 0.18 metric ton) CO_2.

To improve convenience of reading and application, we have presented the emissions data in a summary table (Table I). The data from this comprehensive and extensive monitoring of broiler production houses are expected to enhance the national emissions inventory on animal feeding operations.

Table I. Summary of air emissions from two commercial broiler houses in western Kentucky continually monitored over a 13-month period involving nearly 6 consecutive flocks (mean ± S.E. or S.D.)

Emission Values	Gaseous and Particulate Matter Constituents						
	NH_3	$_2S$	NMHC	TSP	PM_{10}	$PM_{2.5}$	CO_2
Annual Total per House (± S.E.)	5.1 ± 0.19 US ton (4620 ± 171 kg)	42.3 ± 2.1 lb (19.2 ± 0.92 kg)	510 lb ± 59.6 lb (231 ± 27.0 kg)	1731 ± 58.6 lb (785 ± 26.6 kg)	727 ± 93.4 lb (330 ± 42.3 kg)	71.7 ± 4.4 lb (32.5 ± 2.0 kg)	718 ± 21.6 US ton (651 ± 9.8 metric ton)
Annual Average per 1,000 Birds Marketed (± S.E.)	**H** 78.1 ± 3.1 lb	0.32 ± 0.01 lb	3.9 ± 0.45 lb	13.2 ± 0.46 lb	5.56 ± 0.71 lb	0.55 ± 0.04 lb	5.49 ± 0.16 US ton
Annual Average per Bird Marketed (± S.E.)	35.4 ± 1.32 g	0.147 ± 0.01 g	1.77 ± 0.21	6.01 ± 0.21 g	2.52 ± 0.33 g	0.25 ± 0.01 g	4.98 ± 0.15 kg
Annual Average per AU Marketed (± S.E.)	6.25 ± 0.23 kg	26.0 ± 1.26 kg	0.29 ± 0.03 kg	1.06 ± 0.04 kg	0.45 ± 0.06 kg	0.044 ± 0.003 kg	881 ± 37.5 kg
Daily Mean per House (± S.D.)	31.4 ± 14.9 lb (14.2 ± 6.8 kg)	0.14 ± 0.09 lb (65.7 ± 42 g)	1.68 ± 0.94 lb (0.8 ± 0.4 kg)	6.13 ± 4.13 lb (2.78 ± 1.87 kg)	2.57 ± 1.88 lb (1.16 ± 0.85 kg)	0.25 ± 0.22 lb (0.11 ± 0.1 kg)	2.55 ± 1.32 US ton (2.31 ± 1.2 metric ton)
Downtime Daily Mean per House (± S.D.)	18.5 ± 17.8 lb (8.39 ± 8.1 kg)	0.02 ± 0.028 lb (9.0 ± 12.5 g)	0.45 ± 0.64 lb (0.2 ± 0.3 kg)	0.12 ± 0.19 lb (0.05 ± 0.086 kg)	0.052 ± 0.085 lb (0.024 ± 0.039 kg)	0.03 ± 0.06 lb (0.014 ± 0.027 kg)	0.21 ± 0.20 US ton (0.19 ± 0.18 metric ton)

NMHC = non-methane hydrocarbon; TSP = total suspended particulate, AU = animal unit = 500 kg live body weight

Introduction

According to recent estimates by EPA (2005), broiler operations constitute 54% of poultry contributions to the U.S. ammonia inventory, and 14.8% of animal agriculture emissions. A comprehensive review by the National Academy of Science (NAS) (National Research Council, 2003) regarding air emissions data pertaining to U.S. animal feeding operations (AFOs) concluded that such data are lacking for U.S. animal production conditions. The review called for collection of baseline emission data and development of process-based models to predict such air emissions. In response to the NAS recommendations, the United States Department of Agriculture (USDA) has made quantification of air emissions from AFOs one of the top priorities in its Initiative for Future Agriculture and Food System (IFAFS) Program and subsequently the National Research Initiative (NRI) Program. As a result, since 2002 great strides have been made toward collection of baseline air emissions from U.S. AFO facilities. Noticeable among the funded studies was the six-state (IA, IN, IL, MN, NC, TX) project on air emissions from cattle and swine facilities, and the three-state (IA, KY and PA) project on ammonia emissions from layers (in Iowa and Pennsylvania; Liang et al., 2005) and broilers (in Kentucky and Pennsylvania; Wheeler et al., 2006). There is a lack of air emissions (except for ammonia) data for broiler housing systems. During this time period, more research findings on ammonia emissions from European broiler houses have been reported (Nicholson et al., 2004). However, with the exception of the study by Lacey et al. (2003), information regarding emission rates of particulate matter (PM), hydrogen sulfide (H_2S) and nonmethane hydrocarbons (NMHC) from broiler houses remains meager.

The objective of this study was to determine and report air emissions based on continuous measurement of aerial pollutant concentrations and fan airflow data over a one-year period from two broiler houses representative of commercial broiler production in the southeastern United States. The aerial pollutants quantified in this monitoring study include ammonia (NH_3), carbon dioxide (CO_2), H_2S, NMHC, total suspended particulate (TSP), PM with aerodynamic diameter $\leq$ 10 μm (PM_{10}), and PM with aerodynamic diameter $\leq$ 2.5 μm ($PM_{2.5}$). The emissions data presented in this report were collected using continuous air emissions monitoring over a 13-month period at two Tyson broiler production houses in western Kentucky.

Monitoring System Description

Study Sites and Monitoring System Overview

Two broiler houses, located on two different sites (40 miles or 64 km apart), associated with Tyson Foods broiler operations in western Kentucky were selected. Their locations are shown in Figure 1, and the location of the specific house at each site is shown in aerial photos in Figure 2. The monitored broiler production houses used tunnel ventilation and static pressure controlled box air inlets along the sidewalls (Figure 3), which are representative of the typical production practices in terms of housing style (tunnel ventilation) and environmental control strategy (pancake brooders along with space heaters), bird management (half-house brooding), and litter management and handling schemes (de-caking of litter between flocks and annual litter removal).

To continuously quantify dynamic air emissions from the broiler production systems, an accurate and responsive measurement system was required. The mass of air pollutants emitted from a facility is the product of the pollutant concentration difference between outgoing and incoming air streams and volume of air exchanged through the facility. The use of intermittent ventilation by cycling ventilation fans off and on, especially when the birds were young, made it necessary to coincide in-house pollutant concentrations to periods of fan operation in order to properly capture the representative emissions.

Concentrations of the gaseous and PM constituents were measured with the following instruments: photoacoustic NH_3 and CO_2 analyzer (0-2000 ppm ± 1% NH_3; 0-34000 ppm ± 1% CO_2; INNOVA model 1412, INNOVA AirTech Instruments A/S, Denmark[1]), UV pulsed-fluorescence H_2S analyzer (0-20000 ppb ± 0.5%; Model 101E, Teledyne API, San Diego, CA), dual-channel methane/NMHC/total hydrocarbon analyzer with a dual flame ionization detector (FID) (0-100 ppm ± 1%; Model 200, VIG Industries Inc., Anaheim, CA), and Tapered Element Oscillating Microbalance (TEOM) PM monitors (0-10,000 ± 5 ug/m^3; Model 1400a, Thermo Fisher Scientific, Waltham, MA). The gaseous and PM analyzers were used in conjunction with a custom-fabricated multi-point sampling and data acquisition system. Building ventilation rate of the exhaust air was based on individual fan performance curves obtained on-site using the Fan Assessment Numeration System (FANS) developed in the US (Gates et al., 2004).

Each broiler house had its own Mobile Air Emissions Monitoring Unit (MAEMU) that housed the gaseous and PM concentration measurement and fan flow monitoring systems, and provided an environment-controlled space (Figure 4). Air sampling lines from the broiler house sampling points (representing the building exhaust air streams) to the MAEMU/analyzers were protected against in-line moisture condensation with insulation and temperature-controlled resistive heating cable. Fan operational status and building static pressure were both continuously monitored (1-second intervals). These data were used in conjunction with individual fan operation curves to calculate the exhaust ventilation rate by each fan during operation. A real-time data acquisition system (DAQ) program was developed using LabView 7 software (National Instruments Corporation, Austin, TX) and used to acquire data, automate control of sampling locations, display real-time data, and deliver data and system operation status (Figures 5 and 6). The system was connected to the internet via a high-speed satellite. Each MAEMU housed a gas sampling system (GSS), gas analyzers, environmental instrumentation, a computer, data acquisition system, and other peripheral devices and equipment needed for the study. Gaseous emissions were sampled continuously at 120-second intervals. NH_3 and CO_2 samples were continuously collected and analyzed every 30 seconds, with every fourth concentration value used as the stabilized reading in the emission calculation. PM concentrations were recorded at 300-s intervals. Emissions were calculated using the concentrations measured when the house ventilation system was in operation. Complete details of the monitoring system and data collection are described below.

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[1] Mention of product or company names is for presentation clarity and does not imply endorsement by the authors or their affiliation not exclusion of other suitable products.

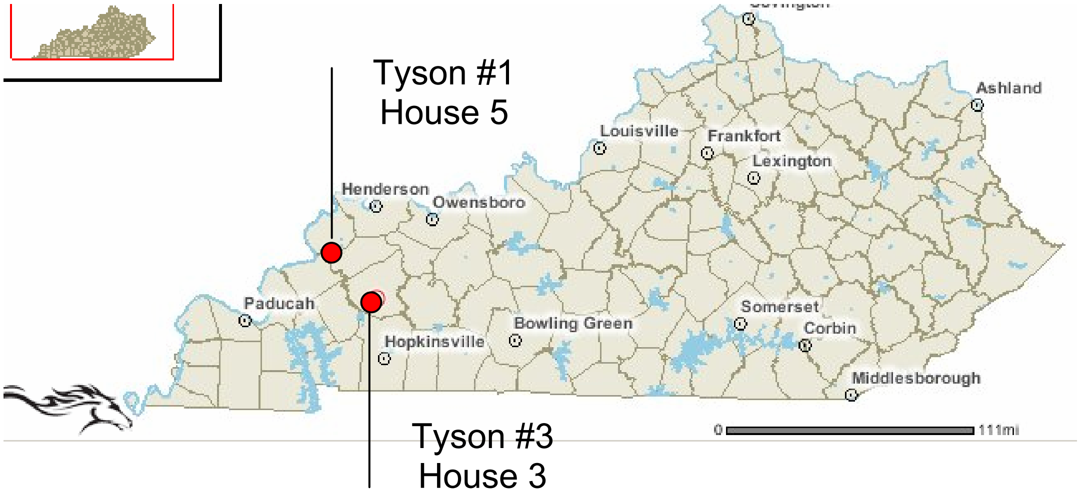


Figure 1. Broiler house air emission measurement sites in Kentucky.

Figure 2. Aerial photos indicating the locations of each monitored broiler house.

Figure 3. Tunnel ventilation fans and static pressure-controlled box air inlets representative of typical southeastern U.S. broiler facilities.

Figure 4. Environmentally-controlled Mobile Air Emissions Monitoring Units (MAEMU).

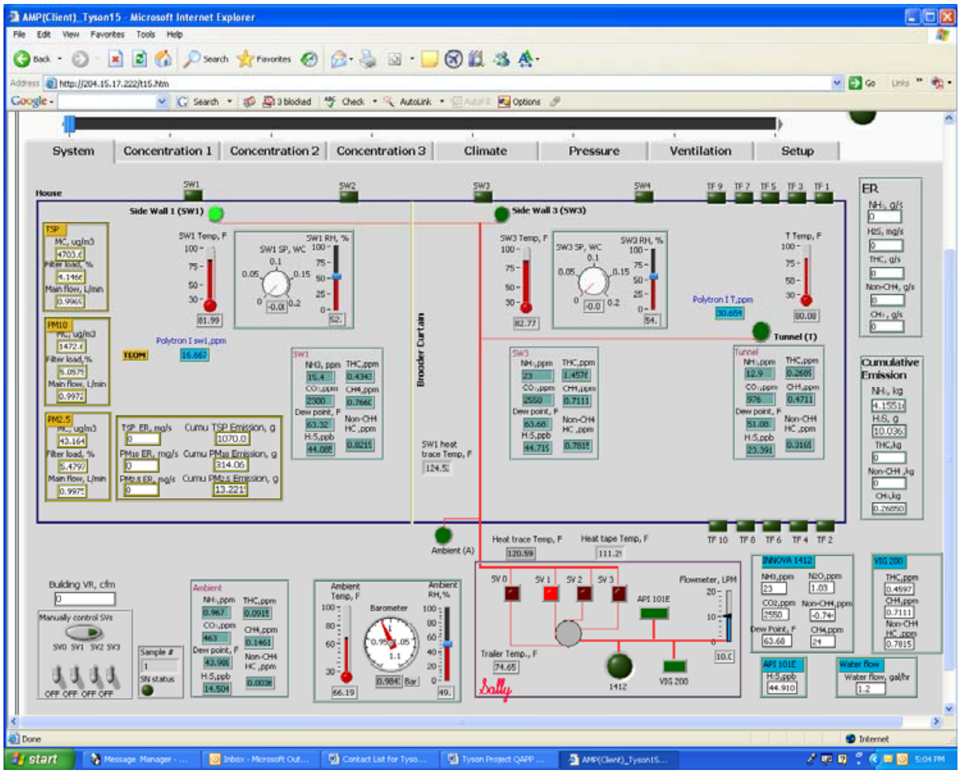


Figure 5. Screen display of the broiler emissions monitoring program developed in LabView 7.

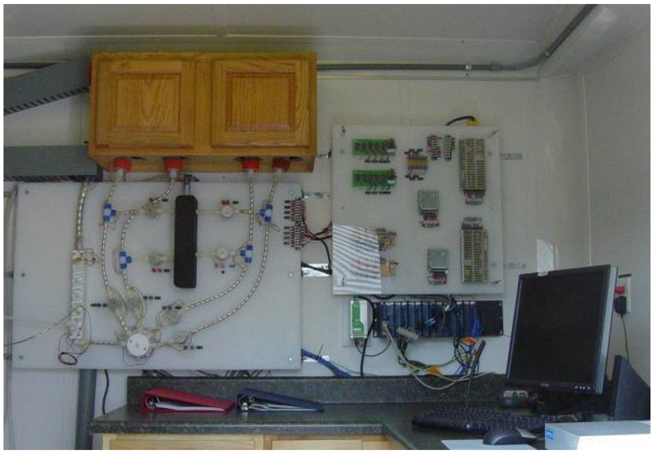


Figure 6. Photograph of the positive-pressure gas sampling system used in the study.

Broiler House Characteristics

The two broiler houses each measured 43 ft x 510 ft (13.1 m x 155.5 m) and were built in the early 1990s. Each houses had insulated drop ceilings (about R19), box air inlets (6 x 26 inch or 15 x 66 cm) along the sidewalls (26 per sidewall), 26 pancake brooders (30,000 Btu/hr or 8.8 kW each), three space furnaces (225,000 Btu/hr or 65.9 kW each), four 36-inch (91-cm) diameter sidewall exhaust fans spaced about 120 ft (36.6 m) apart, and ten 48-inch (123-cm) diameter tunnel fans. One 36-inch (91-cm) fan (SW1) used for minimum ventilation was located in the brooding end of the house. Two 80-ft (24-m) sections of evaporative cooling pads were located in the opposite end from the tunnel fans. The houses were also equipped with foggers for additional cooling, if needed. Rice hulls were used as litter bedding in both houses.

Flock Characteristics

The sampling periods were 13 months (Feb 14, 2005 to March 14, 2007) and 12.5 months (Feb 20, 2005 to March 5, 2007) for Tyson 1-5 and Tyson 3-3, respectively. The 13 month duration assured that the project characterized long-term emissions, hence the impacts of climatic conditions of different seasons and grow-out cycles (litter age and condition). At the ending dates, six full flocks had been monitored from Tyson 1-5 and the sixth flock was ongoing for Tyson 3-3 (Table 1). Each house had an initial, nominal placement of 25,800 Cobb-Cobb straight-run (mixed sex) broilers in winter and 24,400 in summer. The average grow-out period was 52 days. An automatic bird weigh-scale system (Model RSC-2, Rotem, Petach Tikva, Israel) was placed in each house to continuously monitor bird body weight. Bird mortality was also recorded, allowing for expression of emission on the basis of per bird or per 500 kg animal unit (AU). Both houses had new bedding at the beginning of monitoring. During the one-year period, one cleanout of the litter was performed for Tyson 1-5 on Aug 26, 2006 (after 3 flocks) and new bedding was placed on Aug 29, 2006; Tyson 3-3 had a litter cleanout after 5 flocks (on Feb 3, 2007) and new bedding was placed (on Feb 5, 2007).

Table 1. Description of flock and downtime (empty house between flocks) information during the aerial emissions monitoring study

	Start Date	End Date	Flock No.	House Condition	Litter condition*	# of birds placed	Total # of days	Complete-data days (CDD)						
								NH_3	CO_2	H_2S	NMHC	TSP	PM_{10}	$PM_{2.5}$
Tyson 1-5	2/14/2006	4/4/2006	1	Occupied	BUL	25,830	50	50	50	50	29	48	48	48
	4/5/2006	4/20/2006		Empty	BUL		16	14	14	14	4	6	6	6
	4/21/2006	6/9/2006	2	Occupied	BUL	22,995	50	50	50	50	41	48	46	48
	6/10/2006	6/21/2006		Empty	BUL		12	11	11	10	11	6	0	5
	6/22/2006	8/10/2006	3	Occupied	BUL	24,465	50	50	50	27	17	45	47	33
	8/11/2006	9/4/2006		Empty	Mixed		25	24	24	9	17	4	4	0
	9/5/2006	10/25/2006	4	Occupied	NB	25,695	51	51	51	51	49	48	48	44
	10/26/2006	11/16/2006		Empty	BUL		22	21	21	21	20	2	2	2
	11/17/2006	1/9/2007	5	Occupied	BUL	25,080	54	50	50	50	46	46	46	42
	1/10/2007	1/21/2007		Empty	BUL		12	12	12	12	11	5	2	5
	1/22/2007	3/14/2007	6	Occupied	BUL	26,600	52	48	48	48	23	46	46	46
Tyson 3-3	2/20/2006	4/10/2006	1	Occupied	BUL	25,515	50	44	44	19	24	46	46	46
	4/11/2006	5/21/2006		Empty	BUL		41	39	39	15	16	21	21	21
	5/22/2006	7/11/2006	2	Occupied	BUL	24,450	51	48	48	32	33	46	46	46
	7/12/2006	7/27/2006		Empty	BUL		16	15	15	8	1	8	8	8
	7/28/2006	9/19/2006	3	Occupied	BUL	24,380	54	53	53	46	30	51	51	51
	9/20/2006	10/4/2006		Empty	BUL		15	14	14	14	10	8	8	8
	10/5/2006	11/27/2006	4	Occupied	BUL	25,778	54	53	49	49	34	52	52	50
	11/28/2006	12/13/2006		Empty	BUL		16	14	14	14	8	5	8	8
	12/14/2006	2/2/2007	5	Occupied	BUL	24,970	51	27	27	47	32	47	47	47
	2/3/2007	2/11/2007		Empty	BUL		9	8	8	8	5	3	3	3
	2/12/2007	3/5/2007	6	Occupied	NB	26,013	22	22	22	22	10	11	11	11

* NB= New bedding; BUL= Built-up litter

Monitoring System Specifics

Concentrations of NH_3 and CO_2 for the background (or incoming air) and exhaust air were measured with an advanced photoacoustic multi-gas analyzer (INNOVA model 1412, INNOVA AirTech Instruments A/S, Denmark), an EPA-accepted measurement instrument for AFO NH_3 emission monitoring. This type of analyzer has been widely used by European scientists and recently used by U.S. scientists in AFO air emission studies (Fergusun et al. 1998ab, Fenyvesi, et al., 2001, Nicks et al., 2003, Guarino et al., 2003, Li, 2006,). These units proved to be accurate, responsive and stable. The INNOVA 1412 multi-gas analyzer was setup with a 1-second (s) sampling integration time and fixed flushing time: 2 s for the chamber and 3 s for the tubing; the required time to complete one sampling cycle for NH_3, CO_2 and dew-point temperature measurements was approximately 22 s. The response time of the analyzer to step changes in gas concentrations was tested extensively. The response time for the measured concentration to reach 98% of the calibration gas value (T-98) for the given NH_3 calibration gas was 88 seconds using NH_3 calibration gas of both 22.8 and 60.8 ppm (±2% accuracy) (Matheson Gas Products, Inc., Montgomeryville, PA). Thus, four measurement cycles (88 seconds) were required to reach the 98% response level for NH_3. Using this approach, the first three readings were discarded and only the fourth reading was used for emission calculations. In April 2006, hydrocarbon and nitrous oxide (N_2O) filters were added to the INNOVA 1412. The time to complete a single measurement cycle was increased from 22 s to 30 s. In turn, this increased the time to complete four cycles from 88 s to 120 s. As practiced before, only the fourth cycle measurements were used for the emissions calculations.

The UV pulsed fluorescence H_2S analyzer (Model 101E, Teledyne API, San Diego, CA) is a microprocessor controlled analyzer that determines the concentration of H_2S in a sample of gas drawn through the instrument. It requires that sample gases be supplied at ambient atmospheric pressure in order to establish a constant gas flow through the sample chamber. The 98% response time of the API 101E is 96 s. According to the response time of INNOVA 1412, the last H_2S readings correlated to the four INNOVA cycles were used for the H_2S emission calculation.

A VIG model 200 methane/nonmethane/total hydrocarbon analyzer (Model 200, VIG Industries Inc., Anaheim, CA) uses column technology to separate methane and non-methane from total hydrocarbons and uses a dual FID (flame ionization detectors) to measure each component in the air sample. The response time of NMHC is 70 s, and the NMHC reading was updated every 3 minutes. Every NMHC reading from the VIG 200 analyzer was identified with the corresponding sampling location and used for the emission calculation.

Air samples were drawn from three locations in each house as well as from an outside location to provide the ambient background data (Figure 7). One sampling location was near the primary minimum ventilation (36-in) sidewall fan (SW1) used for cold weather ventilation (in the brooding half of the house). The second sampling location was near the third sidewall (36-in) fan (SW3, non-brooding end). The third location was at the tunnel end (TE). The ambient sample location (A) was between the inlet boxes opposite of the sidewall with the exhaust fans. The mass of pollutant in the background (inlet) air was subtracted from that in the exhaust air when calculating aerial emissions from the house.

Placement of the air sampling ports was as follows: for the two sidewall sampling locations, the sampling ports and temperature sensors were located 4 ft (1.2 m) from the fan in the axial direction, 7.5 ft (2.3 m) in the radial direction, and 3 ft (1 m) above the floor. For the tunnel-end sampling location, the sampling port and temperature sensor were located at the center line of the house (i.e. 21.5 ft or 6.6 m from each sidewall) and 24 ft (7.3 m) from the end wall. Sampling locations and placement of the sampling ports were chosen to maximize representativeness of the air leaving the houses. Each sample inlet point was equipped with dust filters to keep large PM from plugging the sample tubing, servo valves, and the measurement instruments. Each sample port consisted of two separate filter inlets joined in a "tee" to provide redundancy in the event of filter clogging.

A positive pressure gas sampling system (PP-GSS) was used in the MAEMU for measurement of broiler house air emissions (Figure 8). The PP-GSS continuously pumps sample air from all locations using the location-designated individual pumps. The sample air was by-passed when not analyzed. The schedules of sampling events and sequences were as follows. If the ventilation fans at the three in-house sampling locations (SW1-location 1, SW3-location 2 and TE-location 3) were all running, air samples from each location were collected sequentially via the controlled operation of the servo valves of the PP-GSS. In this case, sampling/analysis sequence was SW1, SW3, TE, and then the cycle was repeated. If fans at SW3 or TE were not running (for example, during half-house brooding), sample analysis was repeated for the SW1 location only, and the same was true for TE sampling when fans at SW1 and SW3 were not running (for example, during tunnel ventilation mode). Every two hours, air samples from the ambient (background) location were collected and analyzed for 8 minutes. The longer sample analysis time for the ambient point was to account for the longer response time of the instrument when measuring a potentially large step change in gas concentration. Selection of the 2-hour interval for the analysis of the ambient concentrations was due to the fact that the ambient conditions remained relatively constant in comparison to the in-house conditions. This arrangement helped maximize the number of data points collected from the exhaust air and thus provided more data for determination of house emissions.

The PM mass concentration of the exhaust air was measured with the Rupprecht & Patashnick TEOM series 1400a monitor (Thermo Fisher Scientific, Waltham, MA) designated as Reference Method number EQPM-1090-79 as per 40 CFR Part 58. For measuring TSP, PM_{10}, and $PM_{2.5}$, three different inlet heads were used. The TEOM 1400a is a gravimetric instrument that draws ambient air through a filter at a constant flow rate, continuously weighing the filter and calculating near real-time (2 s) mass concentration. The mass concentration was calculated by an internal exponential smoothing algorithm based on the total mass loaded on the filter. The TEOMs, located inside the house, operated with the following parameters: a flow rate of 0.59 ft^3/min (0.035 ft^3/min main flow and 0.555 ft^3/min auxiliary flow) (a total of 16.7 L/min flow with 1 L/min main flow and 15.7 L/min auxiliary flow); 300 s averaging time for the total mass and mass rate/mass concentration; and 50°C sample stream temperature. The output of the mass concentration was based on a standard temperature and pressure of 25°C and 1 atmosphere (atm), respectively. The mass concentration was recorded at 1-s intervals and the average readings, which were correlated to the INNOVA 1412 sampling interval, were used for the PM emissions calculation.

Considerable discussion and investigation went into the placement of the TEOM PM samplers (TSP, PM_{10}, and $PM_{2.5}$) in the house. Since no data were available in terms of TEOM responses to different air velocity fields as would be encountered in the broiler houses, we conducted an in-house evaluation of the TEOM performance for air velocity ranging from 250 to 1200 ft/min (1.3 – 6 m/s). The results revealed that the TEOM readings were unaffected by the tested air velocity range. Prior to the TEOM tests, we had assumed continuity in PM concentrations from the center of the house to the exhaust. Since we were concerned that the TEOMs might not function properly under high velocity conditions near the exhaust fan, the TEOMs were located near the center, across the width of the house. Comparison of two TEOM readings near the building center versus near the exhaust fan revealed that concentrations near the exhaust were generally lower than concentrations near the building center. Since velocity showed no impact on the concentration measurement and we were to quantify the emissions leaving the house, we placed the TEOMs near the exhaust fan(s).

The specifics of final TEOM placement were as follows. During the half-house brooding period, the TEOMs were placed near SW1. The TSP TEOM was located 2 ft (0.6 m) from the fan in the axial direction, 3.5 ft (1.1 m) in the radial direction to the left of the fan, and 5 ft (1.5 m) above the floor. The PM_{10} TEOM was located 2 ft (0.6 m) from the fan in the axial direction, 3.5 (1.1 m) in the radial direction to the right of the fan, and 5 ft (1.5 m) above the floor. The $PM_{2.5}$ TEOM was located 2 ft (0.6 m) from the fan in the axial direction, 7 ft (2.2 m) in the radial direction to the right of the fan, and 5 ft (1.5 m) above the floor. Once the birds were released into the full house (between 10-14 days of age), the TEOMs were moved to the TE location. For the TE sampling location, the TSP TEOM was located 16 ft (4.9 m) from the tunnel fan in the axial direction, 36 ft (11 m) from the tunnel end of the house, and 5 ft (1.5 m) above the floor. The PM_{10} TEOM was located 16 ft (4.9 m) from tunnel the fan in the axial direction, 32 ft (9.8 m) from the tunnel end of the house, and 5 ft (1.5 m) above the floor. The $PM_{2.5}$ TEOM was located 16 ft (4.9 m) from the tunnel fan in the axial direction, 28 ft (8.5 m) from the tunnel end of the house, and 5 ft (1.5 m) above the floor. The TEOMs were placed outside the broiler houses to measure the ambient background PM concentrations at Tyson 1-5 from March 22 to April 21, 2007.

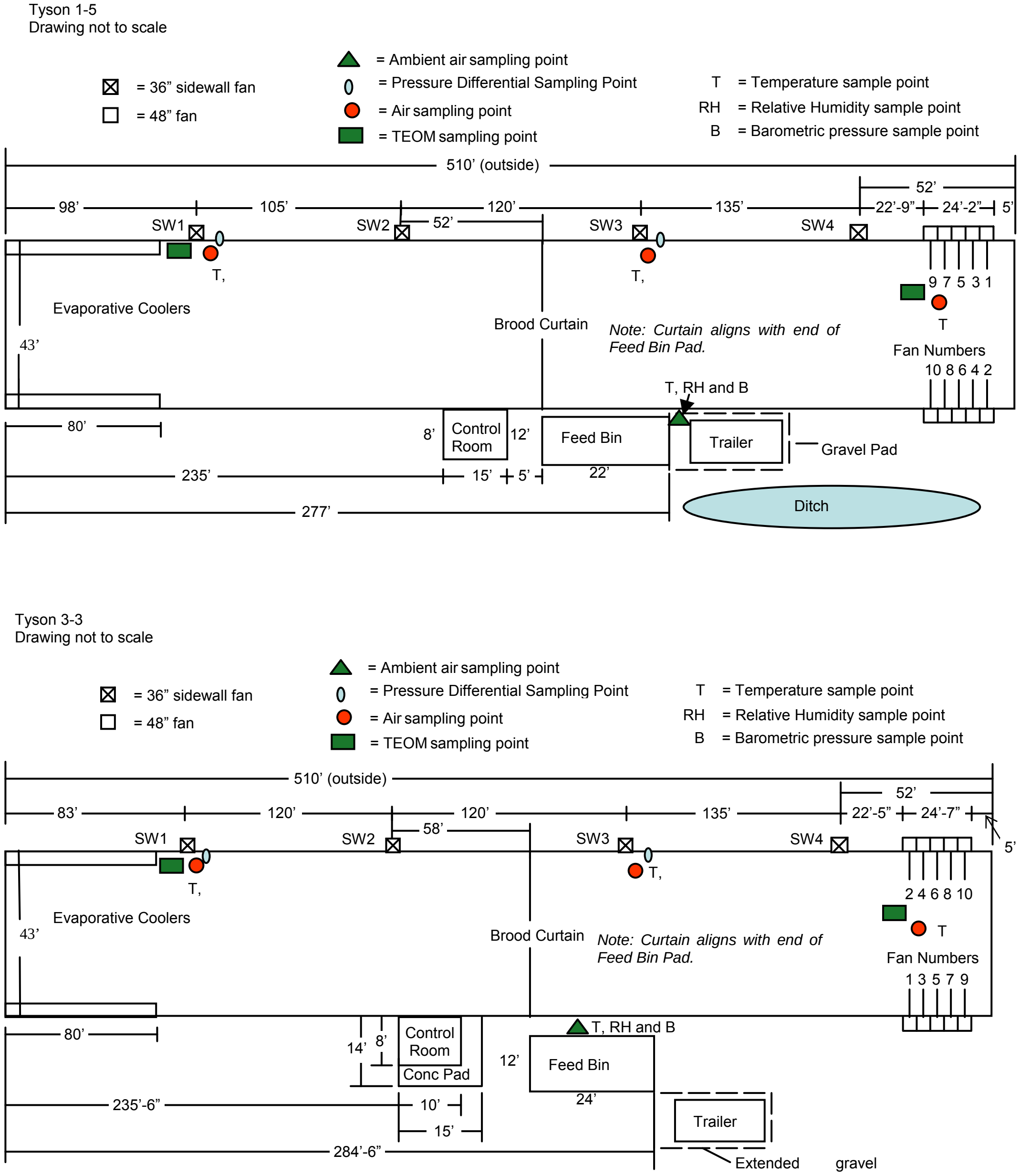


Figure 7. Schematic layout of Tyson 1-5 and Tyson 3-3 broiler houses.

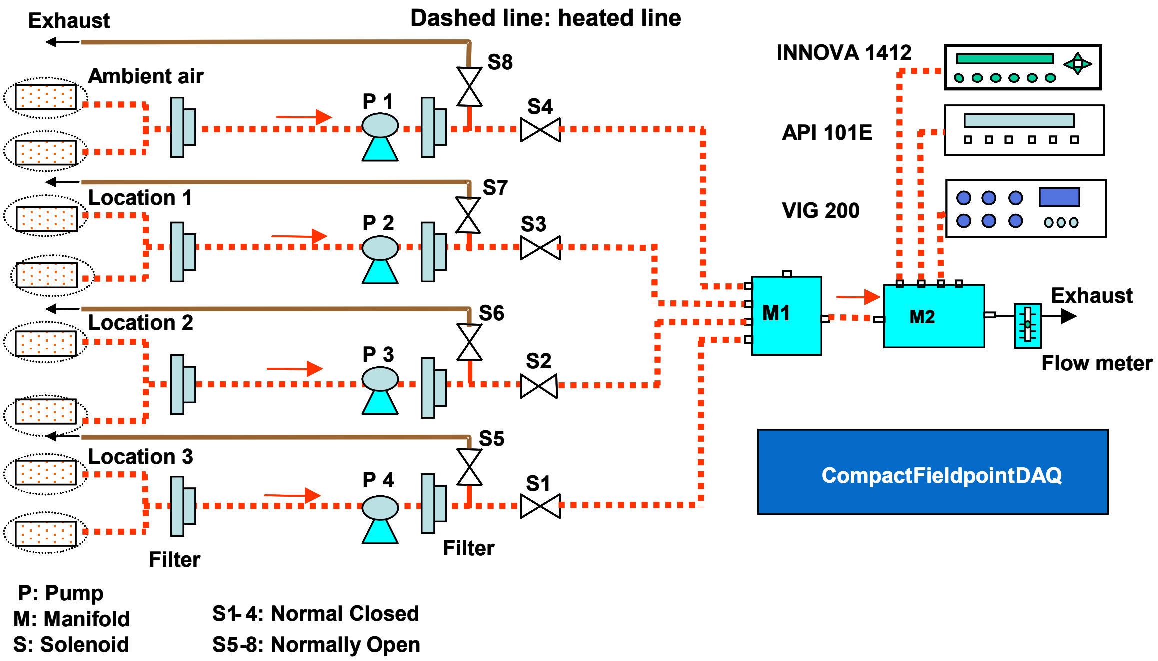


Figure 8. Schematic representation of the positive pressure gas sampling system (PP-GSS) used in the MAEMU for measurement of broiler house air emissions.

The PP-GSS continuously collected air from all locations with the location-specific pumps. Teflon tubing (Fluorotherm FEP tubing) of 3/8-inch (0.95-cm) o.d. and 1/4-inch (0.64-cm) i.d. was used to deliver the sample air. The sample air was by-passed when not analyzed. Use of individual pumps to continuously draw air from the respective sampling locations reduced line-purging time and eliminated possible cross-location residual effect, especially between ambient/background air and exhaust air samples. The choice of sequential sampling was based on the assumption that any concentration changes at the given location during the two adjacent measurements (maximum of 360 seconds) followed a linear pattern. Hence, linear interpolation from the two adjacent measured values was used to determine intermediate values for the location, as needed. The use of one sampling location at the tunnel fan end of the house assumed good mixing of air and thus uniform distribution of the aerial concentrations during tunnel ventilation conditions. Examination of ammonia concentrations across the house in this section, through concurrent measurements using four INNOVA 1412 analyzers, confirmed the validity of this assumption. Moreover, the vertical stratifications in aerial concentrations were measured and found to be negligible when the exhaust fans were in operation. Incidentally, appreciable vertical stratifications existed when the fans were off. Only samples collected when fans were operating were used for the calculation of ammonia emissions from the broiler houses.

Ventilation rates of the houses were measured using the following procedure. First, each exhaust fan was individually calibrated *in-situ* with a state-of-the-art fan assessment numeration system (FANS) to obtain the actual ventilation curves (airflow rate vs. static pressure) (Gates et al., 2004). This calibration was essential to the accurate measurement of the house ventilation rate because actual fan airflow rates can vary in excess of 25% from one another and from the nominal values supplied by the fan manufacturer (Figure 9). The deviation arises from the field operational conditions that differ drastically from those under which the default values were established, for example, loose motor belts, and dirty shutter or fan blades. After the actual airflow curves were established for all of the exhaust fans and their combinations, runtime of each fan was monitored using an inductive current switch (with analog output) attached to the power supply cord of each fan motor (Figure 10). Analog output from the current switches was connected to the compact Fieldpoint modules. Concurrent measurement of each house static pressure was made with two static pressure sensors (Model 264, Setra, Boxborough, MA), each for half of the house. While the static pressure was not expected to differ at the two locations, two sensors were used to provide redundancy in this critical measurement. Summation of airflows from the individual fans during each monitoring cycle or sampling interval produced the overall house ventilation rate. This method of determining dynamic ventilation rates of mechanically ventilated animal confinement has been successfully used in recent AFO air emission studies in the United States (Liang et al, 2005; Wheeler et al. 2006). Fan runtime and static pressure was recorded continuously (1-second intervals).

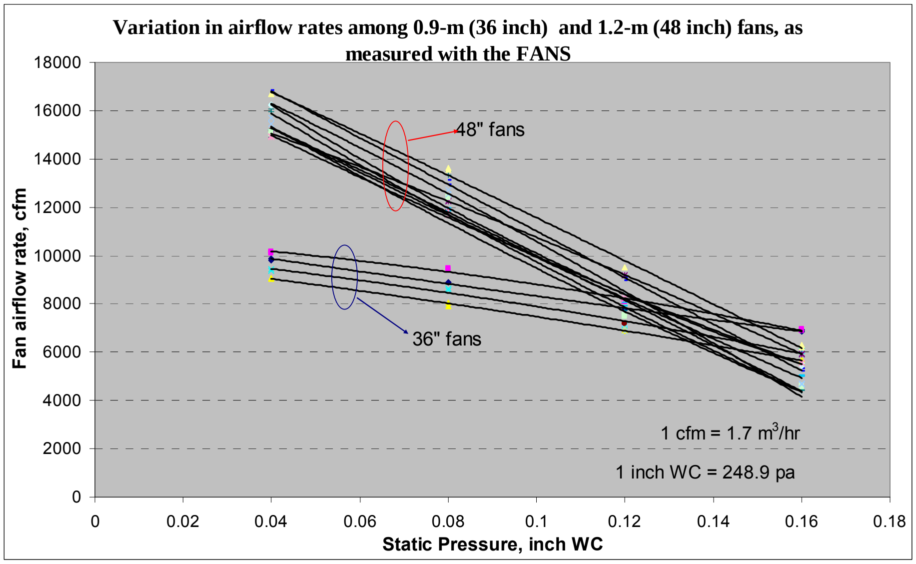
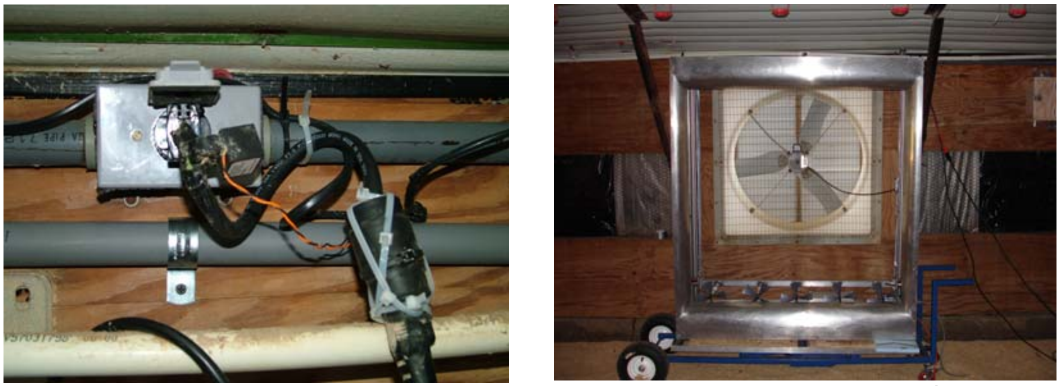


Figure 9. Variation in fan airflow rates among the seemingly identical 36-inch (0.9 m) or 48-inch (1.2 m) fans in Tyson 1-5 broiler house.



Fan runtime sensor **Fan calibration by FANS unit**

Figure 10. Photographical views of the fan operational sensor and the FANS unit.

Indoor and outdoor temperature and relative humidity (RH) were measured with robust and stable temperature (Type T thermocouple, Cole-Parmer, Vernon Hills, IL) and RH probes (HMW60, Vaisala, Woburn, MA) that were connected to the PC-based data acquisition system (DAQ). In addition, portable temperature/RH loggers were used as back-ups. Analog output of the static pressure sensors was also connected to the DAQ.

All the variables of air pollutants concentration, fan runtime, static pressure, air temperature and RH were continuously measured and recorded at 1-second intervals throughout the one-year study period. The collected raw data were archived and backed up daily.

Emission Rate Determination

Gaseous or PM emission rate (ER) from an animal house to the atmosphere is the difference between the quantity of gases or PM leaving the house and the quantity of gases or PM entering the house. The relationship of ER to gaseous or PM concentration of inlet and exhaust air and building ventilation rate may be expressed as follows:

$$\mathrm{ER_G} = \sum_{e=1}^{3} Q_e \left([G]_e - \frac{\rho_e}{\rho_i}[G]_i \right) \times 10^{-6} \times \frac{w_m}{V_m} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \qquad [1]$$

$$\mathrm{ER_{PM}} = \sum_{e=1}^{3} Q_e \left([PM]_e - \frac{\rho_e}{\rho_i}[PM]_i \right) \times 10^{-6} \times \frac{T_{std}}{T_a} \times \frac{P_a}{P_{std}} \qquad [2]$$

where $\mathrm{ER_G}$ = Gaseous emission rate for the house (g hr^{-1} $house^{-1}$)

$\mathrm{ER_{PM}}$ = PM emission rate for the house (g hr^{-1} $house^{-1}$)

Q_e = ventilation rate of the portion of the house at location "e" (SW1, SW3 or TE) at field temperature and barometric pressure (m^3 hr^{-1} $house^{-1}$)

$[G]_i$ = Gaseous concentration of incoming house ventilation air, parts per million by volume (ppm_v)

$[G]_e$ = Gaseous concentration of exhaust house ventilation air of the portion of the house at location "e" (ppm_v)

$[PM]_i$ = PM concentration of incoming house ventilation air (ug/m^3)

$[PM]_e$ = PM concentration of exhaust house ventilation air of the portion of the house at location "e" (ug/m^3)

w_m = molar weight of air pollutants, g $mole^{-1}$

V_m = molar volume of NH_3 gas at standard temperature (0°C) and pressure (1 atmosphere) (STP), 0.022414 m^3 $mole^{-1}$

T_{std} = standard temperature, 273.15 K

T_a = absolute house temperature, (°C+273.15) K

P_{std} = standard barometric pressure, 101.325 kPa

P_a = atmospheric barometric pressure for the site elevation, kPa

ρ_e = air density at exhaust fan location "e", kg dry air m^{-3} moist air

ρ_i = air density at outside conditions, kg dry air m^{-3} moist air

As can be seen from equations [1] and [2] and description of the variables shown above, multiple measurements are required to determine the gaseous or PM ER.

System Checks

Accuracy is defined as the degree of agreement between an observed value and an accepted reference value. For a given measurement system, it includes combination of random error (precision) and systematic error (bias). In this study, the following accuracy checks were implemented:

- Gas analyzers
- Exhaust fan flow rates
- TEOM PM monitors
- Static pressure sensors
- Temperature and RH sensors
- Barometric pressure sensor
- PP-GSS leakage and pump flow rates

After installation of the monitoring systems, and prior to the initiation of formal data collection, a series of system checks were conducted to insure that the monitoring system was operating correctly and that collected data would be representative of the emissions from the broiler houses during operation. The dynamic response times of the analyzers were evaluated in the lab prior to installation in the field. Among the lab tests, the response time of NH_3 measurement from INNOVA 1412 was longest as compared to gaseous measurements (CO_2 from INNOVA 1412, H_2S from API 101E, and NMHC from VIG 200). The actual on-site performance of the sampling system was also tested. Tests were performed by injecting ammonia span gas into the in-house sampling port of the longest sampling line (tunnel end, see Figure 11). The results of

INNOVA 1412 analyzers from both houses are shown in Figures 12 and 13. For both sampling systems, the fourth ammonia concentration reading (30 s X 4=120 s) reached 96% and 97% of the span concentration.

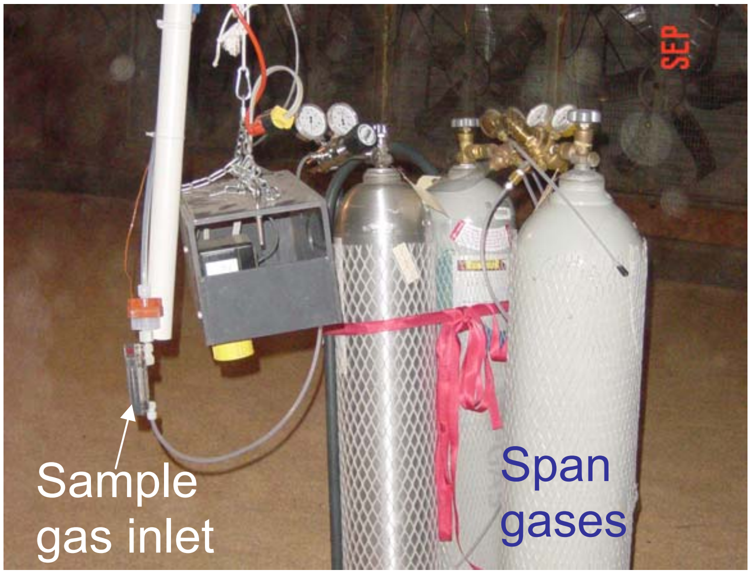


Figure 11. Picture of span gas injection at the in-house sampling point.

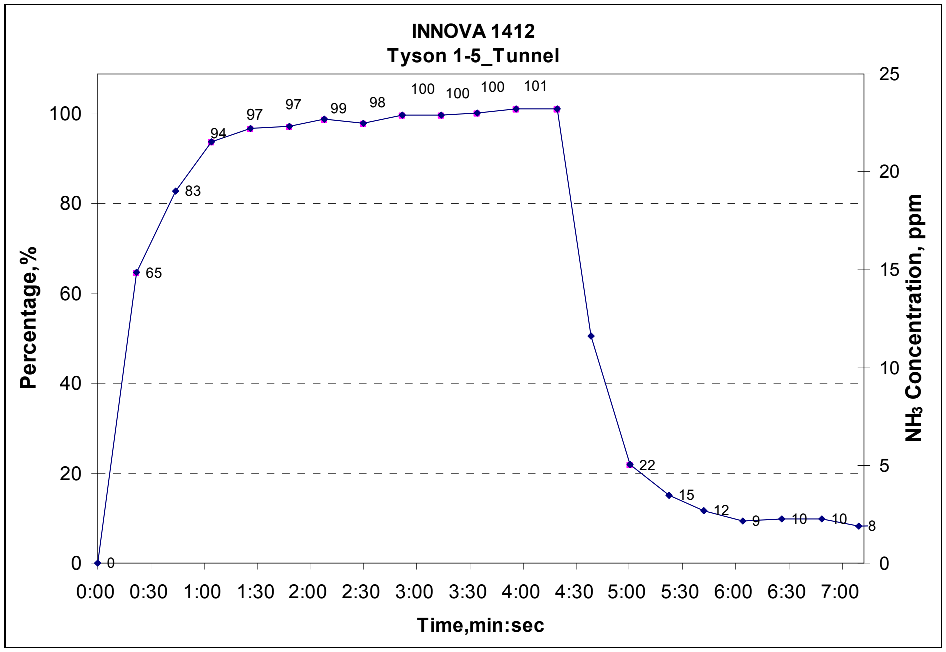


Figure 12. Response time check of the sampling system and INNOVA analyzer at Tyson 1-5.

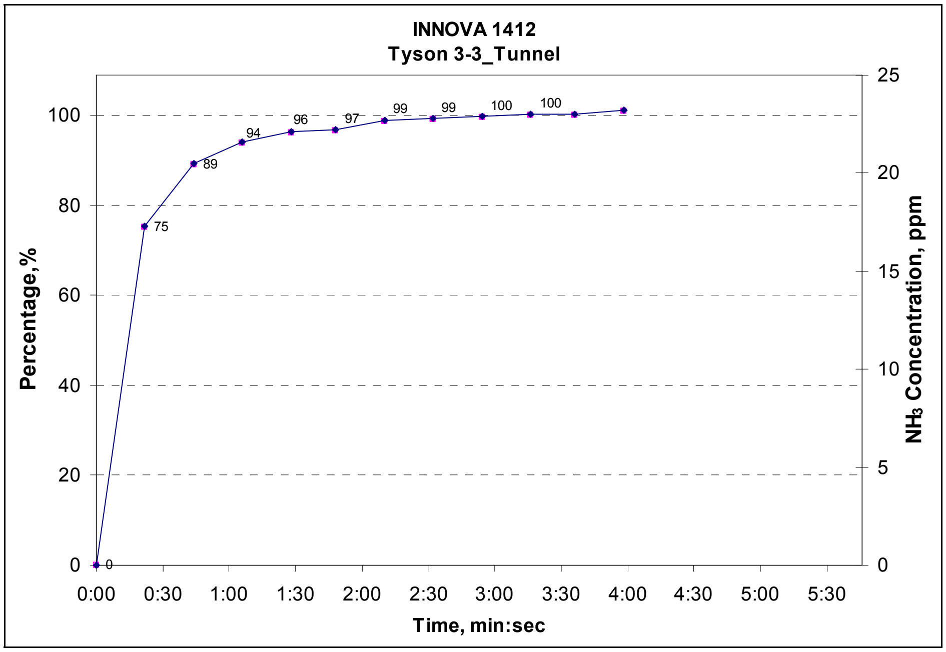


Figure 13. Response time check of the sampling system and INNOVA analyzer at Tyson 3-3.

In addition to a span gas challenge of the entire system at the farthest in-house sampling location, tests were conducted to compare the readings of a calibrated INNOVA 1412 analyzer located inside the monitoring trailer with three other calibrated INNOVA 1412 analyzers located at three sampling locations in the broiler house (SW1, SW3 and TE). The three in-house INNOVA 1412 analyzers continuously took samples during the entire testing period (Figure 14). All INNOVA 1412 analyzers were synchronized and calibrated with the same NH_3 calibration gases before the test.

Figure 14. One of the three in-house INNOVA analyzers used to compare readings to its counterpart inside the MAEMU.

To further evaluate the INNOVA's dynamic response, the number of sampling cycles for the INNOVA in the MAEMU per location was set to 4, 6 or 8 cycles per location (30s per sampling cycle). The NH_3 readings by the INNOVA 1412 in the MAEMU were compared with the respective readings by the three in-house INNOVA 1412s (Figure 15). Only the last readings from the MAEMU in each sampling cycle for each location were compared with the most recent readings from the INNOVAs in the house. Five pairs of readings for each sampling cycle setting at each location were taken. A two-way ANOVA test was conducted on the difference between in-house and MAEMU analyzer concentration readings with number of cycles per location and location in the house taken as main effects. There was neither a sampling number effect (P = 0.17) nor a location effect (P = 0.24). Table 2 provides a summary comparison of continuous in-house NH_3 concentration readings with those obtained from location cycling by the MAEMU INNOVA at 4, 6, and 8 sampling iterations for Tyson 1-5. The results indicate that the NH_3 reading in the MAEMU matched the reading in the house at all three locations and there was no difference in using 4, 6 and 8 sampling iterations at each location. Hence, four sampling iterations were chosen to maximize the sampling frequency for each location. Because the fan operation period could be as short as 30 s while the birds were young and during cold weather, it was essential to quickly move between the sample locations to capture the temporal variability in ammonia concentration arising from the intermittent (on/off) operation of the fans. Since the NH_3 reading in the MAEMU matched the reading in the house at each location, it indicated that there was no leakage in the entire sampling system. The same test was conducted for Tyson 3-3 and yielded the same results.

During weekly field visits, the integrity of each sampling line was checked by connecting a flow meter at the pump-end and blocking the in-house sampling port (Figure 16). If the flow meter read zero, it indicated no leakage in the sampling line under the negative pressure (from the in-house sampling port to the corresponding sampling pump inside the MAEMU). No leakage was detected throughout the monitoring period.

Table 2. Comparison of in-house NH_3 concentration readings (ppm) by respective INNOVA analyzers with those obtained from location cycling by the INNOVA analyzer inside the MAEMU.

No. of Sampling Iterations	$NH_{3(in\text{-}house)} - NH_{3(MAEMU)}$ For sampling locations of			(ppm) Mean (S.E.)
	SW1	SW3	Tunnel	Mean
4	0.72 (0.45)	0.20 (0.19)	0.31 (0.08)	0.41^a (0.10)
6	0.26 (0.17)	0.08 (0.10)	-0.19 (0.22)	0.05^a (0.10)
8	0.18 (0.20)	-0.02 (0.16)	0.46 (0.12)	0.20^a (0.17)
Mean	0.39^b (0.17)	0.09^b (0.09)	0.19^b (0.11)	

*Column or row means with the same superscript letter are not significantly different (P>0.10)

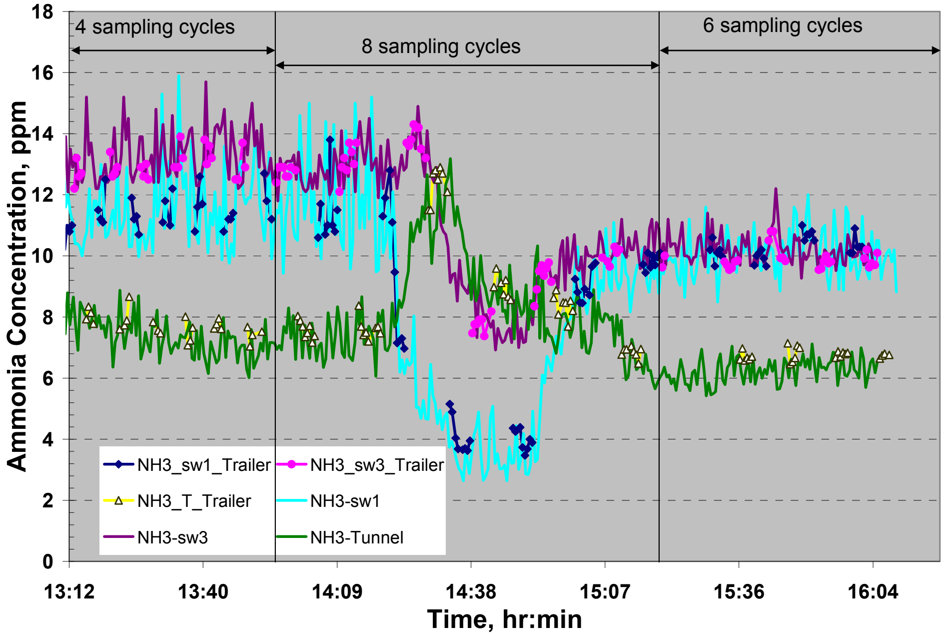


Figure 15. Comparison of ammonia readings from the MAEMU and in-house INNOVAs.

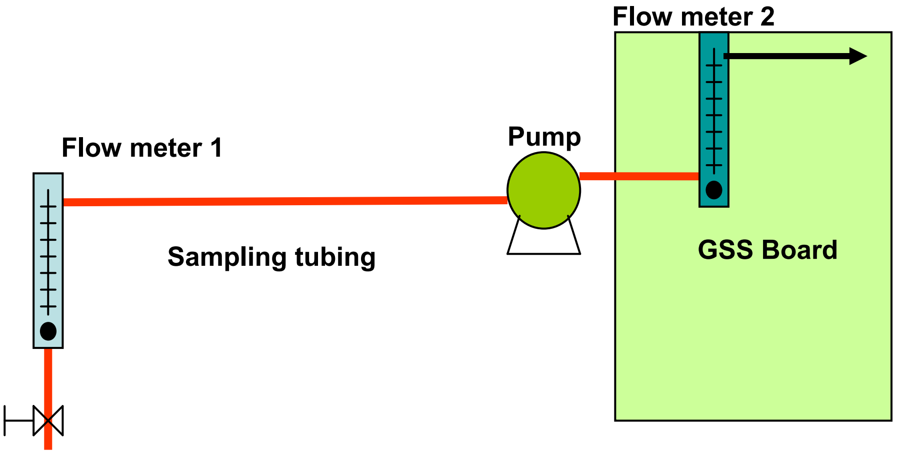


Figure 16. Schematic representation of the gas sampling system (GSS) integrity (leakage) check.

Non-methane Hydrocarbon (NMHC) Speciation (EPA Method TO-15/17)

The EPA air consent agreement with animal feeding operations (AFOs) specifies the use of EPA TO-15 for the speciation of NMHC emitted from these facilities. Sorbent tube sampling may be a more effective technique in the speciation of NMHCs from AFOs due to its ability to capture both volatile and highly polar compounds. Stainless steel canisters (Entech Instruments, Inc., Simi Valley, CA) were used to collect the air samples from the two broiler houses; a gas chromatograph – mass spectrophotometer (GC-MS) method was used to speciate the NMHC compounds. A solid sorbent method (TO-17) was used simultaneously to collect the air samples on glass sorbent tubes containing Carbopack X and Carbopack C (2:1

packing volume) custom-made by Supelco, Inc. (Bellafonte, PA) with a GS 301 gas sampler (Gerstel, Inc., Baltimore, MD). Two collection and speciation trials were conducted on April 19, 2006 at Tyson 3-3 (empty house) and Feb 6, 2007 at Tyson 1-5 (with birds in house). The air samples were collected from nine different locations throughout the whole house, including each air sampling location (Figure 17). The top 25 compounds were speciated with the TO-15 & TO-17 methods.

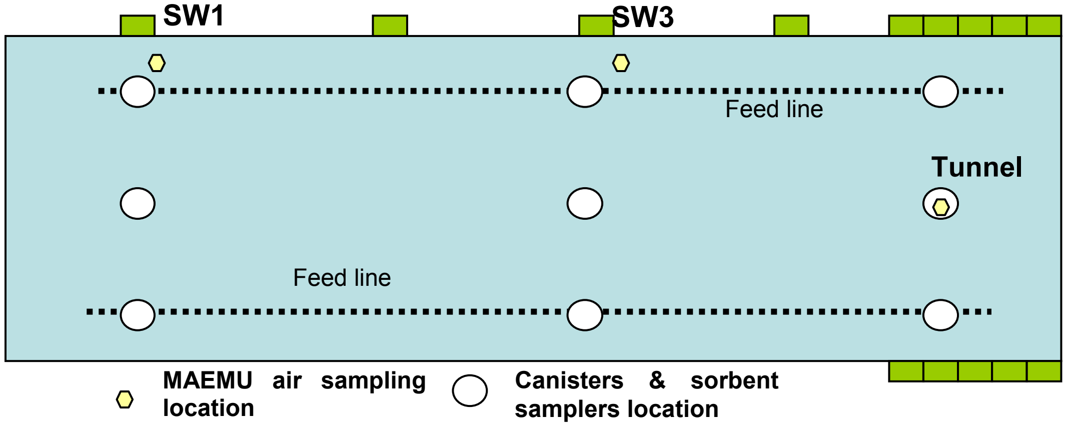


Figure 17. Schematic layout of air sampling locations for NMHC speciation.

Quality Assurance/Quality Control of Data Collection and Analysis

Strict Quality Assurance/Quality Control (QA/QC) procedures were followed throughout the data collection and data analysis processes. All measurement instruments underwent initial checks and calibrations, followed by regular operational checks and follow-up calibrations as specified by the quality assurance project plan (QAPP) (Moody et al., 2007). The frequency of each check/calibration depended on the instruments. For instance, the NH_3 gas analyzer was checked with calibration gases weekly or semi-weekly, even though our past experience had indicated that this type of photoacoustic NH_3 analyzer has excellent stability. Calibration gases were certified with concentration of 22.6, 22.8, or 25 ppm ammonia (balanced in air, certified grade with 2% accuracy, Matheson Tri-gas, PA). The INNOVA 1412 analyzers were checked once a week before February 2006 and then were checked twice a week after February 2006 to meet our data quality goal. The QC standard of instrument calibration was 5%. Internal technical system performance evaluations were performed between flocks.

In general, the broiler houses had approximately two weeks of downtime between flocks. However, the downtime at Tyson 3-3 was 41 days after the first flock due to change of the managerial personnel at the site. During each downtime, ISU and UK project personnel conducted a thorough internal technical systems audit at each site. This audit included a visual inspection of all system components, and a flow check at each of the four sample points. During the system performance evaluation, the INNOVA 1412, API 101E, and VIG 200 analyzers were recalibrated. All TEOMs were checked for leakage. The flow rate of TEOMs was audited every six months and the mass balances of TEOMs were verified after the one-year monitoring using a mass standard (TEOM Operation Manual). All temperature sensors were checked against a certified thermometer after every flock. The RH sensors and pressure sensors were checked or calibrated against a calibrated sensor or a RH sensor calibration kit (HMK 15, Vaisala, Woburn, MA) every six months. If the check result fell outside of 5% QC standard, recalibration was performed and the corresponding data were corrected, following a linear relationship between values from the previous check and current check.

The performance curves of the ventilation fans were checked after each flock. All exhaust fans were cleaned before the start of a new flock. An uninterrupted power supply (UPS) was used for the DAQ system to avoid loss of data due to power outage.

As described in the QAPP (Moody et al., 2007), a data processing program was run daily to process the data collected on the previous day. This program calculated data completeness and automatically flagged out-of-range data. A sample qualifier or a result qualifier consists of three alphanumeric characters, which act as indicators of the fact and the reason that the data value (a) did not produce a numeric result, (b) produced a numeric result, but it is qualified in some respect relating to the type or validity of the result. Qualifiers are used both in the field and in the laboratory to signify data that may be suspect due to contamination, special events, or failure of QC limits. Appendix I in the QAPP (Moody et al., 2007) contains a complete list of the data qualifiers for the field and laboratory activities. Almost all monitored parameters have simple range checks programmed. For example, valid times must be between 00:00 and 23:59, summer temperatures must be between 10 and 50 degrees Celsius, etc. The data operator is notified immediately when data are out of range. The operator has the option of correcting the entry or overriding the range limit. The specific values used for range checks vary depending on season. The default range values for data acceptance are provided in standard operation procedures (SOPs). The response action to data flagged as out of range were to investigate and document the reason that the data were flagged and to follow-up with a site visit if any data flags were the result of equipment malfunction and correct the problem. Once problems were identified, the data could be corrected or invalidated, and corrective actions were taken for field or laboratory operations. The ISU project personnel reviewed the flagged data within two working days to confirm that the data were either invalid and should be excluded or valid and should be kept. To avoid errors introduced into determination of average values due to partial data days, which would result in biased time weights, only complete-data days (CDD) that included over 75% valid data were used in calculating average daily means (ADM). Based on the on-site surveillance and daily data flagging/review, daily data completeness for each variable was calculated.

Two external technical systems audits were conducted by independent personnel during the project. Battelle personnel (commissioned by EPA) audited the systems and QAPP on September 25-26, 2006 and agricultural air monitoring experts, Drs. Larry Jacobson and David Parker, (commissioned by the study PI's) audited the measurement methods on January 8 – 10, 2007. Both audits found that the QAPP was being fully and successfully implemented at both sites.

Uncertainty Analysis of Emission Rate

Component error analysis is used to quantify uncertainty when a quantity such as daily emission rate is calculated from multiple measurements, each with its own degree of uncertainty. A component error analysis (Doeblin, 1990) provides statistical meaning to a statement on the magnitude of error in the calculation of daily ER. This analysis had been performed for an earlier project that measured broiler house ammonia emissions and documented in a copyrighted Ph.D. dissertation (Casey, 2005), a journal article arising from this project (Gates et al, 2009), and a manuscript in preparation (Casey et al., 2009). The uncertainty analysis of ER for this study is described in detail in the project QAPP and Gates et al. (2009). The resultant ER uncertainty was 10% or less based on the accuracies of the associated measurement component uncertainties and operating ranges for ventilation fans. Consequently, data quality objectives (DQOs) and measurement quality objectives (MQOs) were developed in the QAPP to guide the achievement of 10% or less ER uncertainty.

Results and Discussion

Data Completeness

According to USEPA (2002): “Data completeness is a measure of the amount of valid data obtained from a measurement system, expressed as a percentage of the number of valid measurements that should have been collected”. In this study, a data completeness goal of 75% of the scheduled sampling was established. The data completeness is primarily affected by unpredictable field events, including instrument malfunction, power outages due to adverse weather, and broiler house maintenance. When any of these events occurred, the corresponding emission data were flagged. After one-year monitoring (Mar 14, 2007 for Tyson 1-5 and Mar 5, 2007 for Tyson 3-3), six full flocks had been monitored at Tyson 1-5; the 6th flock had been monitored for 22 days (0.4 flock) for Tyson 3-3. The complete data days (CDD) for each flock and between flocks are summarized in Table 1 for each constituent.

The weather conditions for the period are reported in Table 3. The range of daily average ambient temperatures was 14 to 86 ^{o}F for the two sites.

Table 3. Daily average temperature and relative humidity (RH) summary for Tyson 1-5 and Tyson 3-3 over the one-year period from Feb 2006 to March 2007. (S.D. = standard deviation)

	Outside Temp., ^{o}F		Outside RH, %		Inside Temp., ^{o}F		Inside RH, %	
	T1-5	T3-3	T1-5	T3-3	T1-5	T3-3	T1-5	T3-3
Mean	57.8	57.1	73.3	72.7	72.1	73.1	60.6	62.1
S.D.	17.0	17.4	12.4	11.6	9.4	9.1	10.9	11.5
Max	85.6	85.9	99.7	97.4	101.7	89.7	89.0	94.7
Min	14.1	15.8	37.4	37.3	42.2	39.6	30.8	30.8

Ammonia (NH_3): For the 365-d annual emission calculation, the complete-data days (CDDs) were 353 out of 365 days (96.7% data completeness or DC) and 323 out of 365 days (88.5% DC) for Tyson 1-5 and Tyson 3-3, respectively. By the end of the monitoring, the CDDs were 381 out of 394 days (97.6% DC) for Tyson 1-5 and 337 out of 379 days (88.9% DC) for Tyson 3-3. The 718 house-day (11.4 flocks) emission data were used for calculating the ER of daily mean, daily maximum, flock total, and during downtime. The CDDs for each flock and downtime are summarized in Table 1.

Hydrogen sulfide (H_2S): For the 365-d annual emission calculation, the CDDs were 314 out of 365 days (86.0% DC) and 260 out of 365 days (71.2% DC), respectively, for Tyson 1-5 and Tyson 3-3. By the end of the six flocks, the CDDs were 342 out of 394 days (86.8% DC) for Tyson 1-5 and 274 out of 379 days (72.3% DC) for Tyson 3-3. The 616 house-days (11.4 flocks) emission data were used for calculating the ER of daily mean, daily maximum, flock total, and during downtime.

Nonmethane hydrocarbon (NMHC): For the 365-d annual emission calculation, the CDDs were 250 out of 365 days (68.5% DC) and 201 out of 365 days (55.1% DC), respectively, for Tyson 1-5 and Tyson 3-3. By the end of the six flocks, the CDDs were 268 out of 394 days (68.0% DC) for Tyson 1-5 and 203 out of 379 days (53.6% DC) for Tyson 3-3. The 471 house-days (11.4 flocks) emission data were used for calculating the emission rate of daily mean, daily maximum, flock total, and during downtime.

TSP: For the 365-d annual emission calculation, the CDDs were 281 out of 365 days (77.0% DC) and 295 out of 365 days (80.8% DC), respectively, for Tyson 1-5 and Tyson 3-3. By the end of the six flocks, the CDDs were 304 out of 394 days (77.2% DC) for Tyson 1-5 and 298 out of 379 days (78.6% DC) for Tyson 3-3. The 602 house-days (11.4 flocks) emission data were used for calculating the emission rate of daily mean, daily maximum, flock total, and during downtime.

PM_{10}: For the 365-d annual emission calculation, the CDDs were 272 out of 365 days (74.5% DC) and 298 out of 365 days (81.6% DC), respectively, for Tyson 1-5 and Tyson 3-3. By the end of the six flocks, the CDDs were 295 out of 394 days (74.9% DC) for Tyson 1-5 and 301 out of 379 days (79.4% DC) for Tyson 3-3. The 596 house-days (11.4 flocks) emission data were used for calculating the ER of daily mean, daily maximum, flock total, and during downtime.

$PM_{2.5}$: For the 365-d annual emission calculation, the CDDs were 256 out of 365 days (70.1% data completeness) and 296 out of 365 days (81.1% data completeness), respectively, for Tyson 1-5 and Tyson 3-3. By the end of the six flocks, the CDDs were 279 out of 394 days (70.8% data completeness) for Tyson 1-5 and 299 out of 379 days (78.9% data completeness) for Tyson 3-3. The 578 house-days (11.4 flocks) emission data were used for calculating the ER of daily mean, daily maximum, flock total, and during downtime.

Carbon dioxide (CO_2): For the 365-d annual emission calculation, the complete-data days (CDDs) were 353 out of 365 days (96.7% DC) and 319 out of 365 days (87.4% DC) for Tyson 1-5 and Tyson 3-3, respectively. By the end of the monitoring, the CDDs were 381 out of 394 days (97.6% DC) for Tyson 1-5 and 333 out of 379 days (87.9% DC) for Tyson 3-3. The 714 house-days (11.4 flocks) emission data were used for calculating the ER of daily mean, daily maximum, flock total, and during downtime.

Bird Growth Data

The bird growth data from the two houses were collected for every flock. A bird growth curve was derived using the 11 full flocks of data (Figure 18). The daily bird weights at the two separate houses were compared and there was no significant difference between the two sites ($P = 0.88$). Therefore, the single curve was used to represent the growth during the 52-day growth cycle for both sites.

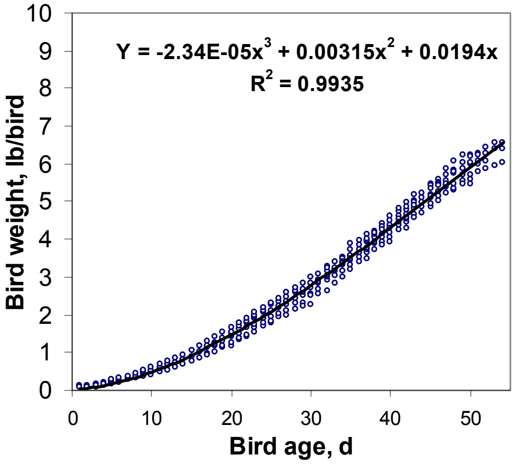


Figure 18. Broiler growth curve for 11 flocks from Tyson 1-5 and Tyson 3-3

Emission Rate (ER)

The daily ER of each house was calculated based on the gaseous and PM concentrations and the building ventilation rates. Regression was used to test for significance of bird age, ventilation rate (VR), bedding status, house temperature and RH. Regression equation was used to predict gaseous or PM ER vs. the significant independent variables.

NH_3 Emission

NH_3 ER Estimation/Prediction

Ammonia emission from the flocks with new bedding and bird age less than 7 d was significantly lower than later periods in the flock production cycle. Therefore, the ERs of the first 6 d with new bedding would not fit the relationship of ER vs. bird age, body weight, VR, air temperature and RH. For the flocks with built-up litter and bird age older than 6-d with new bedding, the relationship of ER, bird age, body weight, VR, air temperature and RH was investigated.

Ammonia ER was highly correlated to bird age, body weight and VR, but was weakly correlated with inside RH and not correlated with outside temperature, outside RH or inside temperature. Moreover, a strong positive relationship was found among bird age, body weight and VR. Among the three variables, bird age was the predominant factor affecting NH_3 ER. Because of unusually high mortality in flock 6 at Tyson 1-5, this flock was not used in ER prediction. The

NH_3 ER per house or per bird from all data (except flock 6 at Tyson 1-5), as shown in Figures 19 and 20, may be described using the following regression equations:

$$\boldsymbol{NH_3\ ER,\ lb\ d^{-1}\ house^{-1}} = \boldsymbol{a} + \boldsymbol{b\ X} + \boldsymbol{c\ X^2} + \boldsymbol{d\ X^3} \qquad [3]$$

where

X = bird age, d, if built-up litter is used;

X = (bird age – 6) if new bedding is used or bird age is ≥ 7 d;

NH_3 **ER** = 0.55 lb/d-house if bird age < 7 d for new bedding

Table 4 provides the prediction parameter estimates for the two houses, individually, and averaged over the 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.64 to 0.80 and show the strongest relationship between ER and bird age.

Table 4. Coefficient Estimates of ammonia ER prediction models for the houses, Tyson 1-5 and Tyson 3-3 (ER is not included when bird age is < 7d with new bedding) (S.E. = standard error)

House	S.E. (lb/d-house)	**a** (± S.E.)	**b** (± S.E.)	***c*** (± S.E.)	***d*** (± S.E.)	r^2
T1-5	9.70	7.9 (± 1.27)	N/S	0.063 (± 4.9 e^{-03})	-1.02 e^{-03} (± 1 e^{-04})	0.64
T3-3	9.09	12.7 (± 2.49)	-1.34 (± 0.40)	0.138 (± 0.017)	-2 e^{-03} (±2 e^{-04})	0.80
Overall	9.94	12.2 (± 1.91)	-0.97 (± 0.285)	0.1115 (± 0.016)	-1.6 e^{-03} (± 1.7 e^{-04})	0.71

For the flocks on new bedding, there was no clear effect of bird age, VR, air temperature, or RH on ER. Therefore, the first 6-d ERs could be estimated by using the average ER (± S.D.), 0.55 lb/d-house (± 0.42) measured for the first 6-d ERs from three flocks on new bedding.

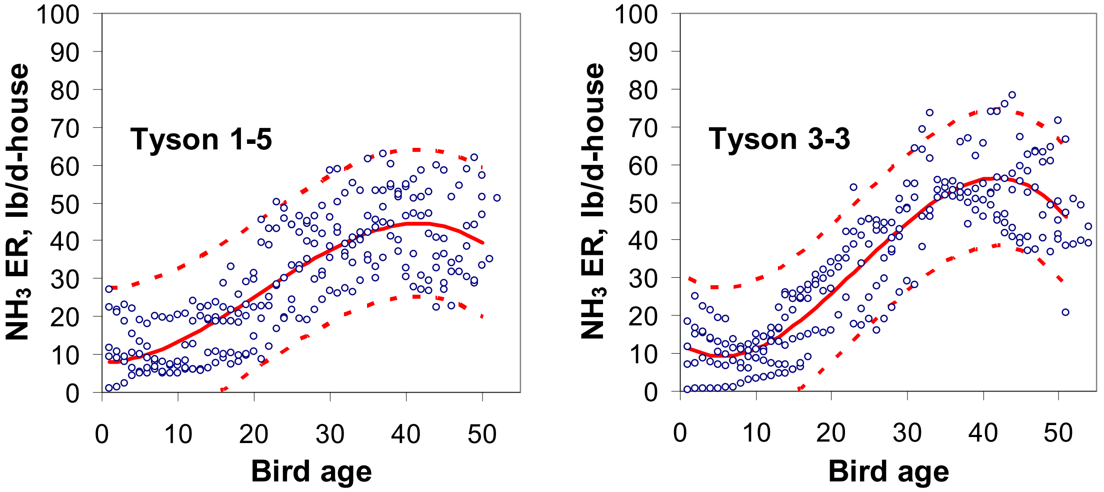


Figure 19. NH_3 emission rate (ER) per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line and the dash lines are 95% prediction limits.

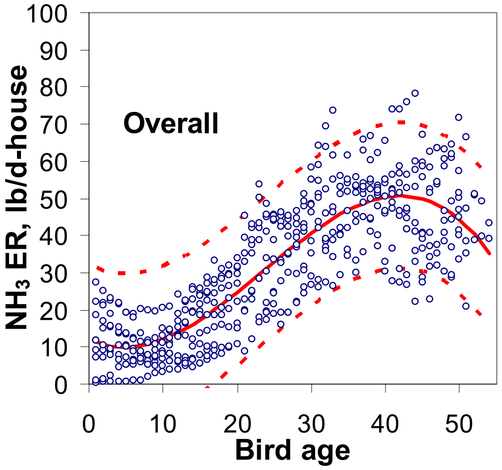


Figure 20. NH_3 emission rate (ER) per house vs. bird age. The solid line is the regression line and the dash lines are 95% prediction limits.

Figure 21 provides the daily NH_3 ER for the two houses for the entire monitoring period of 11.4 flocks and downtime between flocks. The daily ER varied from 0 to 98.6 lb/d-house (0 to 44.7 kg/d-house). When the houses were occupied by birds, the highest ER was 67.4 and 78.2 lb/d-house (30.6 and 35.5 kg/d-house) for Tyson 1-5 and Tyson 3-3, respectively. The highest daily emission of 98.6 lb/d-house (44.7 kg/d-house) occurred at Tyson 1-5 between flock 2 and flock 3. The highest emission happened on April 6, 2006 when the litter was disturbed during a between-flock litter decaking operation. Note that the emissions between the vertical dashed lines in Figure 21 represent periods between flocks when no birds were in the houses (i.e., downtime). The average ER for Tyson 1-5 over the six flocks was 29.5 ± 12.9 lb/d-house (13.4 ± 5.9 kg/d-house) which was not significantly different from 32.2 ± 15.9 lb/d-house (14.6 ± 7.2 kg/d-house) for Tyson 3-3 (P=0.35). The average ER of 11.4 flocks was 31.4 ± 14.9 lb/d-house (14.2 ± 6.8 kg/d-house).

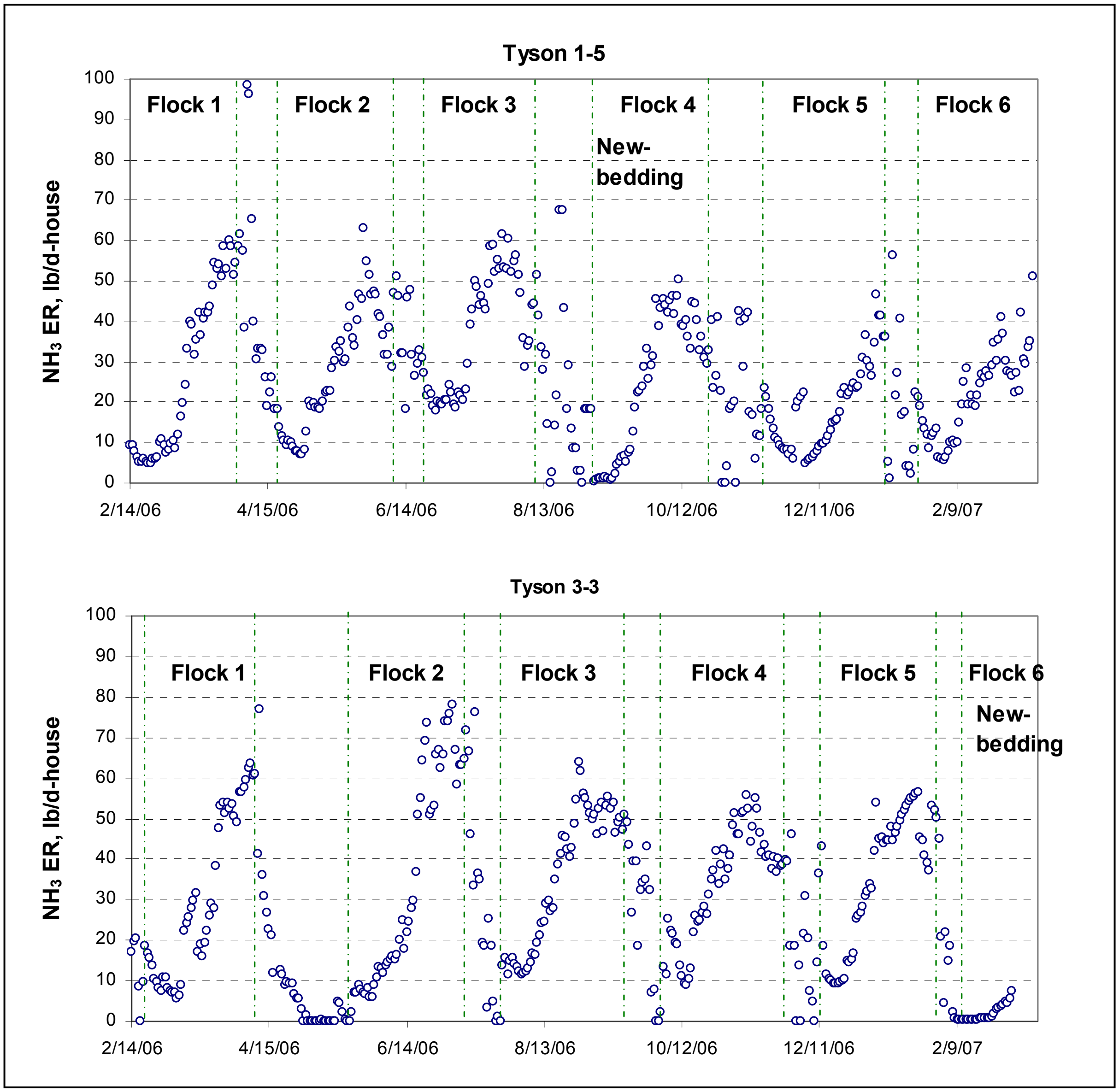


Figure 21. Daily NH_3 emission over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

NH_3 ER during Downtime between Flocks

Ammonia emissions from the two houses were continuously monitored when the houses were empty between flocks or during downtime. Ventilation rate (VR) of the houses had a significant impact on the ER when VR was lower than 80,000 cfm (135,900 m^3/hr) (Figure 22). However, it was also related to the litter management practice, e.g. litter decaking. The average ER for the two houses during downtime was 18.5 ± 17.8 lb/d-house (8.39 ± 8.1 kg/d-house), which was approximately two-thirds of the mean ER when birds were present in the houses.

The NH_3 ER per house during downtime could be described using the following regression equation:

$$NH_3\ ER,\ lb\ d^{-1}\ house^{-1} = 0.0006\ VR \qquad [4]$$

where

VR = Ventilation rate, cfm house^{-1}

NH_3 ***ER*** = 41.2 lb/d-house if VR ≥ 80000 cfm

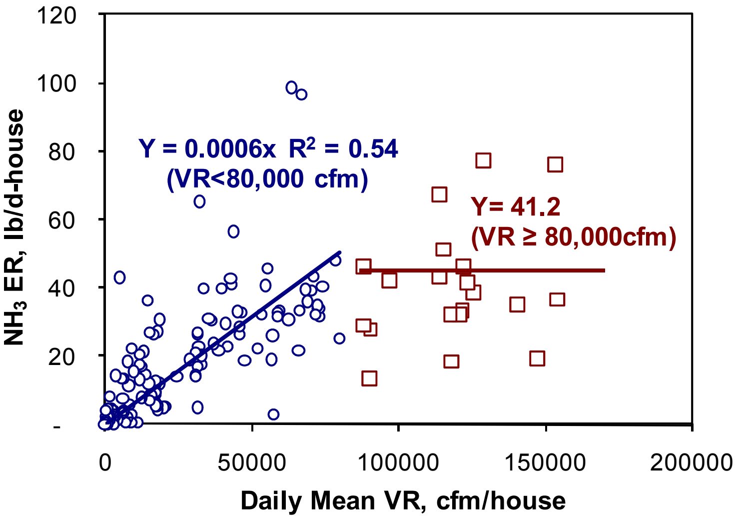


Figure 22. NH_3 emission rate(ER) vs. ventilation rate (VR) during downtime.

NH_3 ER per Animal Unit (AU)

Figures 23 and 24 present NH_3 ER in terms of 500 kg AU (kg/AU-d) for all 11.4 flocks from the two houses. The ER per AU versus bird age shows the different trends for the flocks with new bedding and built-up litter. The ER per AU of two flocks with new bedding (Tyson 1-5 flock 4, Sept to Oct, 2006, and Tyson 3-3 flock 6, Feb, 2007) was relatively low. The ER per AU of the flocks with built-up litter started high but trended downward in the first week and stabilized with bird growth. There was no significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU (P=0.73). The daily ER per AU (± S.D.) was 0.48 ± 0.60 and 0.48 ± 0.48 kg/d-AU for Tyson 1-5 and Tyson 3-3, respectively. The overall daily ER per AU was 0.48 ± 0.53 kg/d-AU.

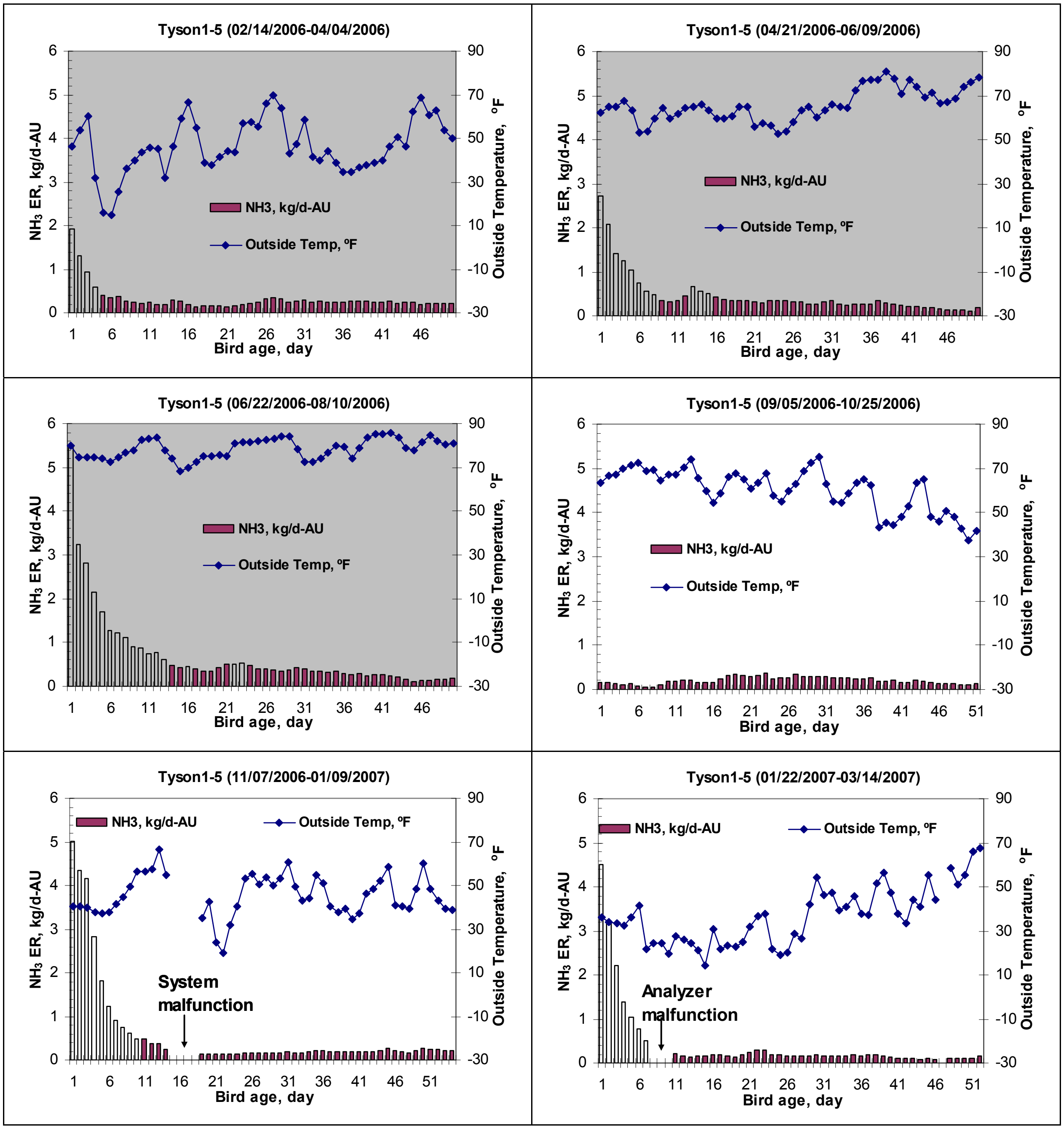


Figure 23. Tyson 1-5 NH_3 ER per AU (500 kg) mean outside temperature vs. bird age

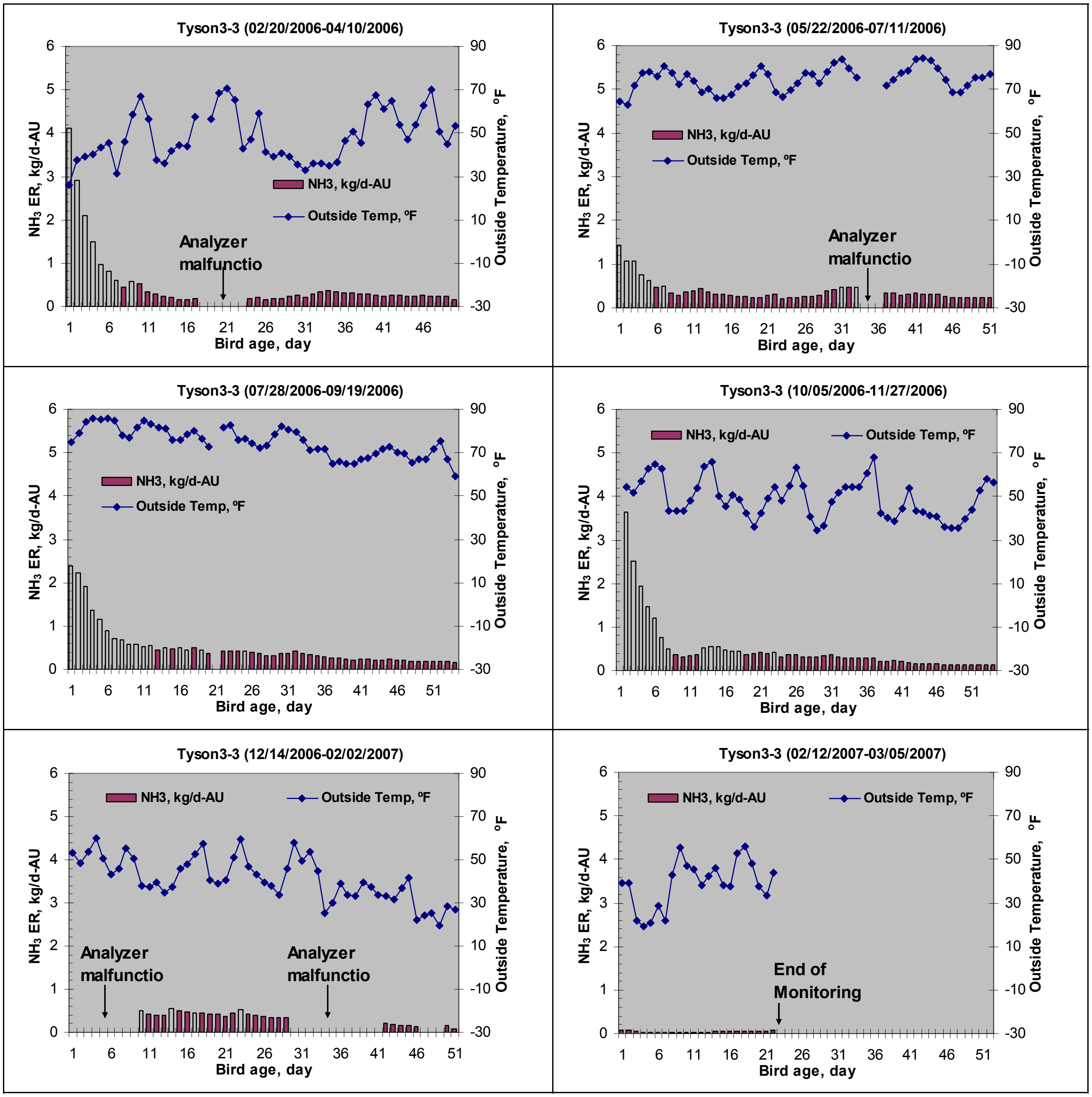


Figure 24. Tyson 3-3 NH_3 emission rate (ER) per animal unit (AU, 500 kg live body weight) and mean outside temperature vs. bird age

Effects of Environmental Variables on NH_3 ER

To assess the impact of environmental variables on the NH_3 emission from the two broiler houses, a multiple regression analysis was performed to relate NH_3 ER (lb/d-house) to bird age (d), interior temperature (^{o}F), RH (%), VR (cfm/bird) and bedding status (0 for new bedding; 1 for built-up litter). The daily mean values of the above variables were used for the regression analysis. The results of the regression analysis are shown in Table 5. House RH and VR had significant effects on NH_3 ER at $\alpha = 0.05$. As RH and VR increased, so did NH_3 ER (lb/d-house).

Table 5. Multiple regression analysis of daily NH_3 ER with bird age (d), RH (%), and litter status (LS) as inputs (R^2=0.76)

$$NH_3\ ER,\ lb\ d^{-1}\ house^{-1} = \beta_0 + \beta_1 x\ Age + \beta_2\ x\ Age^2 + \beta_3\ x\ Age^3 + \beta_4\ x\ RH_i + \beta_5\ x\ VR + \beta_6\ x\ LS$$

Term	Estimate	S.E	t Ratio	Prob>|t|
β_0= Intercept	-0.95	2.88	-0.33	0.74
β_1= Bird age, d	-0.87	0.261	-3.32	0.0009
β_2= Bird age^2, d^2	0.11	0.012	9.26	<.0001
β_3= Bird age^3, d^3	- 1.6 e^{-03}	1.5 e^{-04}	-10.9	<.0001
β_4= Inside RH, %	0.18	0.045	4.11	<.0001
β_5= VR, cfm/bird	2.82	0.407	6.93	<.0001
β_6= LS, 0 or 1	N/S			

Annual NH_3 Emission

The annual NH_3 emission from each house is the accumulation of daily ERs over 365 days. However, some daily emissions were missing due to various reasons (for example, power outage from adverse weather and instrument malfunctions). Based on the regression of the ER vs. bird age from Equation [3], the annual emissions were 4.9 and 5.3 US tons (4.4 and 4.8 metric ton) for Tyson 1-5 and Tyson 3-3, respectively. On the basis of birds marketed the average ammonia emissions over a six-flock period were 75.2 and 81.0 lb per 1,000 birds marketed (34.1 and 36.7 g/bird-marketed) for Tyson 1-5 and Tyson 3-3, respectively. Combining both houses, the average annual ammonia emission (± S.E.) was 5.1 ± 0.19 US tons per house or 78.1 ± 3.1 lb per 1,000 birds marketed (4.6 metric tons per house or 35.4 ± 1.32 g per bird marketed).

H_2S Emission

H_2S ER Estimation/Prediction

H_2S ER was correlated to the bird age, body weight and VR, weakly correlated with inside RH and not correlated with outside temperature, outside RH or inside temperature. Among the variables, bird age was most predominant. For the flocks on new bedding, there was no clear bedding effect on H_2S ER. Because of the unusually high mortality in flock 5 at Tyson 1-5, this flock was not used to predict the ER. The H_2S ER per house or per bird from all data except for the flock 5 ERs at Tyson 1-5, as shown in Figures 25 and 26, could be described using the following regression equation:

$$\sqrt{H_2S\ ER} = a + b\,X + c\,X^2 + d\,X^3 \qquad [5]$$

where

H_2S ER = lb/d-house;

X= bird age.

Table 6 provides the prediction parameter estimates for the two houses, individually, and over all 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.72 to 0.78 and show the strongest relationship between ER and bird age (Figure 25 and 26).

Table 6. Coefficient estimates of H_2S ER prediction models for houses Tyson 1-5 and Tyson 3-3

House	**a** (± S.E.)	**b** (± S.E.)	**c** (± S.E.)	**d** (± S.E.)	r^2
T1-5	0.102 (± 0.011)	0.009 (± 0.0004)	N/S	N/S	0.72
T3-3	0.056 (± 0.015)	0.016 (± 0.001)	$-\ 1.4\ e^{-04}$ ($\pm\ 2.3\ e^{-05}$)	N/S	0.81
Overall	0.065 (± 0.011)	0.015 (± 0.001)	$-\ 1.0\ e^{-04}$ ($\pm\ 1.8\ e^{-05}$)	N/S	0.76

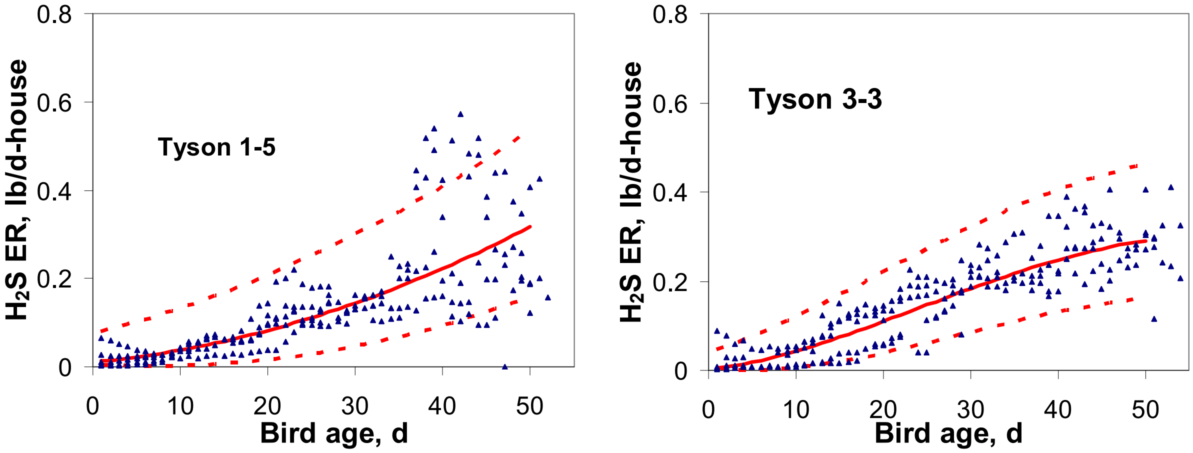


Figure 25. H_2S emission rate (ER) per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line and the dash lines are 95% prediction limits.

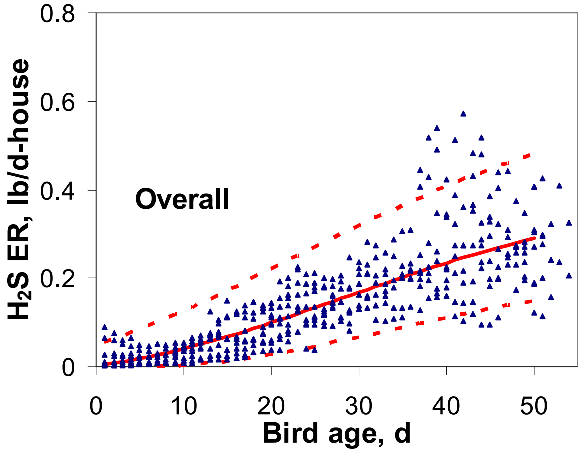


Figure 26. H_2S emission rate (ER) per house vs. bird age. The solid line is the regression line and the dash lines are 95% prediction limits.

Figure 27 provides the daily H_2S ER for the two houses for the entire monitoring period with 11.4 flocks and downtime between flocks. The daily ER varied from 0 to 0.57 lb/d-house (0 to 259.5 g/d-house). The highest ER was 0.57 and 0.41 lb/d-house (259.5 and 186.3 g/d-house) for Tyson 1-5 and Tyson 3-3, respectively. Note that the emissions between the vertical dashed lines represent periods between flocks when no birds were in the houses (i.e., downtime). There was no significant difference between the flocks with new bedding and those with built-up litter (P = 0.1) at α= 0.05. The average ER for Tyson 1-5 over the six flocks was 0.14 ± 0.10 lb/d-house (63.3 ± 44.7 g/d-house) which is not significantly different from 0.15 ± 0.10 lb/d-house (70 ± 43.6 g/d-house) for Tyson 3-3 (P=0.49). The average ER of 11.4 flocks was 0.14 ± 0.09 lb/d-house (65.7 ± 42 g/d-house).

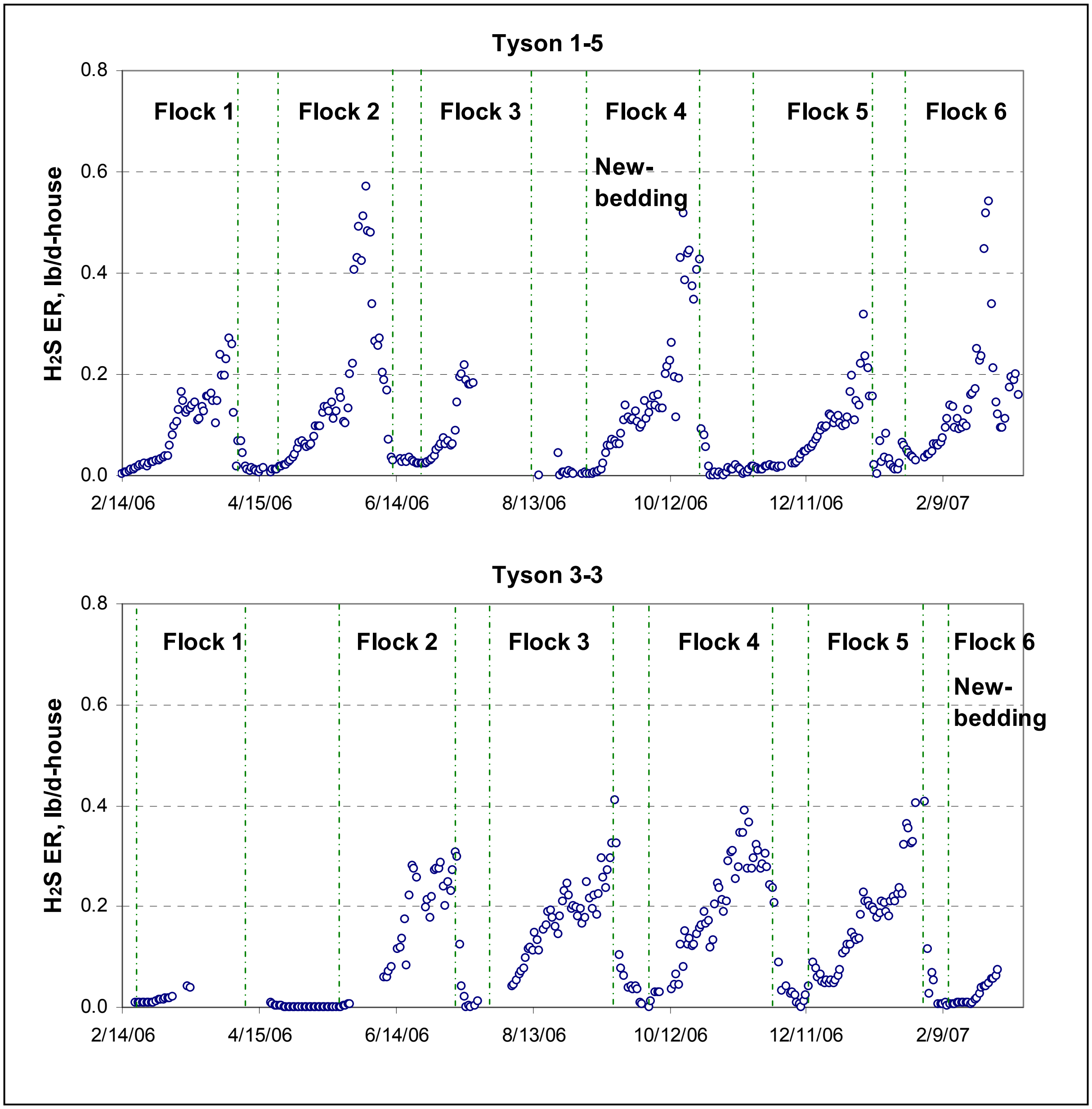


Figure 27. Daily H_2S emission over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

H_2S ER during Downtime between Flocks

The H_2S ER during the downtime was tested to determine the effects of environmental variables. However, no significant effects were found. VR of the houses had a significant impact on the NH_3 ER, but not so on H_2S ER (Figure 28). The average H_2S ER for Tyson 1-5 and Tyson 3-3 downtime was 0.023 ± 0.03 and 0.016 ± 0.026 lb/d-house (10.5 ± 13.4 and 7.3 ± 11.8 g/d-house), respectively. The average ER for the two houses during downtime was 0.020 ± 0.028 lb/d-house (9.0 ± 12.5 g/d-house).

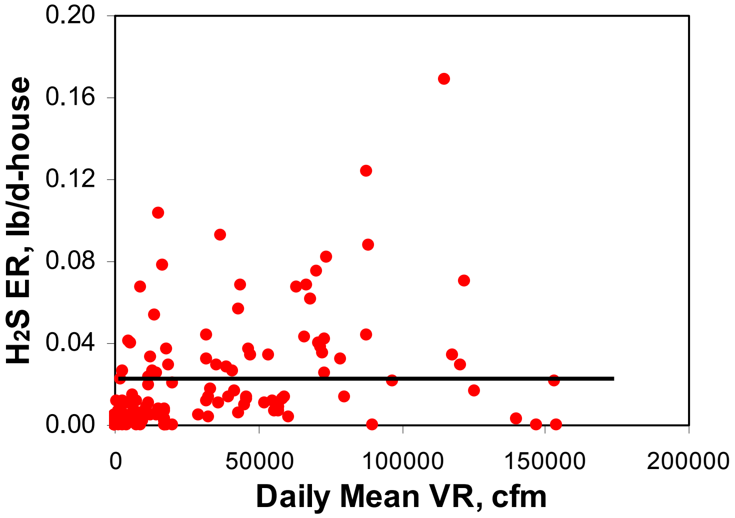


Figure 28. H_2S **emission rate(ER) vs. ventilation rate (VR) during downtime.**

H_2S ER per Animal Unit (AU)

Figures 29, 30, and 31 present H_2S ER in terms of 500 kg AU (g/d-AU) for all 11.4 flocks from the two houses. The ER per AU versus bird age showed different trends for the flocks with new bedding and built-up litter. During the first 10-d, the 1 ½ flocks new bedding (Tyson 1-5 flock 5, Sep to Oct 2006, and Tyson 3-3 flock 6, Feb 2007) had much lower ER per AU than the flocks with built-up litter. The H_2S ERs per AU of the flocks with built-up litter started high but trended to a low level with bird growth. No strong linear or other relationship was found between ER per AU and bird age. Therefore, daily H_2S ER per AU was expressed as 1.47 ± 1.53 g/d-AU. There was no significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU (P=0.4).

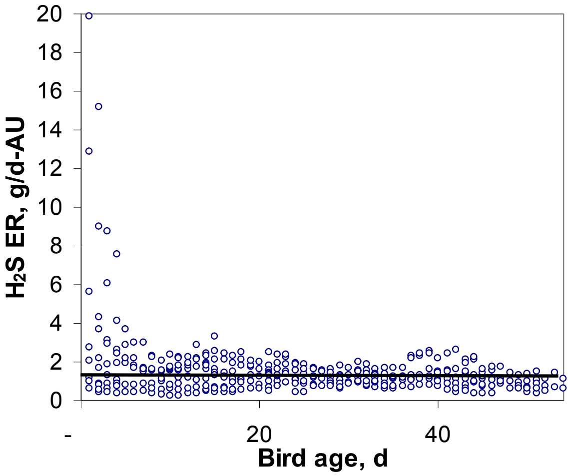


Figure 29. Relationship between H_2S **ER per animal unit (AU, 500 kg) vs. bird age.**

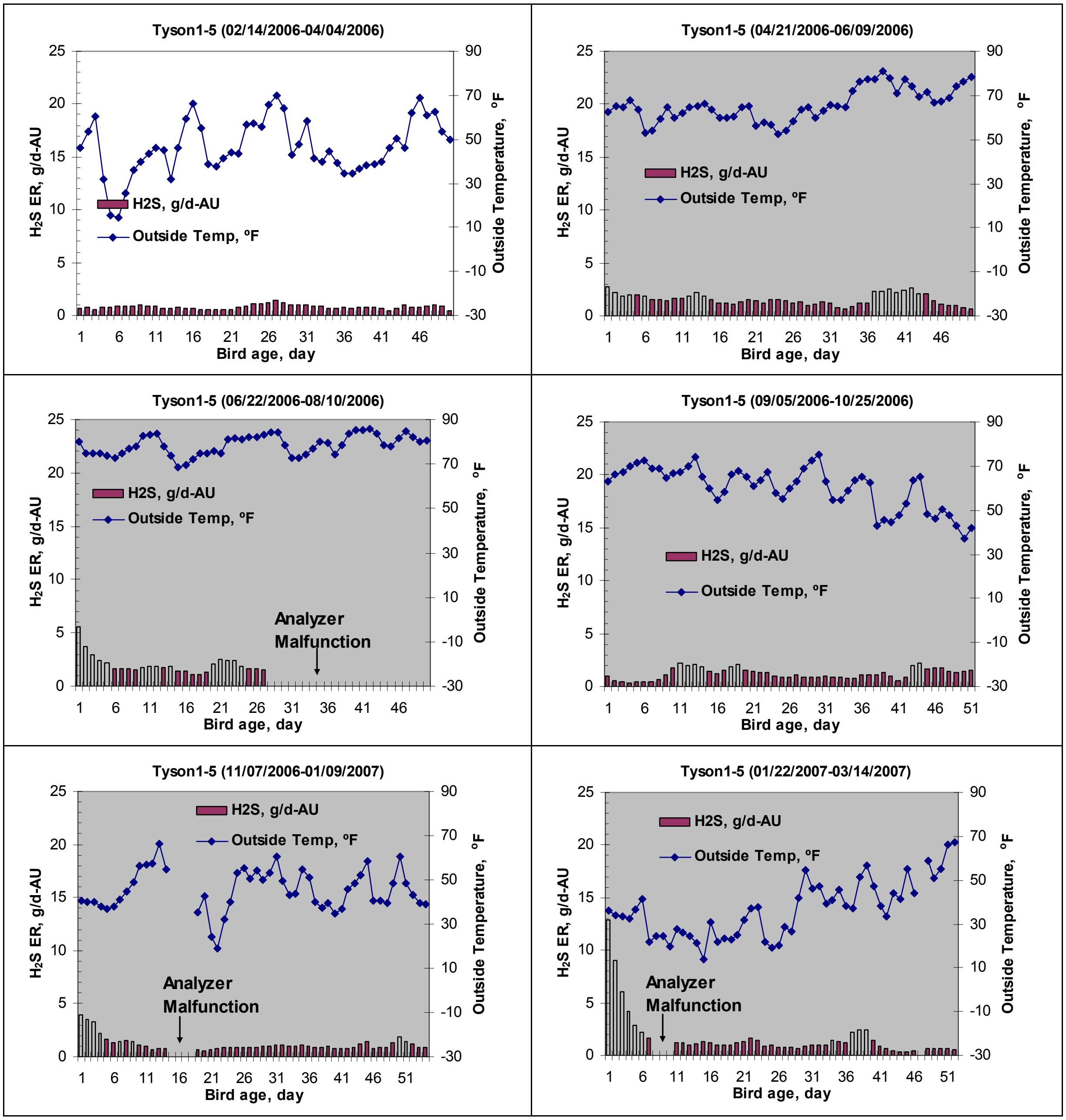


Figure 30. Tyson 1-5 H_2S ER per animal unit (AU, 500 kg) and outside temperature vs. bird age

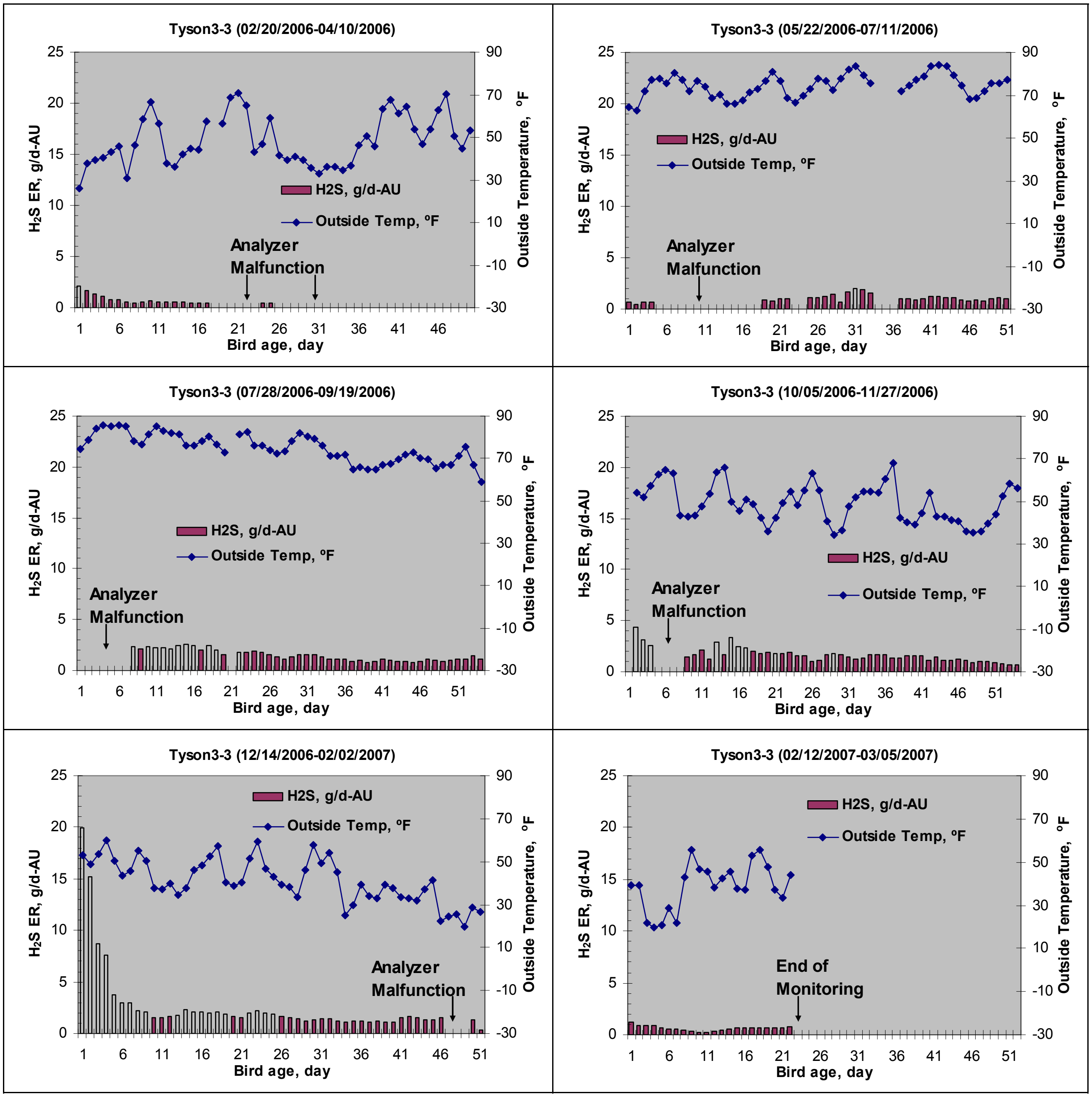


Figure 31. Tyson 3-3 H_2S ER per AU (500 kg) mean outside temperature vs. bird age

Effects of Environmental Variables on H_2S Emission Rate

To assess the impact of environmental variables on H_2S emission from the two broiler houses, a multiple regression analysis was performed to relate daily H_2S ER to bird age (d), interior temperature (^oF), RH (%), VR (cfm/bird) and litter status (0 for new bedding; 1 for built-up litter). The daily mean values of the above variables were used for the regression analysis. The results of the regression analysis are shown in Table 7. The interior RH had a significant effect on H_2S ER at α = 0.05. As RH increased, so did H_2S ER (lb/d-house).

Table 7. Multiple regression analysis of H_2S emission to bird age (d), interior temperature, RH (%), and litter status (LS) (R^2=0.66)

$$H_2S\ ER,\ lb\ d^{-1}\ house^{-1} = \beta_0 + \beta_1 x\ Age + \beta_2\ x\ T_i + \beta_3\ x\ RH_i + \beta_4\ x\ VR + \beta_5\ x\ LS$$

Term	Estimate	S.E	t Ratio	Prob>|t|
β_0= Intercept	-0.272	0.034	-7.94	<.0001
β_1= Bird age, d	0.0058	0.00034	16.8	<.0001
β_2= Inside Temp., ºF	N/S			
β_3= Inside RH, %	0.0046	0.00061	7.54	<.0001
β_4= VR, cfm/bird	N/S			
β_5= LS, 0 or 1	N/S			

Annual H_2S Emission

The annual H_2S emission from each house is the accumulation of daily ERs over 365 days. However, some daily emissions were missing due to various reasons (for example, power outage from adverse weather and instrument malfunctions). When 5.4 flocks were grown for an average of 52 d and the average flock cumulative ER was 7.53 lb/flock (3.42 kg/flock), the annual emission (± S.E.) was 42.3 ± 2.1 lb/yr-house (19.2 ± 0.92 kg/yr-house). On the basis of per 1,000 birds marketed the annual average H_2S emission (± S.E.) was 147 ± 7.1 g.

NMHC Emission

In this report, the NMHC emission rate is expressed using propane (C_3H_8) as a reference. For instance, the unit of lb-NMHC /d-house represents lb-C_3H_8 per day per house.

NMHC ER Estimation/Prediction

NMHC ER was correlated to the bird age, body weight and VR, was weakly correlated with inside RH, and was not correlated with outside temperature, RH, or inside temperature. Among the three variables, bird age was most predominant. For flocks on new bedding, there was no clear bedding effect on NMHC ER. Due to the unusually high mortality in flock 5 at Tyson 1-5, this flock was not used in the ER prediction. The NMHC ER per house or per bird from all data except for the flock 5 ERs at Tyson 1-5, as shown in Figures 32 and 33, could be described using the following regression equation:

$$NMHC\ ER,\ lb\ d^{-1}\ house^{-1} = a + b\,X + c\,X^2 + d\,X^3 \qquad [6]$$

where

X= bird age.

Table 8 provides the prediction parameter estimates for the two houses, individually, and overall 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.63 to 0.65 and show the strongest relationship between ER and bird age.

Table 8. Coefficient Estimates of NMHC ER regression for houses Tyson 1-5 and Tyson 3-3 (ER is not included when bird age is < 7d with new bedding)

House	**a** (± S.E.)	**b** (± S.E.)	**c** (± S.E.)	**d** (± S.E.)	r^2
T1-5	0.22 (± 0.25)	0.133 (± 0.04)	- 5.7 e^{-4} (±1.7 e^{-03})	9.4 e^{-5} (± 2.2 e^{-5})	0.65
T3-3	0.70 (± 0.097)	- 4.0 e^{-03} (±9.0 e^{-03})	9.0 e^{-4} (±1.8 e^{-4})	N/S	0.65
Overall	0.39 (± 0.15)	-0.078 (± 0.0244)	3.0 e^{-03} (±1.0 e^{-03})	5.8 e^{-5} (± 1.3 e^{-5})	0.63

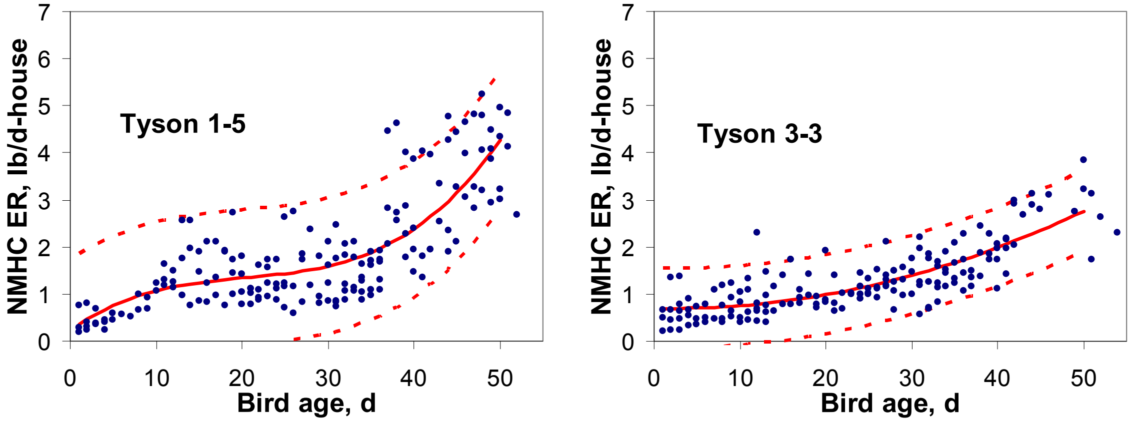


Figure 32. NMHC emission rate (ER) per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line and the dash lines are 95% prediction limits.

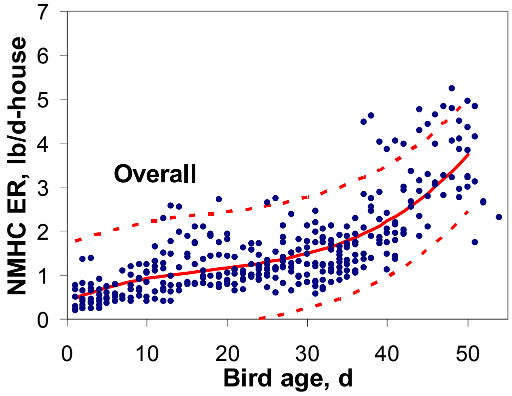


Figure 33. NMHC emission rate (ER) per house vs. bird age. The solid line is the regression line and the dash lines are 95% prediction limits.

Figure 34 provides the daily NMHC ER for the two houses for the entire monitoring period with 11.4 flocks and downtime between flocks. The daily ER varied from 0 to 5.24 lb/d-house (0 to

2.4 kg/d-house). The highest ER was 5.24 and 3.84 lb/d-house (2.4 and 1.7 kg/d-house) for Tyson 1-5 and Tyson 3-3, respectively. The average ER for Tyson 1-5 over the six flocks was 1.86 ± 1.07 lb/d-house (0.8 ± 0.5 kg/d-house) which is significantly different from 1.43 ± 0.69 lb/d-house (0.6 ± 0.3 kg/d-house) for Tyson 3-3 (P=0.017) at α =0.05. The average ER of 11.4 flocks was 1.68 ± 0.94 lb/d-house (0.8 ± 0.4 kg/d-house).

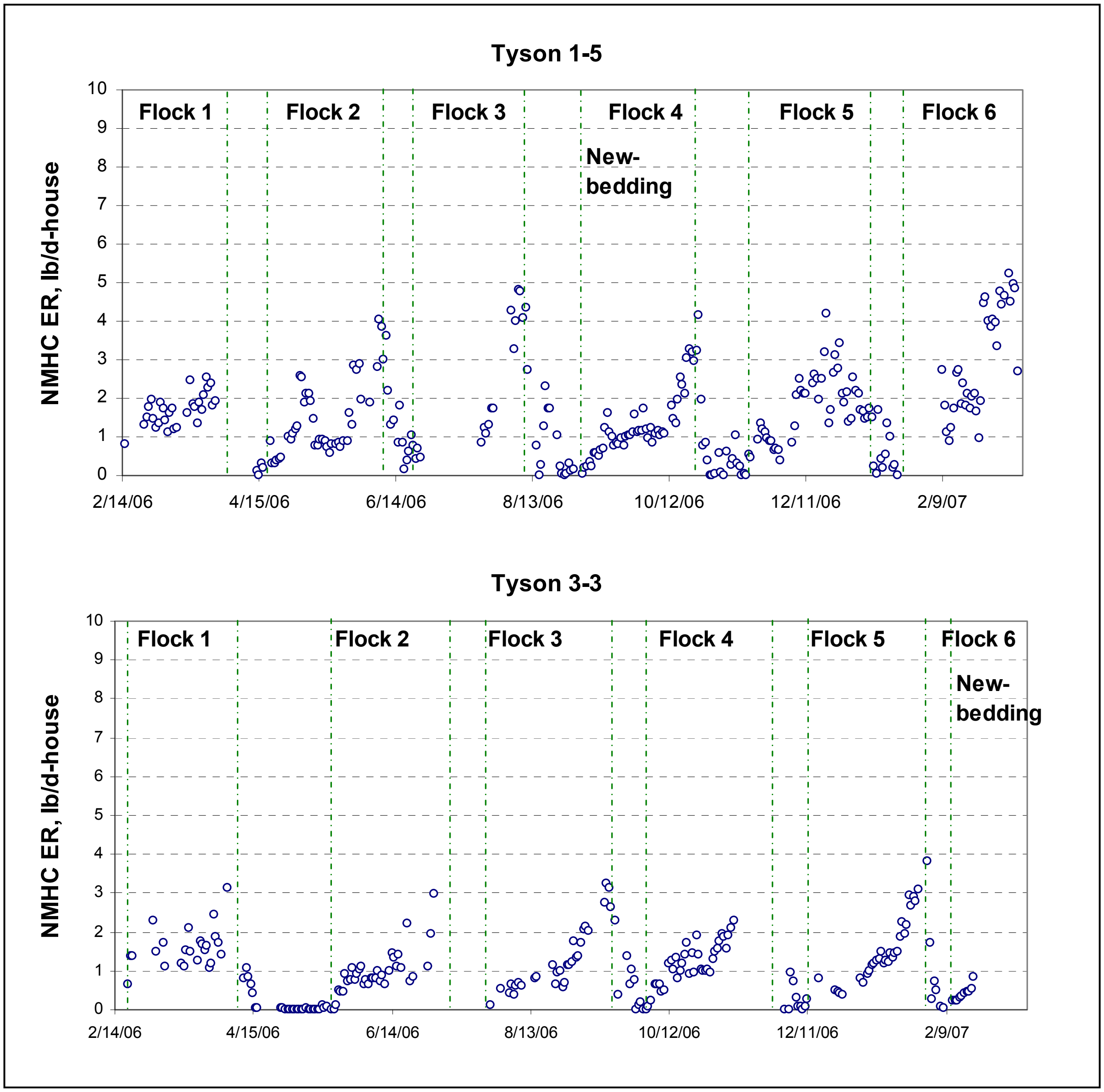


Figure 34. Daily NMHC emission rate (ER) over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

NMHC ER during Downtime between Flocks

The NMHC ER during the downtime was tested for the environmental variables effect. VR of the houses had a linear relationship with NMHC ER (Figure 35). The average NMHC ER for the two houses during downtime was 0.45 ± 0.64 lb/d-house (0.2 ± 0.3 kg/d-house).

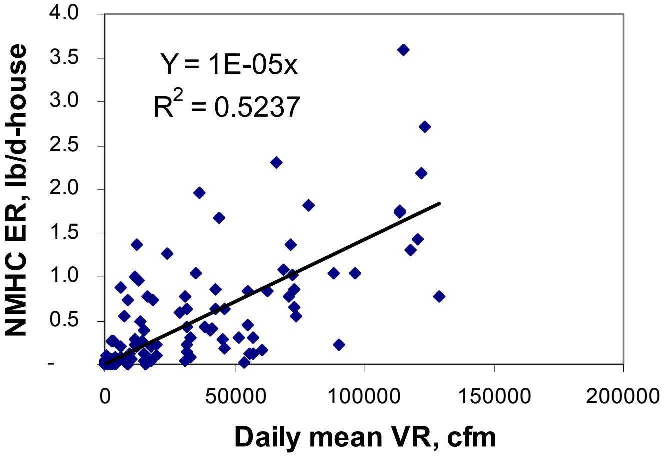


Figure 35. NMHC emission rate(ER) vs. ventilation rate (VR) during downtime.

NMHC ER per Animal Unit (AU)

Figures 36, 37, and 38 present NMHC ER in terms of 500 kg animal unit (kg/d-AU) for all 11.4 flocks from the two houses. The ER per AU versus bird age showed different trends for the flocks with new bedding and built-up litter. ER decreased with bird age. The ER per AU of the flocks with built-up litter started high for the first three weeks but trended downward in the forth week and stabilized to be stable with bird growth. There was no significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU (P=0.4). The daily ER per AU was 0.024 ± 0.022 and 0.28 ± 0.51 kg/d-AU for Tyson 1-5 and Tyson 3-3, respectively. The overall ER per AU was 0.25 ± 0.33 kg/ d-AU.

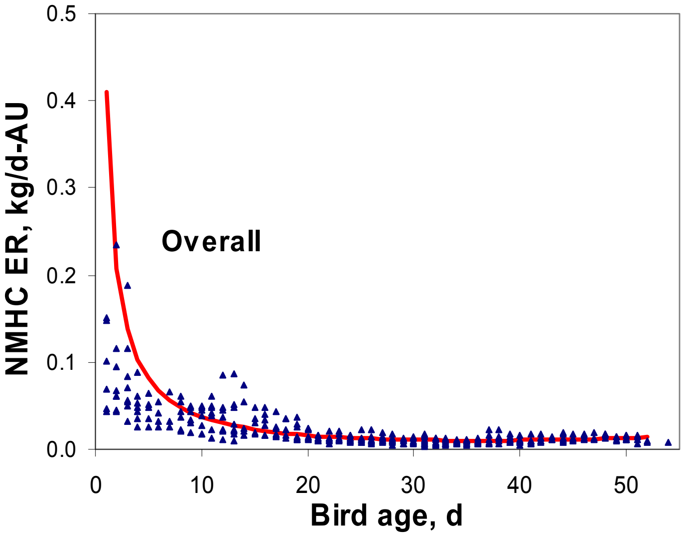


Figure 36. Relationship between NMHC ER per AU (500 kg) vs. bird age.

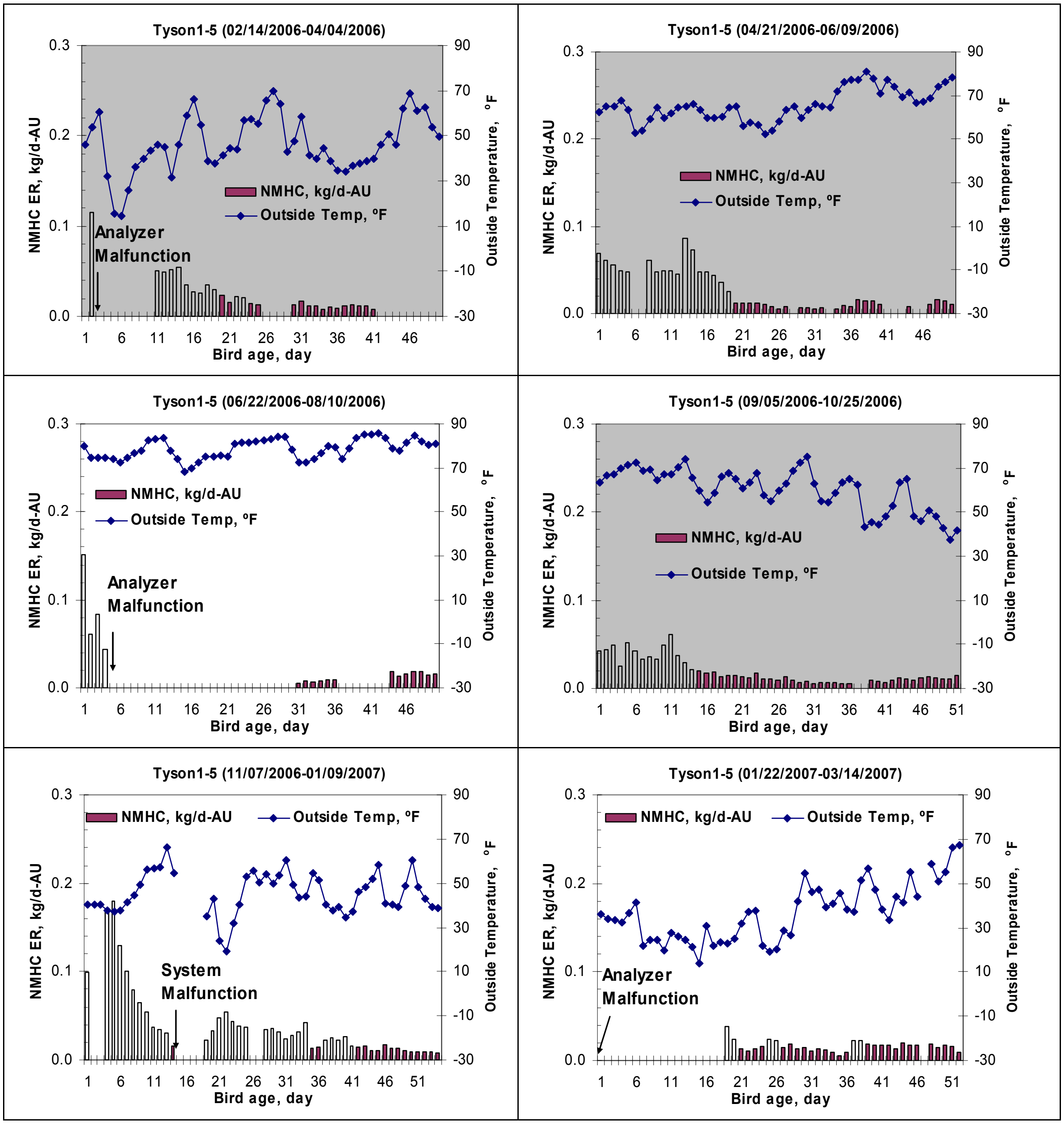


Figure 37. Tyson 1-5 NMHC emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age

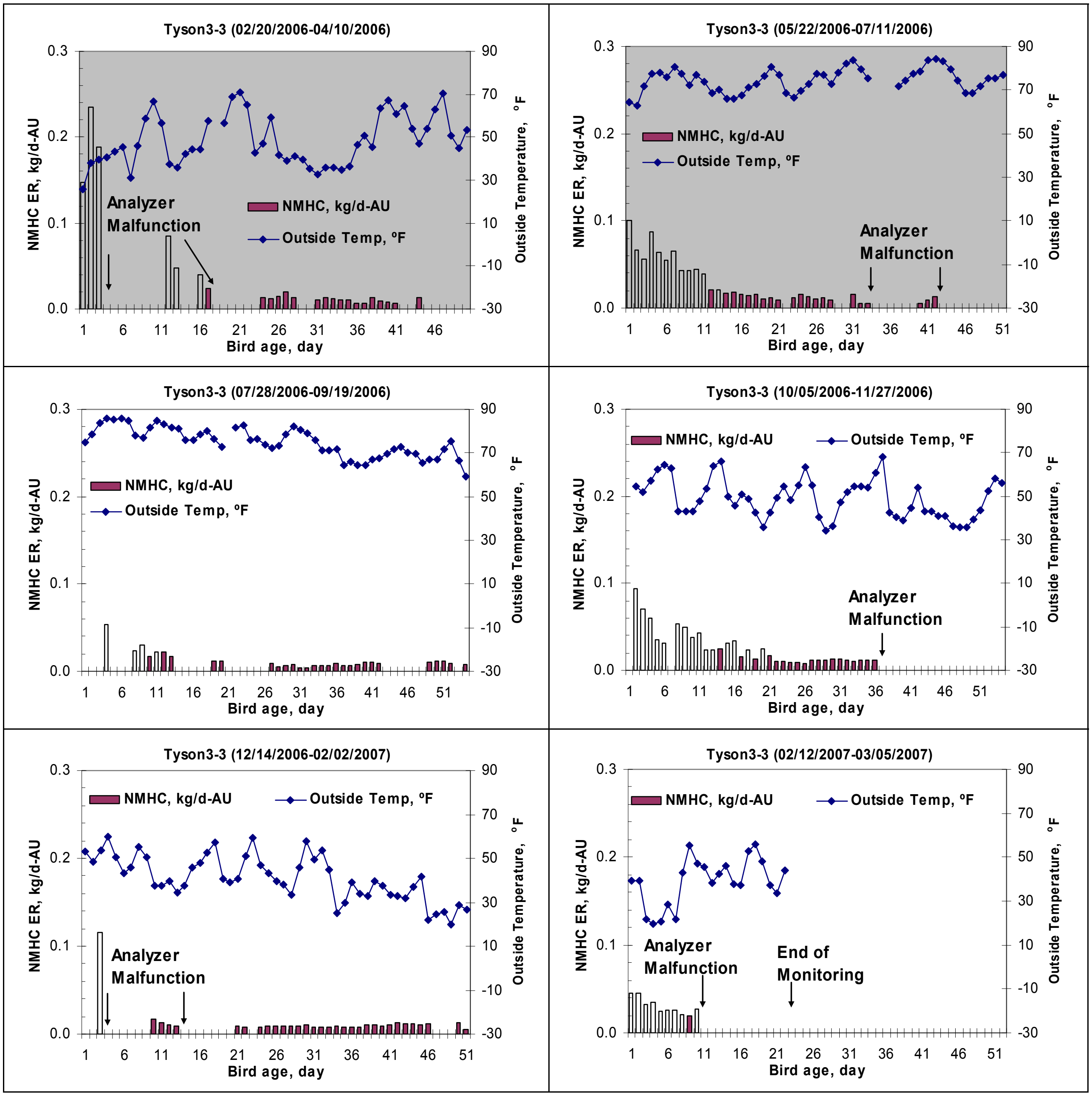


Figure 38. Tyson 3-3 NMHC emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age

Environmental Effect on NMHC ER

To assess the impact of environmental variables on the NMHC emission from the broiler houses, a multiple regression analysis was performed to relate NMHC ER (lb/d-house) to bird age (d), interior temperature (^{o}F), RH (%), VR (cfm/bird) and litter status (0 for new bedding; 1 for built-up litter). Daily mean values of the above variables were used for the regression analysis, and the results are shown in Table 9. Interior RH and litter status showed significant effects on NMHC (P=0.003), with RH negatively related to NMHC ER and new bedding leading to lower NMHC ER.

Table 9. Multiple regression analysis of NMHC ER (lb/d-house) to bird age (d), interior temperature, RH (%), and litter status (LS) (R^2=0.68)

NMHC ER, lb d^{-1} $house^{-1}$= $\beta_0 + \beta_1$x Age+ β_2 x Age^2+ β_3 x Age^3+ β_4 x T_i + β_5 x RH_i+ β_6 x VR+ β_7 x LS

Term	Estimate	S.E	Prob>|t|
β_0= Intercept	1.58	0.25	<0.001
β_1= Bird age	0.079	0.022	<0.001
β_2= Bird age^2, d^2	- 3.0 e^{-03}	1.0 e^{-03}	<0.001
β_3= Bird age^3, d^3	5.7 e^{-05}	1.2 e^{-05}	<0.001
β_4= Inside Temp., ºF	N/S		
β_5= Inside RH, %	-0.026	3.8 e^{-03}	<0.001
β_6= VR, cfm/bird	N/S		
β_7= LS, 0 or 1	0.31	0.086	0.003

Annual NMHC Emission

The annual NMHC emission from each house is the accumulation of daily ERs over 365 days. When 5.4 flocks were grown for an average of 52 d and the average flock cumulative emission was 87.5 lb/flock (39.7 kg/flock), the annual emission (± S.E.) was 510 ± 59.6 lb/yr-house (231 ± 27.0 kg/yr-house). On the basis of number of birds marketed the annual average NMHC emission (± S.E.) was 3.9 ± 0.45 lb per 1,000 birds marketed or 1.77 ± 0.21 g per bird marketed.

NMHC Speciation

Ambient background was not sampled for NMHC. It was assumed that background ambient air consisted of the same NMHC compounds emitted from the houses. Also, it was assumed that the empty house and occupied house had similar chemical profiles for detectable compounds, but the concentrations would change between the empty or occupied house. Air samples from three different sections of empty and occupied houses were speciated (Figure 17). Table 10 provides a list of net concentration levels for the combined top 25 NMHCs from the samples collected in the empty and the occupied house. This table also includes the mass conversion coefficient for all compounds that were identified and quantified. The ER of all the compounds can be calculated by multiplying the NMHC ER with the corresponding mass conversion coefficient provided in Table 10.

Table 10. Top-25 speciated NMHC concentration levels (ppb) and mass conversion coefficients (lb/lb-C_3H_8) for samples collected in the empty and occupied broiler house

Compound	Empty house		Occupied house	
	Sample concentration, ppb	Conversion Coefficient, lb/lb·C_3H_8	Sample concentration, ppb	Conversion Coefficient, lb/lb·C_3H_8
2,3-Butanedione	4.6	0.010	260.7	0.480
2-Pentanone	5.7	0.015	6.5	0.015
2-Butanone	N/A	N/A	14.9	0.023
2-Methyl propanoic acid	N/A	N/A	7.7	0.014
2-Methyl-3-Pentanone	N/A	N/A	12.4	0.040
3-Hydroxy-2-Butanone	3.5	0.007	15.8	0.030
3-Methylindole	1.8	0.013	N/A	N/A
3-Methyl butanoic acid	N/A	N/A	9.4	0.026
4-Ethylphenol	1.8	0.011	N/A	N/A
4-Methylphenol	7.1	0.032	N/A	N/A
Acetamide	N/A	N/A	10.1	0.006
Acetic acid	67.6	0.049	344.1	0.221
Acetone	30.1	0.032	40.9	0.038
Acetonitrile	N/A	N/A	13.5	0.006
Benzalaldehyde	10.7	0.048	N/A	N/A
Benzoic acid	8.2	0.043	N/A	N/A
Butanoic acid	3.3	0.007	18.9	0.036
Butanol	301.2	0.542	39.3	0.062
Dimethyl disulfide	7.2	0.008	7.8	0.008
Dimethyl sulfone	6.9	0.008	4.6	0.005
Ethanol	28.6	0.016	120.1	0.059
Hexane	22.6	0.071	10.5	0.029
Indole	N/A	N/A	3.9	0.020
Isoprene	8.3	0.017	N/A	N/A
Methanol	63.8	0.012	160.4	0.028
Pentane	N/A	N/A	9.0	0.017
Phenol	18.3	0.063	N/A	N/A
Propanoic acid	5.5	0.007	14.4	0.017
Propanol	5.6	0.006	15.6	0.015
Propene	N/A	N/A	10.9	0.007
Sulfolane	1.7	0.005	N/A	N/A
Tetra methyl pyrazine	N/A	N/A	3.4	0.027
Toluene	50.2	0.197	N/A	N/A
Triethyl citrate	14.0	0.282	N/A	N/A
Trimethyl oxazalone	N/A	N/A	5.1	0.018
Unknown compound	10.5	0.122	N/A	N/A

TSP Emission

TSP ER Estimation/Prediction

TSP ER was correlated to the bird age, body weight and VR, was weakly correlated with inside RH and was not correlated with outside temperature, RH, or inside temperature. Moreover, there existed a very strong positive relationship among bird age, body weight and VR. Among the three variables, bird age is the most predominant influencing factor. For the flocks on new bedding, there was no clear bedding effect on TSP ER. Because of the unusually high mortality in flock 5 at Tyson 1-5, this flock was not used in the ER prediction. The TSP ER per house or per bird from all data except for the flock 5 ERs at Tyson 1-5, as shown in Figures 39 and 40, may be described using the following regression equation:

$$\sqrt[3]{\boldsymbol{TSP\ ER}} = \boldsymbol{a + b\,X + c\,X^2} \qquad [7]$$

where

$\boldsymbol{TSP\ ER}$ = lb d^{-1} house^{-1};

$\boldsymbol{X}$= bird age.

Table 11 provides the prediction parameter estimates for the two houses, individually, and overall 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.82 to 0.88 and show the strongest relationship between ER and bird age.

Table 11. Coefficient Estimates of TSP ER regressions for broiler houses Tyson 1-5 and Tyson 3-3

House	**a** (± S.E.)	**b** (± S.E.)	**c** (± S.E.)	r^2
1-5	0.48 (± 0.042)	0.061 (± 4.0 e^{-03})	- 4.7 e^{-4} (±7.8 e^{-5})	0.87
3-3	0.34 (± 0.040)	0.086 (± 4.0 e^{-03})	- 9.7 e^{-4} (±6.9 e^{-5})	0.88
Overall	0.40 (± 0.030)	0.074 (± 3.0 e^{-03})	- 7.5 e^{-4} (±5.3 e^{-5})	0.86

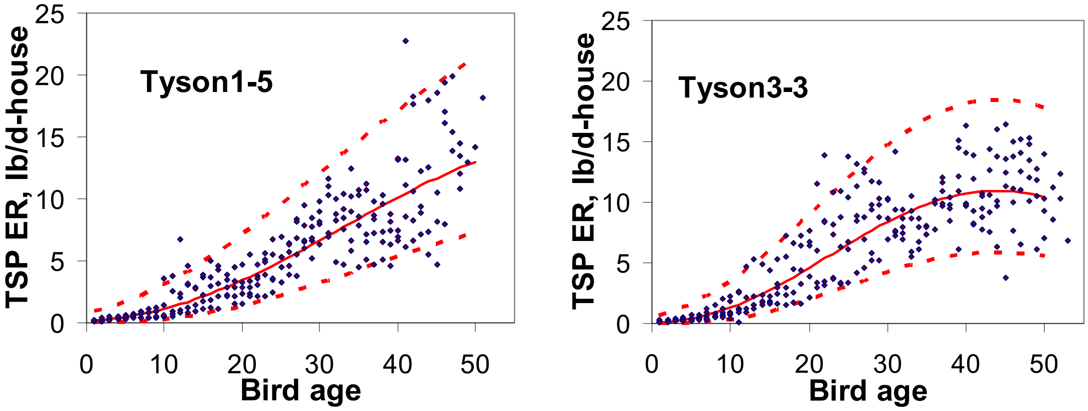


Figure 39. TSP emission rate (ER) per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line and the dash lines are 95% prediction limits.

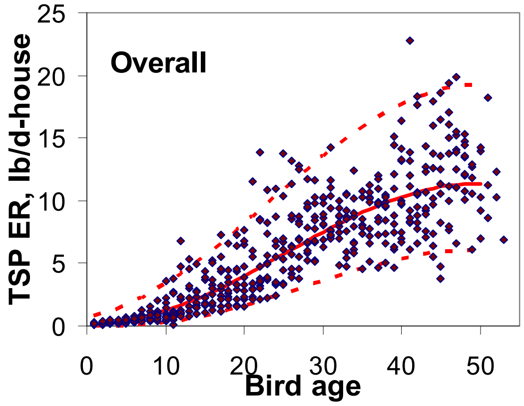


Figure 40. TSP emission rate (ER) per house vs. bird age. The solid line is the regression line; dash lines are 95% prediction limits.

Figure 41 provides the daily TSP ER for the two houses for the entire monitoring period with 11.4 flocks and downtime between flocks. The daily ER varied from 0 to 22.8 lb/d-house (0 to 10.3 kg/d-house). The highest ER was 22.8 and 16.3 lb/d-house (10.3 and 7.3 kg/d-house) for Tyson 1-5 and Tyson 3-3, respectively. Note that the emissions between the vertical dashed lines in Figure 41 represent periods between flocks when no birds were in the houses (i.e., downtime). The average ER was 5.92 ± 4.33 lb/d-house (2.69 ± 1.96 kg/d-house) for Tyson 1-5 and 6.34 ± 4.03 lb/d-house (2.88 ± 1.83 kg/d-house) for Tyson 3-3. The average ER of all 11.4 flocks was 6.13 ± 4.13 lb/d-house (2.78 ± 1.87 kg/d-house).

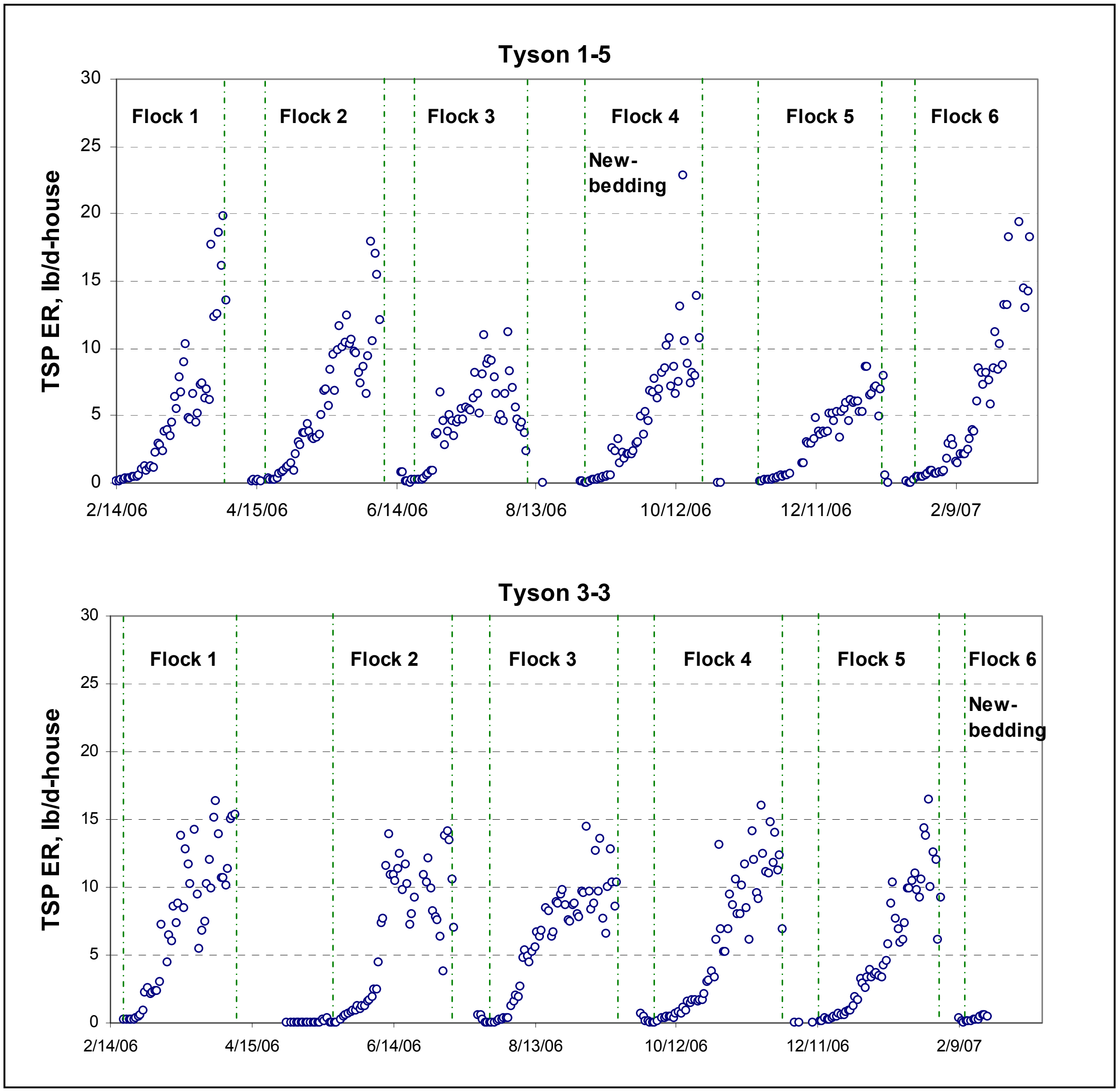


Figure 41. Daily TSP emission rate (ER) over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

TSP ER during Downtime between Flocks

The TSP ER during the downtime was tested for the environmental variables effect. VR of the houses had a linear relationship with TSP ER (Figure 42). The average TSP ER for the two houses during downtime was 0.12 ± 0.19 lb/d-house (0.05 ± 0.086 kg/d-house).

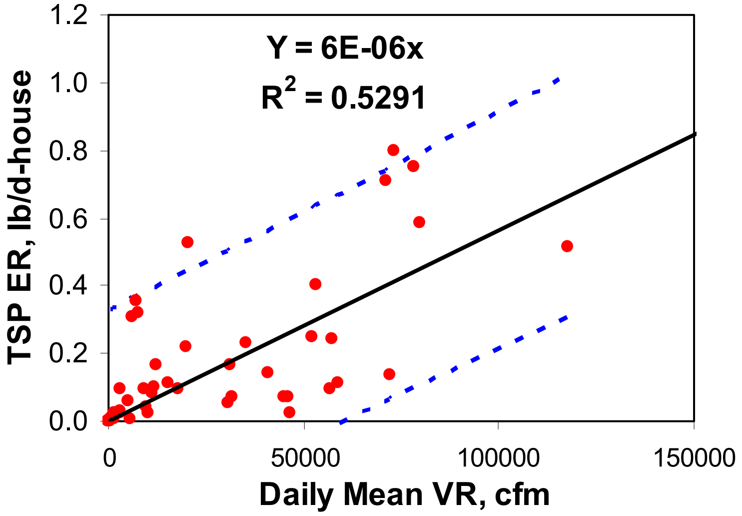


Figure 42. TSP emission rate (ER) vs. ventilation rate (VR) during downtime. The solid line is the regression line; dash lines are 95% prediction limits.

TSP ER per Animal Unit (AU)

Figures 43, 44, and 45 present TSP ER in terms of 500 kg animal unit (kg/d-AU) for all 11.4 flocks from the two houses. There was no clear trend between the ER per AU and bird age (Figure 43). ER per AU of Tyson 1-5 was significantly different to the ER of Tyson 3-3 with P=0.024 at α = 0.05. The daily ER per AU was 0.50 ± 0.13 and 0.54 ± 0.01 kg/d-AU for Tyson 1-5 and Tyson 3-3, respectively. The overall ER per AU was 0.52 ± 0.01 kg/ d-AU.

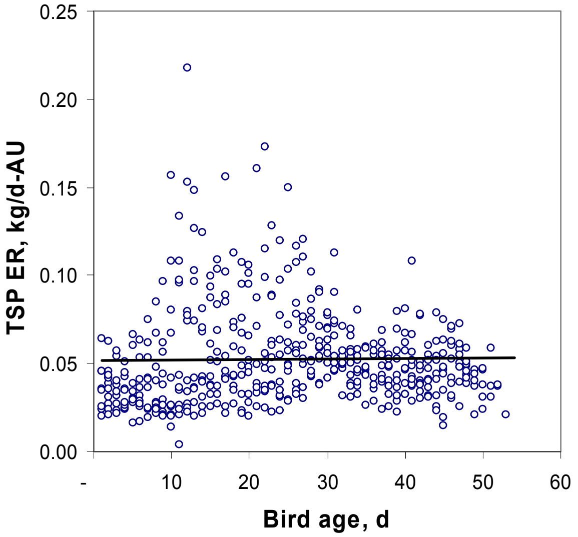


Figure 43. TSP emission rate (ER) per day per AU (500kg) vs. bird age for the two houses over one year period

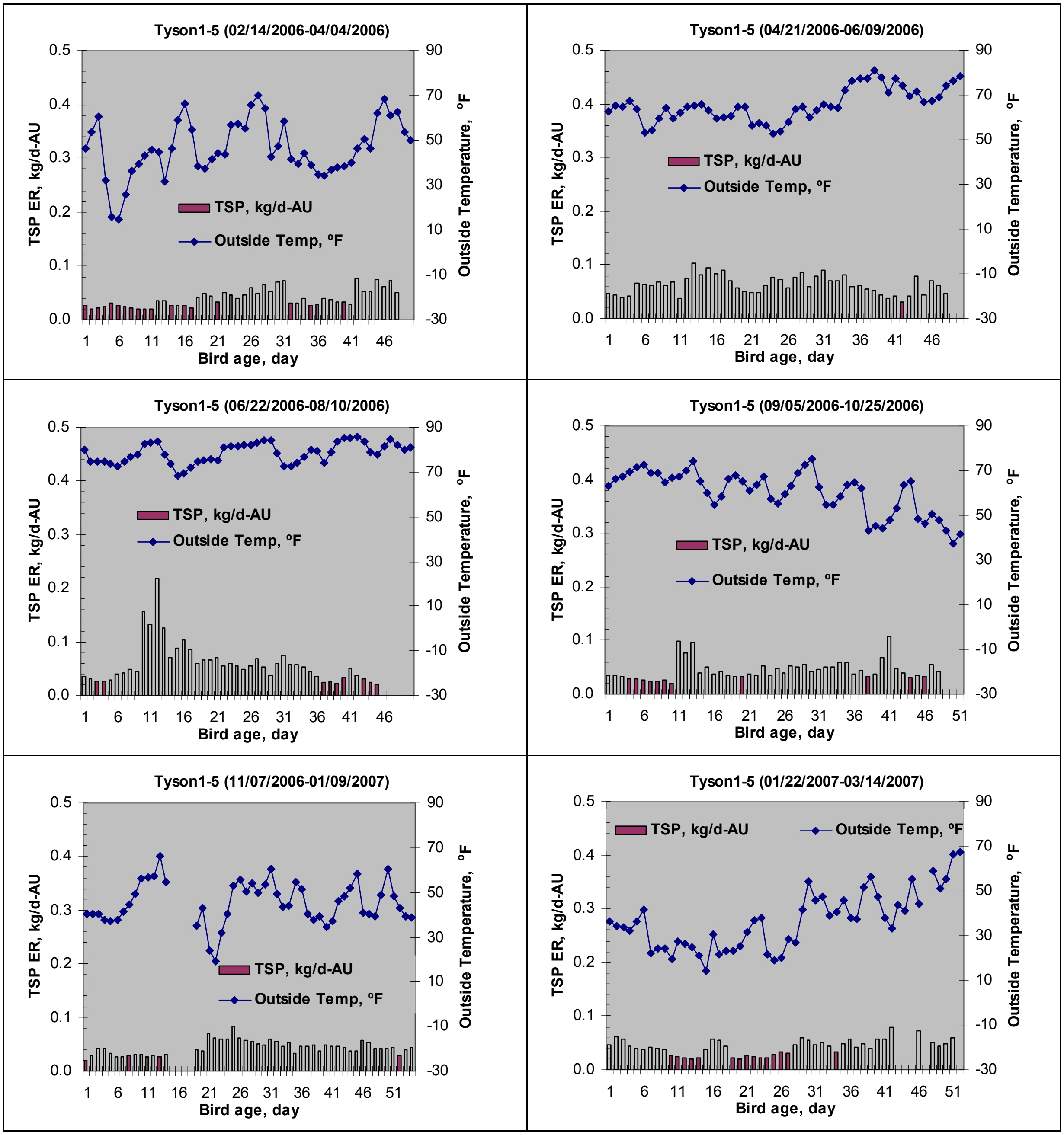


Figure 44. Tyson 1-5 TSP emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

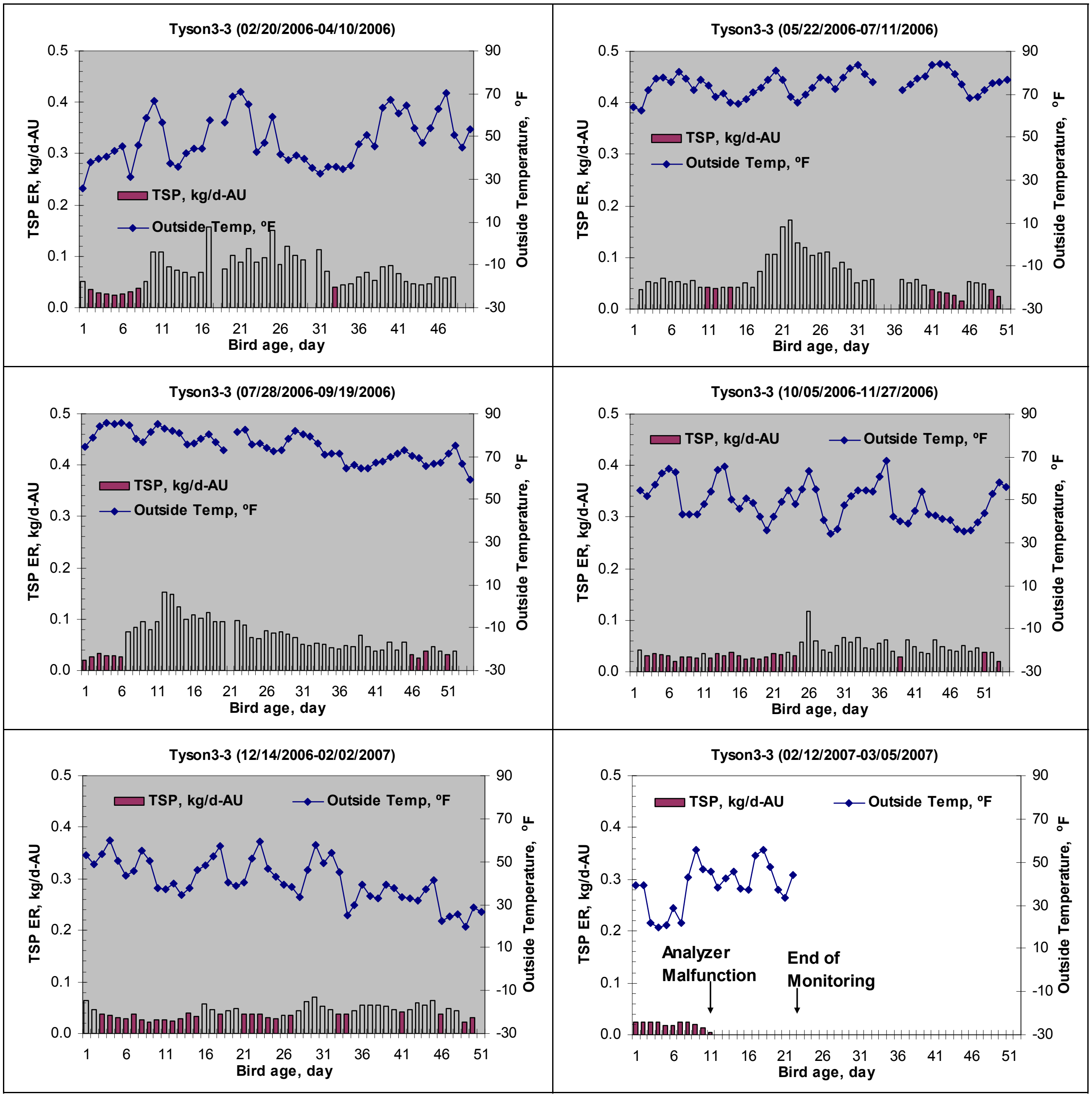


Figure 45. Tyson 3-3 TSP emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

Effects of Environmental Variables on TSP ER

To assess the impact of environmental variables on TSP emission from the two broiler houses, a multiple regression analysis was performed to relate TSP ER to bird age (d), interior temperature (^{o}F), RH (%), VR (cfm/bird) and litter status (0 for new bedding; 1 for built-up litter). The results of the regression analysis are shown in Table 12. Except for interior temperature and litter status, all variables were significant for TSP ER at α = 0.05. The TSP ER (lb/d-house) was positively correlated to temperature and RH.

Table 12. Multiple regression analysis of TSP to bird age, interior temperature, RH, Ventilation rate (VR), and litter status (LS) (R^2=0.87)

$$\sqrt[3]{\textbf{\textit{TSP ER}}} = \beta_0 + \beta_1 \text{x Age} + \beta_2 \text{ x Age}^2 + \beta_3 \text{ x } T_i + \beta_4 \text{ x } RH_i + \beta_5 \text{ x VR} + \beta_6 \text{ x LS}$$

Term	Estimate	S.E	Prob>|t|
β_0= Intercept	1.19	0.092	<.0001
β_1= Bird age, d	0.066	$3.5e^{-3}$	<.0001
β_2= Bird age^2, d^2	0.00	$7.0e^{-5}$	<.0001
β_3= Inside Temp., ºF	N/S		
β_4= Inside RH, %	-0.014	0.002	<.0001
β_5= VR, cfm/bird	0.058	0.0122	0.0018
β_6= LS, 0 or 1	N/S		

Annual TSP Emission

The annual TSP emission from each house is the accumulation of daily ERs over 365 days. When 5.4 flocks were grown for 52 days and the average flock cumulative emission rate was 319 lb/flock (145 kg/flock), the annual emission rate (± S.E.) was 1,731 ± 58.6 lb/year-house (785 ± 26.6 kg/year-house). On the basis of number of birds marketed the annual average TSP emission (± S.E.) was 13.2 ± 0.46 lb per 1,000 birds marketed or 6.01± 0.21 g per bird marketed.

PM_{10} Emission

PM_{10} ER Estimation/Prediction

PM_{10} ER was correlated to bird age, body weight and VR, was weakly correlated with inside RH and not correlated with outside temperature, RH, or inside temperature. Among the three influencing variables, bird age was most predominant. For flocks on new bedding, there was no clear bedding effect on PM_{10} ER. Because of the unusually high mortality in flock 5 at Tyson 1-5, this flock was not used in the ER prediction. The PM_{10} ER per house or per bird from all data except for the flock 5 ER at Tyson 1-5, as shown in Figures 46 and 47, may be described using the following regression equation:

$$\sqrt[3]{PM_{10}\ ER} = a + b\,X + c\,X^2 \qquad [8]$$

where

PM_{10} ***ER*** = lb d^{-1} house^{-1};

X= bird age.

Table 13 provides the prediction parameter estimates for the two houses, individually, and over all 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.86 to 0.88 and show the strongest relationship between ER and bird age.

Table 13. Coefficient Estimates of PM_{10} ER prediction models for the houses, Tyson 1-5 and Tyson 3-3.

House	**a** (± S.E.)	**b** (± S.E.)	**c** (± S.E.)	r^2
T1-5	0.3 (± 0.034)	0.043 (± 0.003)	- 2.6 e^{-4} (±6.1 e^{-5})	0.88
T3-3	0.27 (± 0.031)	0.060 (± 0.003)	- 6.3 e^{-4} (±5.3 e^{-5})	0.87
Overall	0.29 (± 0.024)	0.052 (± 0.002)	- 4.5 e^{-4} (±4.2 e^{-5})	0.86

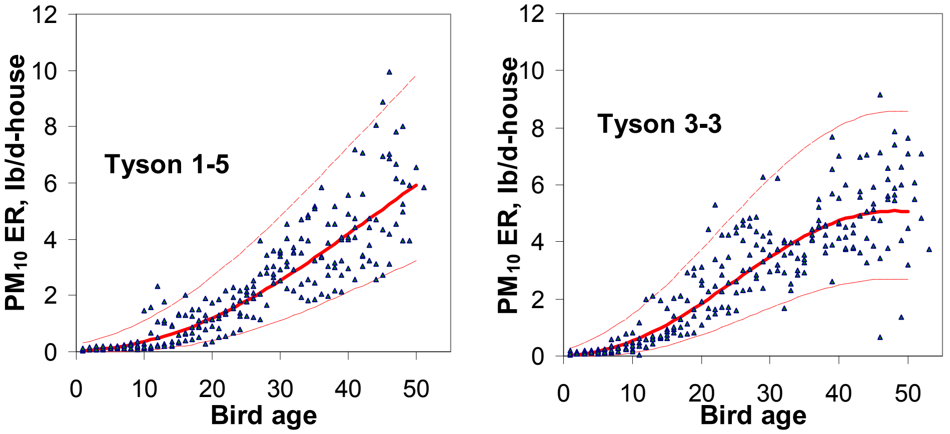


Figure 46. Relationship between PM_{10} ER per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line; dash lines are 95% prediction limits.

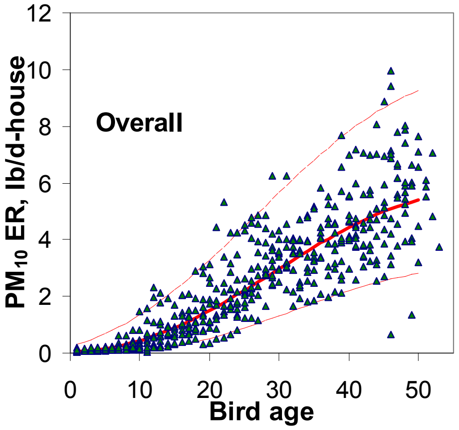


Figure 47. Relationship between PM_{10} ER per house vs. bird age. The solid line is the regression line; dash lines are 95% prediction limit.

Figure 48 provides the daily PM_{10} ER for the two houses for the entire monitoring period with 11.4 flocks and downtime between flocks. The daily ER varied from 0 to 9.95 lb/d-house (0 to 4.5 kg/d-house). The highest ER was 9.95 and 9.43 lb/d-house (4.5 and 4.3 kg/d-house) for Tyson 1-5 and Tyson 3-3, respectively. Note that the emissions between the vertical dashed lines in Figures 48 represent periods between flocks when no birds were in the houses (i.e., downtime). The average ER were 2.43 ± 1.98 lb/d-house (1.10 ± 0.9 kg/d-house) for Tyson 1-5 and 3.1 ± 2.02 lb/d-house (1.4 ± 0.92 kg/d-house) for Tyson 3-3. The average ER of all 11.4 flocks was 2.57 ± 1.88 lb/d-house (1.16 ± 0.85 kg/d-house).

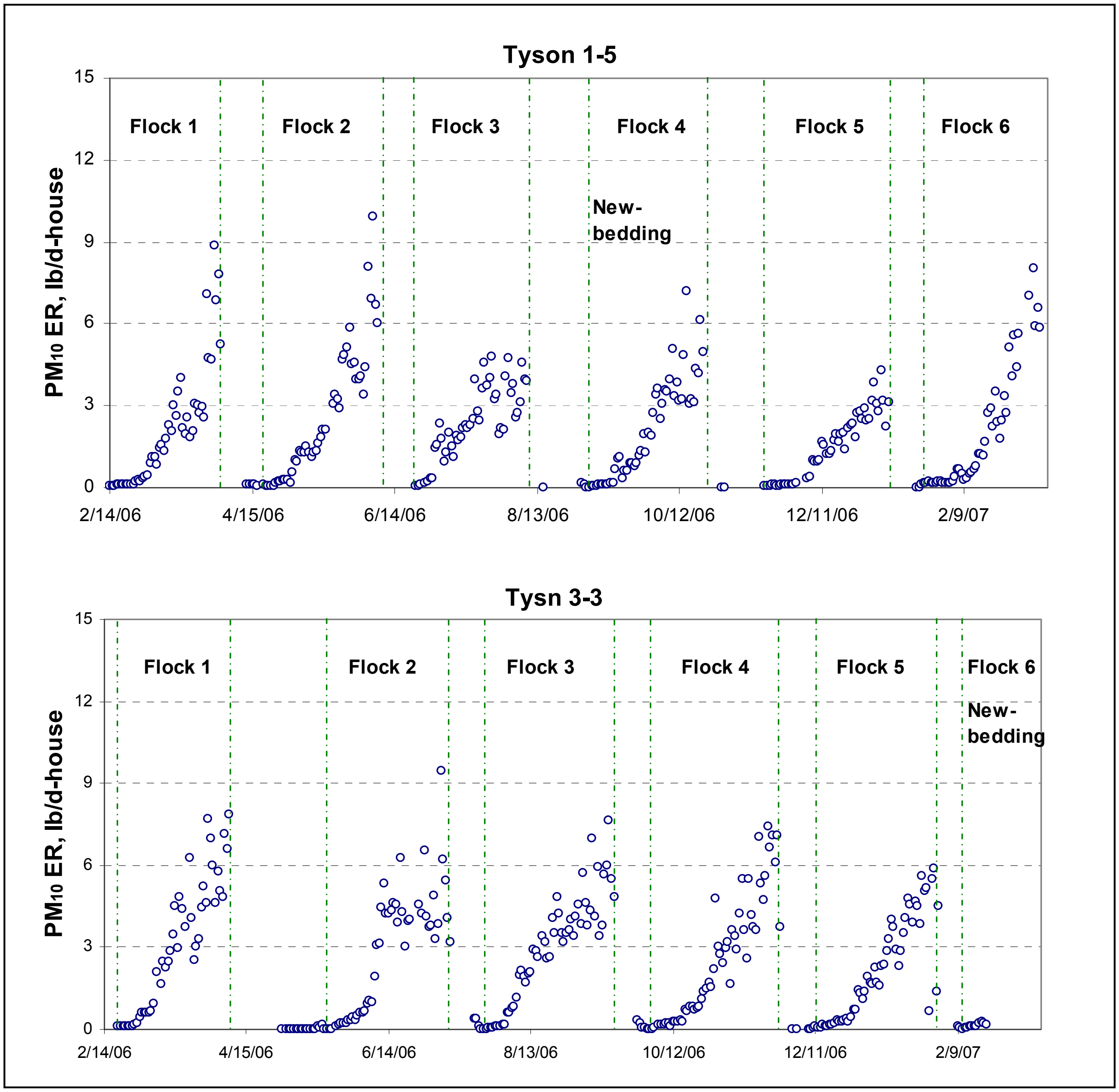


Figure 48. Daily PM_{10} emission over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

PM_{10} ER during Downtime between Flocks

The PM_{10} ER during the downtime was tested for the environmental variables effect. VR of the houses had a linear relationship with PM_{10} ER (Figure 49). The average PM_{10} ER for the two houses during downtime was 0.052 ± 0.085 lb/d-house (0.024 ± 0.039 kg/d-house).

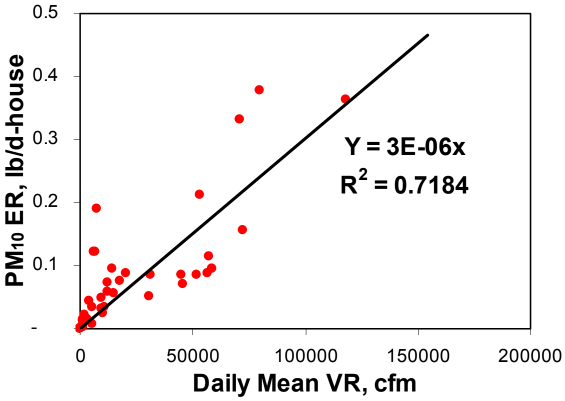


Figure 49. PM_{10} emission rate (ER) vs. ventilation rate (VR) during downtime.

PM_{10} ER per Animal Unit (AU)

Figures 50, 51, and 52 present PM_{10} ER in terms of 500 kg animal unit (g/d-AU) for 11.4 flocks from the two houses. There was no clear trend between the PM_{10} ER per AU and bird age (Figure 50). There was significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU with P<0.0001 at α = 0.05. The daily ER per AU was 18.2 ± 3.34 and 26.7 ± 4.65 g/d-AU for Tyson 1-5 and Tyson 3-3, respectively. The overall ER per AU was 20.3 ± 2.34 g/d-AU.

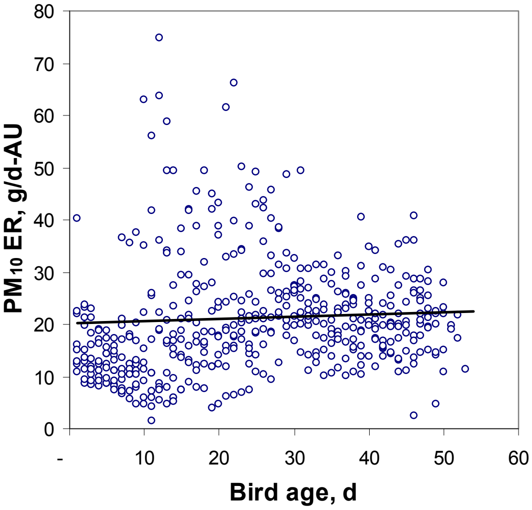
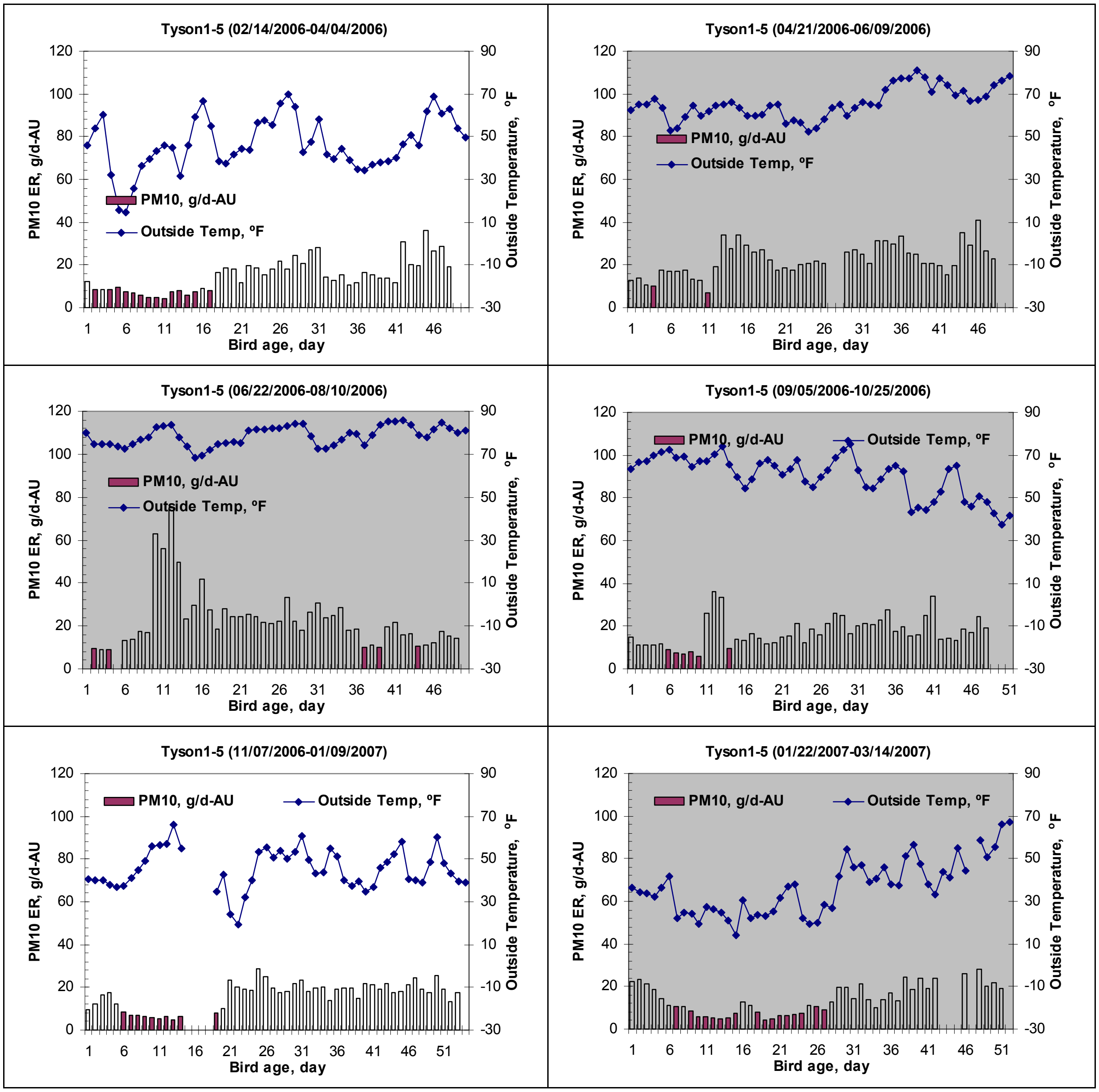


Figure 50. PM_{10} emission rate (ER) per day per animal unit (AU, 500kg) vs. bird age for the two houses over one year period.


Tyson1-5 (02/14/2006-04/04/2006)

Tyson1-5 (04/21/2006-06/09/2006)

Tyson1-5 (06/22/2006-08/10/2006)

Tyson1-5 (09/05/2006-10/25/2006)

Tyson1-5 (11/07/2006-01/09/2007)

Tyson1-5 (01/22/2007-03/14/2007)

Figure 51. Tyson 1-5 PM_{10} emission rate (ER) per animal unit (AU,v500 kg) and mean outside temperature vs. bird age.

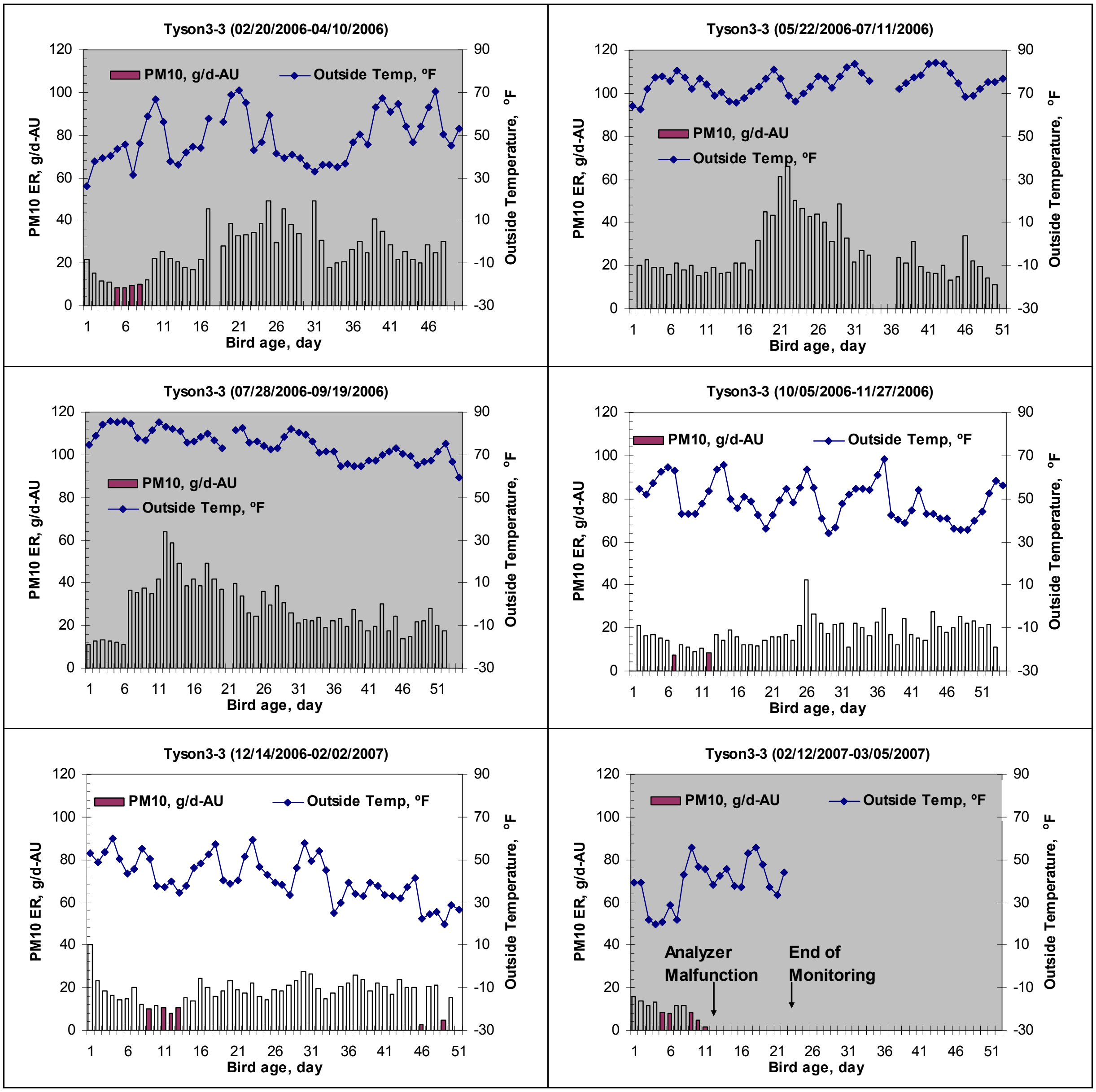


Figure 52. Tyson 3-3 PM_{10} emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

Effects of Environmental Variables on PM_{10} ER

To assess the impact of environmental variables on the PM_{10} emission from the two broiler houses with birds, a multiple regression analysis was performed to relate PM_{10} ER to bird age (d), interior temperature (°F), RH (%), VR (cfm/bird) and litter status (0 for new bedding; 1 for built-up litter). The daily mean values of the above variables were used for the regression analysis. The results of the regression analysis are shown in Table 14. Except for interior temperature and litter status, all variables were significant for PM_{10} ER at $\alpha = 0.05$. The PM_{10} ER (lb/d-house) was positively correlated with temperature and RH.

Table 14. Multiple regression analysis of PM_{10} for bird age, interior temperature, RH, Ventilation rate (VR), and litter status (LS) (R^2=0.88)

$$\sqrt[3]{PM_{10}\ ER} = \beta_0 + \beta_1 \text{x Age} + \beta_2 \text{ x Age}^2 + \beta_3 \text{ x } T_i + \beta_4 \text{ x } RH_i + \beta_5 \text{ x VR} + \beta_6 \text{ x LS}$$

Term	Estimate	S.E	Prob>|t|
β_0= Intercept	0.29	0.10	0.0042
β_1= Bird age, d	0.05	0.0022	<.0001
β_2= Bird age^2, d^2	-4.5 e^{-4}	4.47e^{-5}	<.0001
β_3= Inside Temp., ºF	N/S		
β_4= Inside RH, %	-0.006	0.00095	<.0001
β_5= VR, cfm/bird	0.049	0.0088	<.0001
β_6= LS, 0 or 1	N/S		

Annual PM_{10} Emission

The annual PM_{10} emission from each house is the accumulation of daily ERs over 365 days. When 5.4 flocks were grown to 52 days of age and the average flock cumulative ER was 133.8 lb/flock (60.7 kg/flock), the annual emission (± S.E.) was 727 ± 93.4 lb/yr-house (330 ± e42.3 kg/yr-house). On the basis of number of birds marketed the annual average PM_{10} emission (± S.E.) was 5.56 ± 0.71 lb per 1,000 birds marketed or 2.52 ± 0.33 g per bird marketed.

$PM_{2.5}$ Emission

$PM_{2.5}$ ER Estimation/Prediction

$PM_{2.5}$ ER was correlated to the bird age, body weight and VR, was weakly correlated with inside RH and not correlated with outside temperature, RH, and inside temperature. Among the three influencing variables, bird age is most predominant. For the flocks on new bedding, there was no clear bedding effect on $PM_{2.5}$ ER. Because of the unusually high mortality in flock 5 at Tyson 1-5, this flock was not used to predict the ER. The $PM_{2.5}$ ER per house or per bird from all data except for the flock 5 ERs at Tyson 1-5, as shown in Figures 53 and 54, may be described using the following regression equation:

$$\sqrt[3]{PM_{2.5}\ ER} = a + b\,X + c\,X^2 \qquad [9]$$

where

$PM_{2.5}$ **ER** = lb d^{-1} house^{-1};

X= bird age.

Table 15 provides the prediction parameter estimates for the two houses, individually, and over all 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.86 to 0.88 and show the strongest relationship between ER and bird age.

Table 15. Coefficient Estimates of $PM_{2.5}$ ER prediction models for broiler houses Tyson 1-5 and Tyson 3-3

House	**a** (± S.E.)	**b** (± S.E.)	**c** (± S.E.)	r^2
T1-5	0.147 (± 0.0107)	0.0147 (±3.6 e^{-04})	N/S	0.89
T3-3	0.216 (± 0.009)	0.0136 (±3.0 e^{-04})	N/S	0.88
Overall	0.187 (± 0.007)	0.014 (±2.0 e^{-04})	N/S	0.88

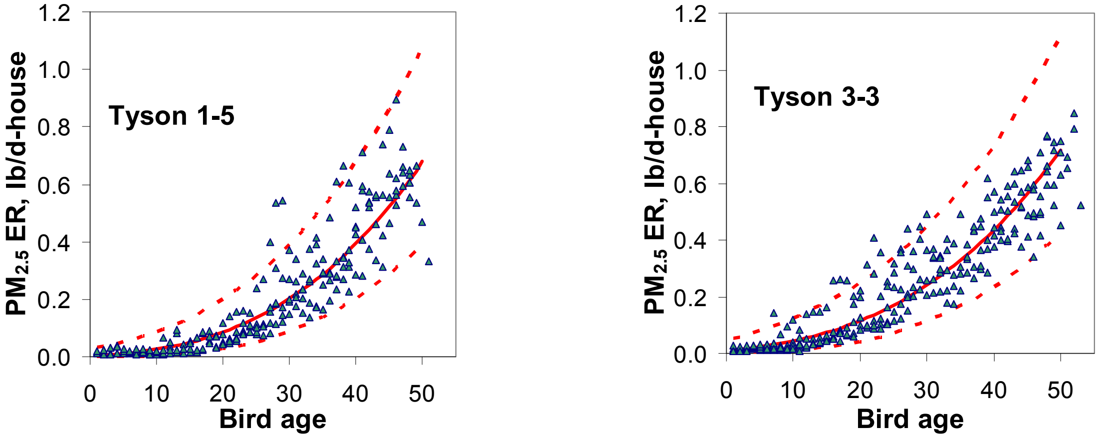


Figure 53. $PM_{2.5}$ emission rate (ER) per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line; dash lines are 95% prediction limits.

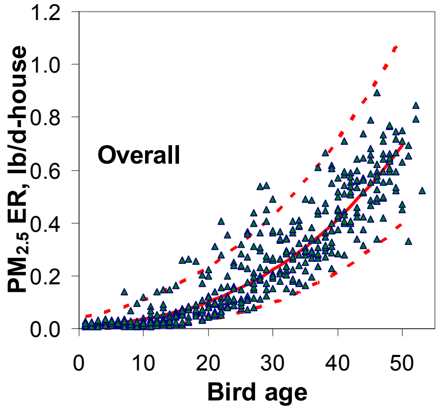


Figure 54. $PM_{2.5}$ emission rate (ER) per house vs. bird age. The solid line is the regression line; dash lines are 95% prediction limits.

Figure 55 provides the daily $PM_{2.5}$ ER for the two houses for the entire monitoring period with 11.4 flocks and downtime between flocks. The daily ER varied from 0 to 0.89 lb/d-house (0 to 0.40 kg/d-house). The highest $PM_{2.5}$ ER was 0.89 and 0.85 lb/d-house (0.40 and 0.39 kg/d-house) for Tyson 1-5 and Tyson 3-3, respectively. Note that the emissions between the vertical dashed lines in Figure 55 represent periods between flocks when no birds were in the houses (i.e., downtime). The daily mean values of the above variables were used for the regression analysis. The average ER was 0.23 ± 0.22 lb/d-house (0.10 ± 0.10 kg/d-house) for Tyson 1-5 and 0.26 ± 0.23 lb/d-house (0.12 and 0.10 kg/d-house) for Tyson 3-3. The average ER of 11.4 flocks was 0.25 ± 0.22 lb/d-house (0.11 and 0.10 kg/d-house).

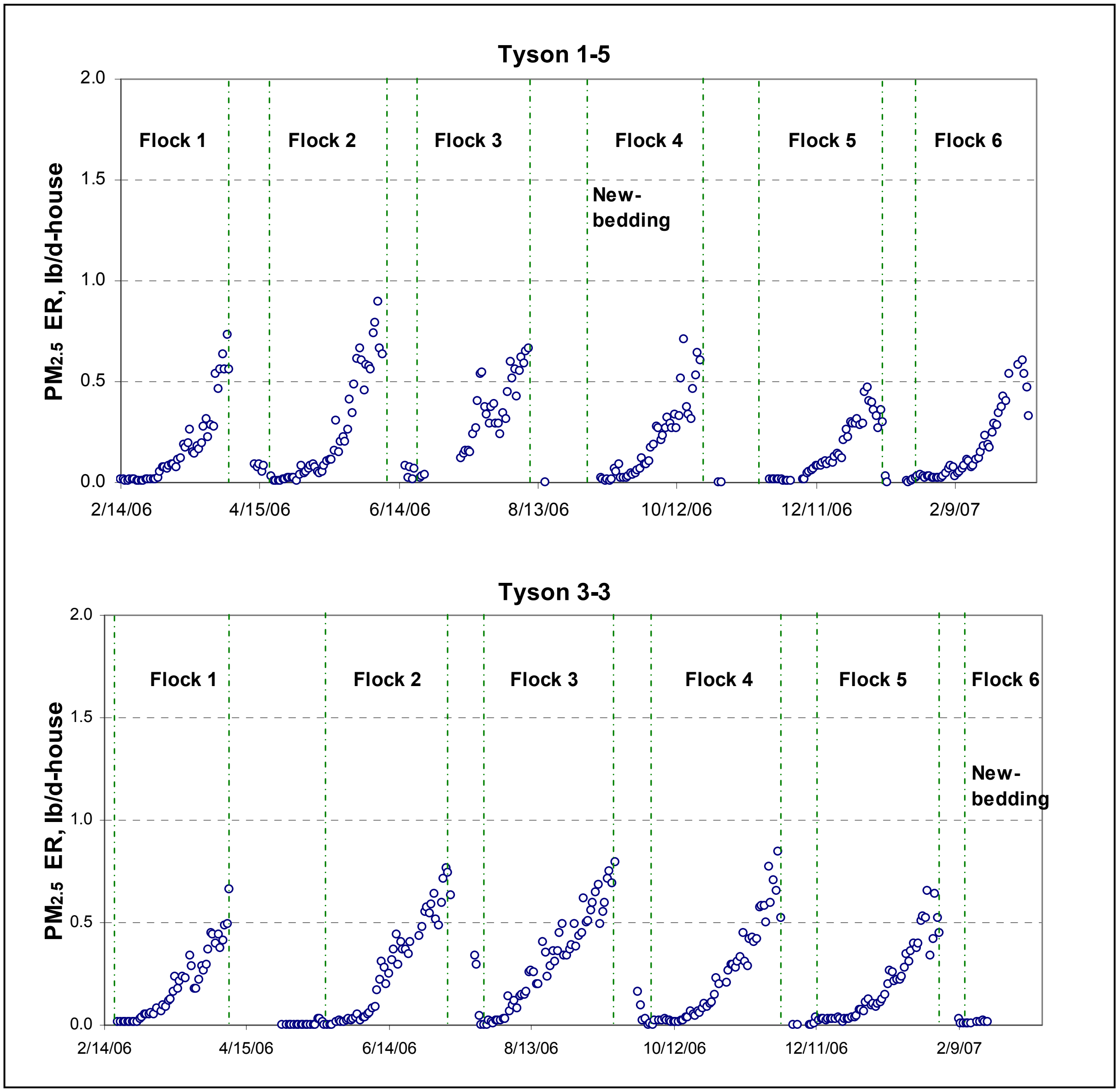


Figure 55. Daily $PM_{2.5}$ emission over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

$PM_{2.5}$ ER during Downtime between Flocks

The $PM_{2.5}$ ER during the downtime was tested for the environmental variables effect. VR of the houses had a linear relationship with $PM_{2.5}$ ER (Figure 56). The average $PM_{2.5}$ ER for the two houses during downtime was 0.03 ± 0.06 lb/d-house (0.014 ± 0.027 kg/d-house).

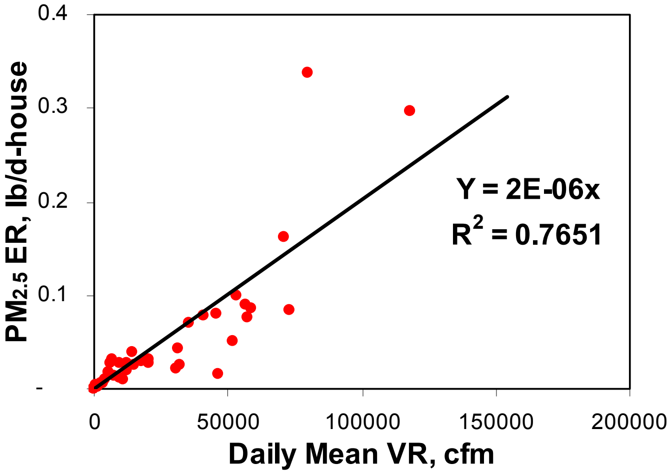


Figure 56. $PM_{2.5}$ emission rate(ER) vs. ventilation rate (VR) during downtime.

$PM_{2.5}$ ER per Animal Unit (AU)

Figures 57, 58, and 59 present $PM_{2.5}$ ER in terms of 500 kg animal unit (g/d-AU) for all 11.4 flocks from the two houses. There was a clear trend between the ER and bird age (Figure 57); the $PM_{2.5}$ ER per AU decreased during the first 11-d and increased slightly afterwards. There was a significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU (P=0.0023). The daily ER per AU was 1.59 ± 0.54 and 2.22 ± 1.35 g/d-AU for Tyson 1-5 and Tyson 3-3, respectively. The overall ER per AU was 1.91 ± 0.86 g/ d-AU.

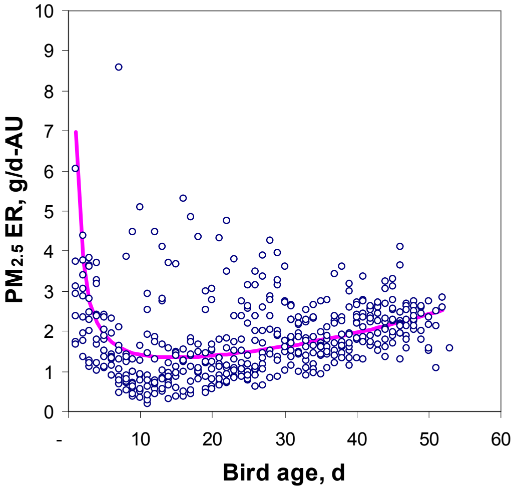


Figure 57. $PM_{2.5}$ emission rate (ER) per day per animal unit (AU, 500kg) vs. bird age for the two houses over one year period.

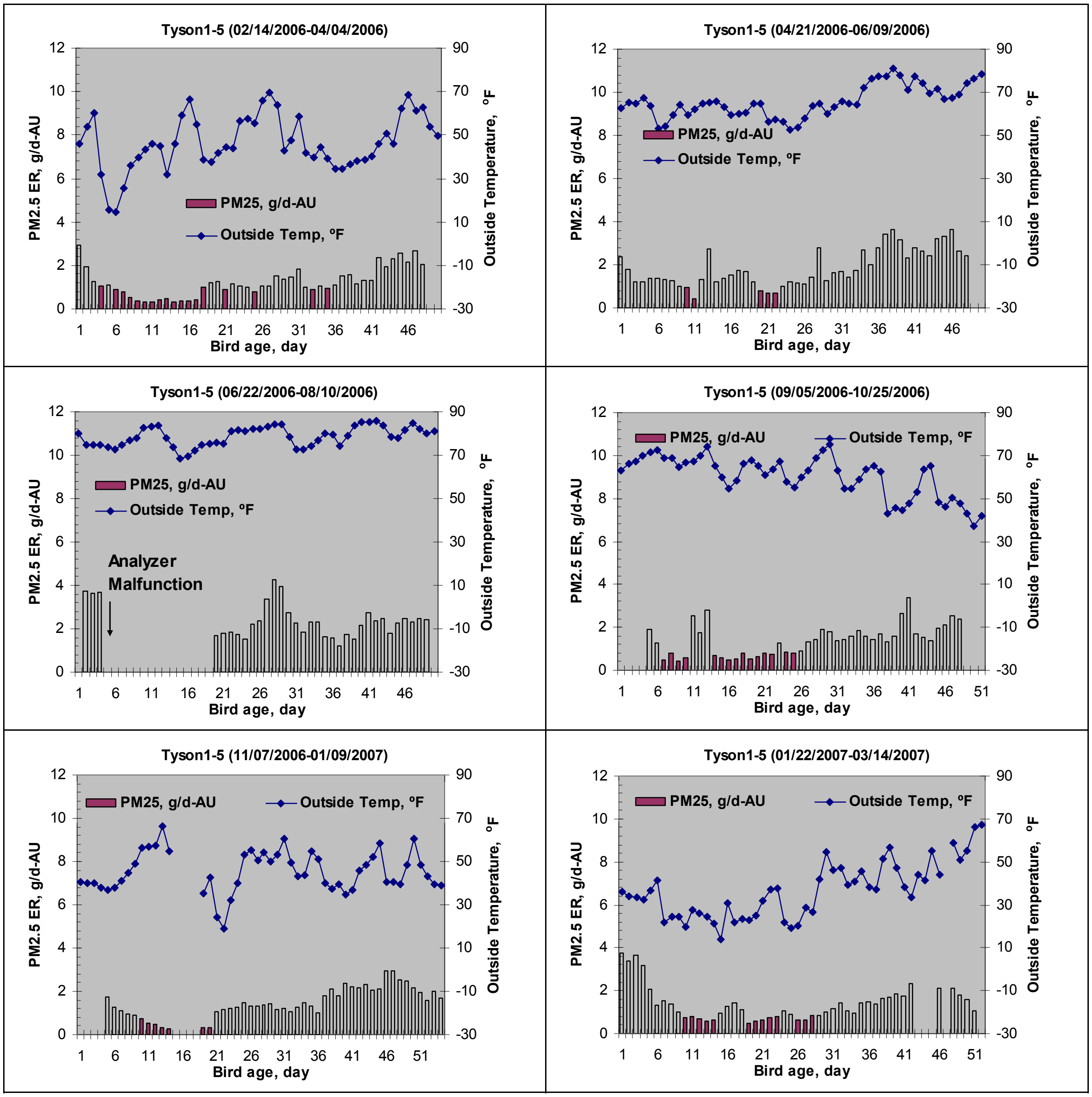


Figure 58. Tyson 1-5 $PM_{2.5}$ emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

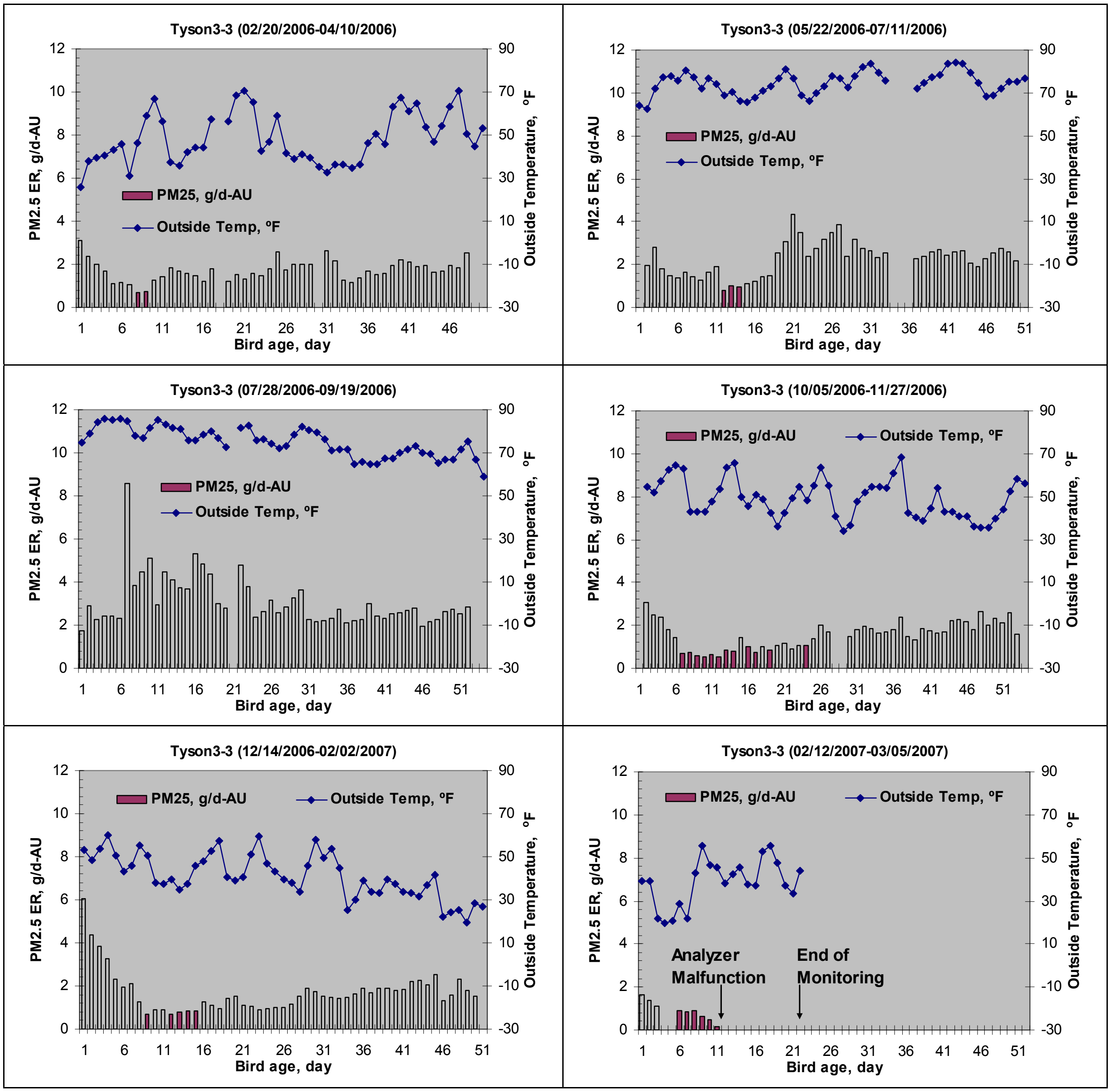


Figure 59. Tyson 3-3 $PM_{2.5}$ emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

Effects of Environmental Variables on $PM_{2.5}$ ER

To assess the impact of environmental variables on the $PM_{2.5}$ emission from the two broiler houses, a multiple regression analysis was performed to relate $PM_{2.5}$ ER to bird age (d), interior temperature (^{o}F), RH (%), VR (cfm/bird) and litter status (0 for new bedding; 1 for built-up litter). The results of the regression analysis are shown in Table 16. Except for interior temperature and bedding, all variables were significant for $PM_{2.5}$ ER at α = 0.05. The $PM_{2.5}$ ER (lb/d-house) was positively correlated with temperature and RH.

Table 16. Multiple regression analysis of $PM_{2.5}$ for bird age, interior temperature, RH, ventilation rate (VR), and litter status (LS) (R^2=0.92)

$$\sqrt[3]{PM_{2.5}\ ER} = \beta_0 + \beta_1 \times \text{Age} + \beta_2 \times \text{Age}^2 + \beta_3 \times T_i + \beta_4 \times RH_i + \beta_5 \times VR + \beta_6 \times LS$$

Term	Estimate	S.E	Prob>|t|
β_0= Intercept	0.158	0.010	<.0001
β_1= Bird age, d	0.012	0.000	<.0001
β_2= Bird age^2, d^2	N/S		
β_3= Inside Temp., ºF	N/S		
β_4= Inside RH, %	N/S		
β_5= VR, cfm/bird	0.039	0.003	<.0001
β_6= LS, 0 or 1	0.034	0.009	0.0001

Annual $PM_{2.5}$ Emission

The annual $PM_{2.5}$ emission from each house is the accumulation of daily ERs over 365 days. When 5.4 flocks were grown to 52 days of age and the average flock cumulative ER is 12.8 lb/flock (5.8 kg/flock), the annual emission (± S.E.) was 71.7 ± 4.4 lb/yr-house (32.5 ± 2.0 kg/yr-house). On the basis of number of birds marketed the annual average $PM_{2.5}$ emission (± S.E.) was 0.55 ± 0.04 lb/1,000 birds marketed or 0.25 ± 0.01 g/bird-marketed.

Relationship among TSP, PM_{10}, and $PM_{2.5}$

The ratios of $PM_{2.5}$/PM_{10}, $PM_{2.5}$/TSP, and PM_{10}/TSP were calculated from daily ERs of TSP, PM_{10}, and $PM_{2.5}$. All three ratios had similar pattern with bird age or growth (Figures 60, 61, and 62). $PM_{2.5}$/PM_{10} ratio rapidly dropped from ~0.17 to ~ 0.06 during the first 17-d period, then the ratio increased to ~0.12 at the end of the 52-d growth period. $PM_{2.5}$/TSP and PM_{10}/TSP ratios had similar trends, with the ratio decreasing during the first 12 d and increasing afterwards. The overall average ratios from the two broiler houses were 0.038, 0.093, and 0.40 for $PM_{2.5}$/TSP, $PM_{2.5}$/PM_{10}, and PM_{10}/TSP, respectively. Fine particulates are thus a small fraction of TSP.

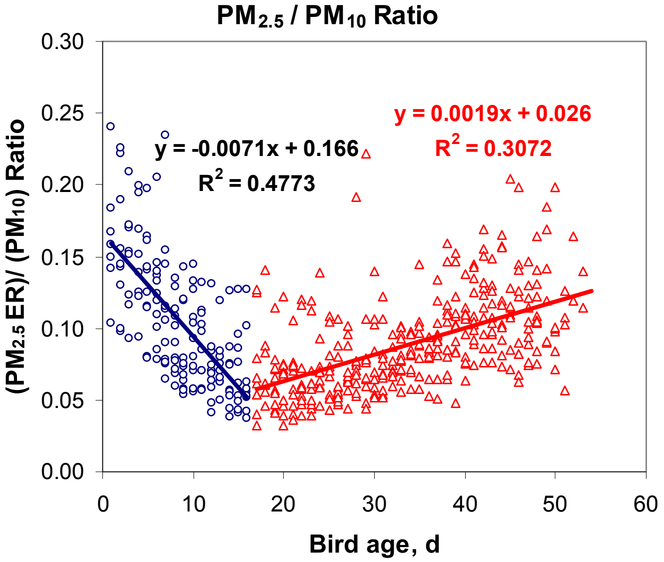


Figure 60. $PM_{2.5}$/PM_{10} ratio vs. bird age.

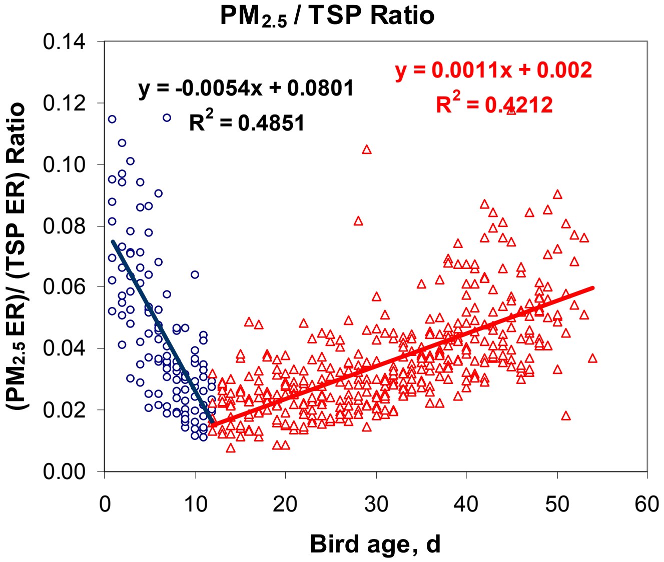


Figure 60. $PM_{2.5}$/TSP ratio vs. bird age.

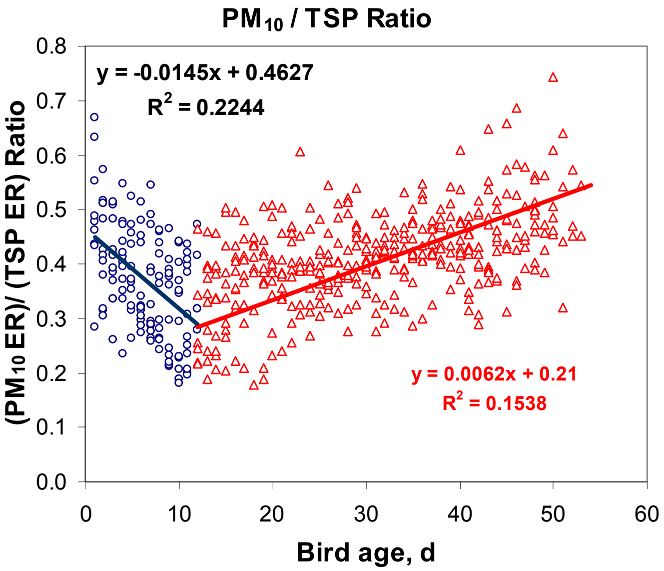


Figure 62. PM_{10}/TSP ratio vs. bird age.

CO_2 Emissions

CO_2 ER Estimation/Prediction

The CO_2 emissions reported in this study represent the combined total of both bird respiration and manure generated CO_2. The carbon dioxide ER was highly correlated to the bird age. The CO_2 ER per house or per bird from all data except for flock 6 at Tyson 1-5, as shown in Figures 63 and 64, may be estimated using the following regression equations:

$$CO_2\ ER,\ US\text{-}ton\ d^{-1}\ house^{-1} = a + b\,X \qquad [10]$$

where

X= bird age, d.

Table 17 provides the prediction parameter estimates for the two houses, individually, and over all 11.4 flocks. The correlation coefficients (r^2) of prediction models vary from 0.64 to 0.80 and show the strongest relationship between ER and bird age.

Table 17. Coefficient estimates of CO_2 ER regressions for broiler houses Tyson 1-5 and Tyson 3-3 (ER is not included when bird age is < 7 d with new bedding)

House	**a** (± S.E.)	**b** (± S.E.)	r^2
T1-5	0.25 (± 0.063)	0.085 (± 0.0021)	0.87
T3-3	0.22 (± 0.065)	0.092 (± 0.0023)	0.83
Overall	0.25	0.087	0.87

	(± 0.045)	(± 0.0015)

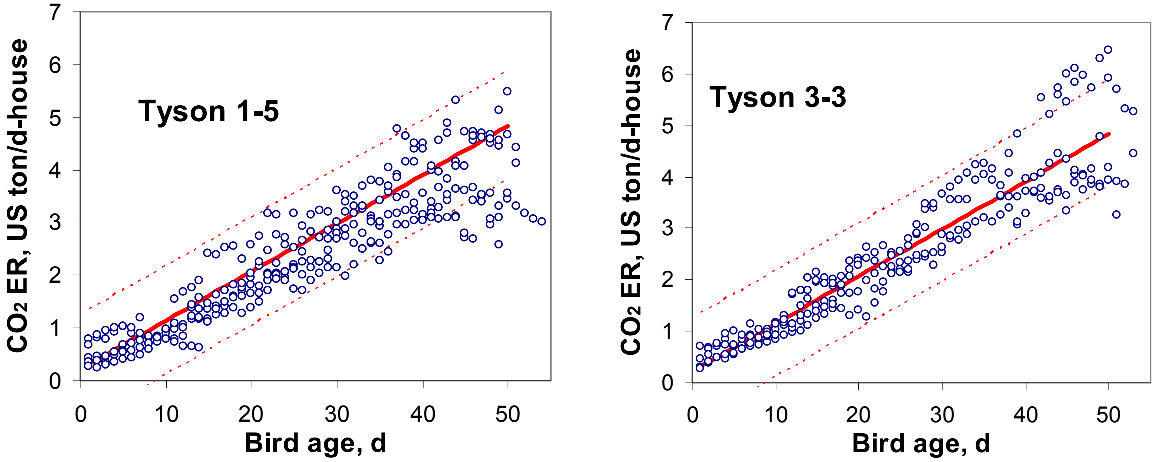


Figure 63. CO_2 emission rate (ER) per house vs. bird age for Tyson 1-5 and Tyson 3-3. The solid line is the regression line; dash lines are 95% prediction limits.

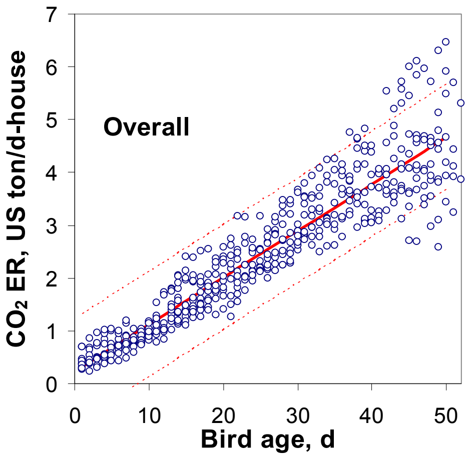


Figure 64. CO_2 emission rate (ER) per house vs. bird age. The solid line is the regression line; dash lines are 95% prediction limits.

Figure 65 provides the daily CO_2 ER for the two houses for the entire monitoring period with 11.4 flocks and downtime between flocks. The daily ER (lb/d-house) varied from 0 to 6.47 US-ton/d-house (0 to 5.87 metric ton/d-house). When the houses were occupied by birds, the highest ER was 5.51 and 6.47 US-ton/d-house (5.0 to 5.87 metric ton/d-house) for Tyson 1-5 and Tyson 3-3, respectively. The average ER for Tyson 1-5 over the six flocks was 2.51 ± 1.29 US-ton/d-house (2.28 ± 1.27 metric ton/d-house) which was not significantly different from 2.66 ± 1.4 US-ton/d-house (2.41 ± 1.27 metric ton/d-house) for Tyson 3-3 (P=0.32). The average ER of 11.4 flocks was 2.55 ± 1.32 US-ton/d-house (2.31 ± 1.2 metric ton/d-house).

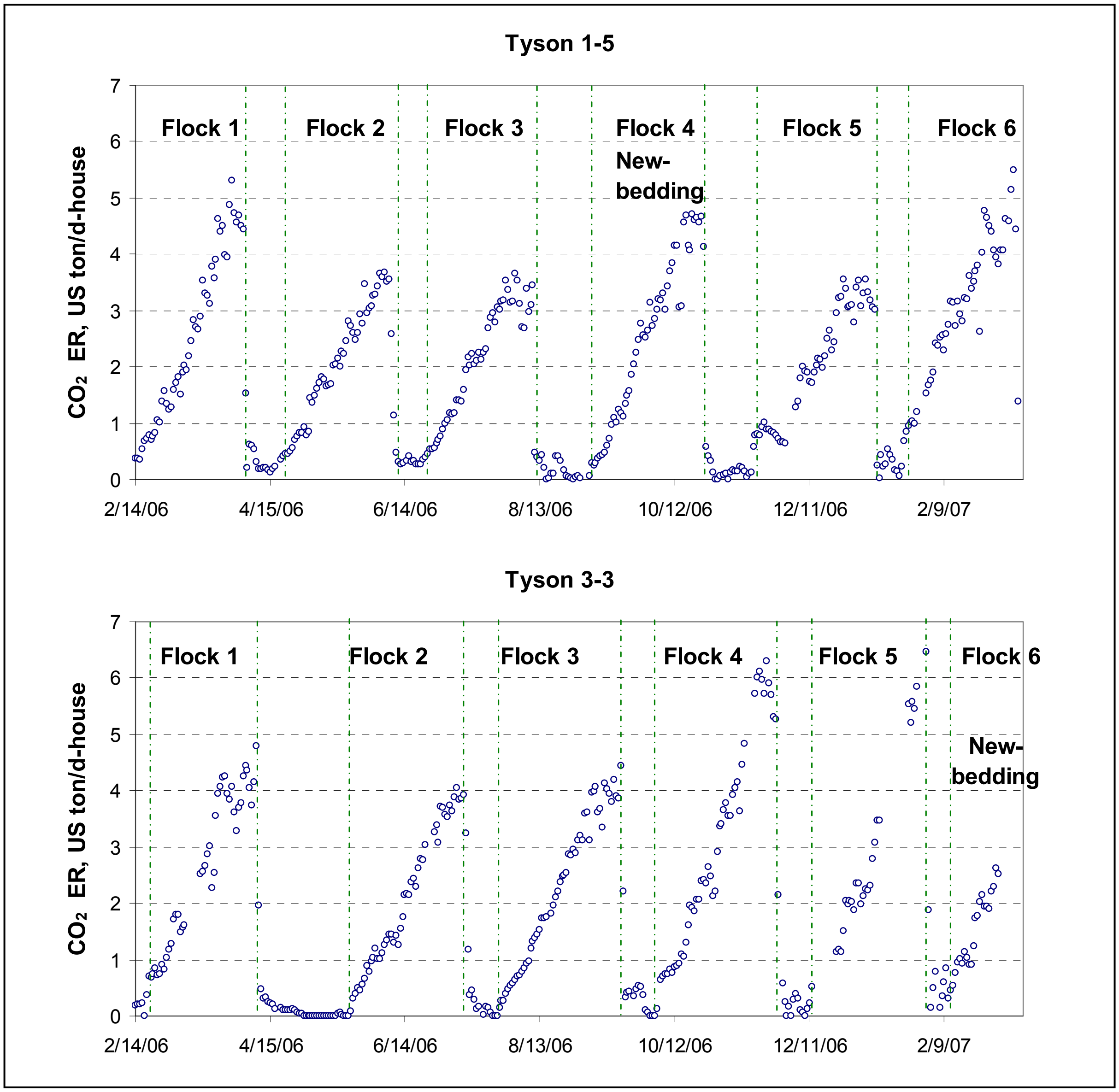


Figure 65. Daily CO_2 emission over the 11.4 flocks for Tyson 1-5 and Tyson 3-3.

CO_2 ER during Downtime between Flocks

CO_2 emissions from the two houses were continuously monitored when the houses were empty between flocks or during downtime. There was no significant relationship between ER and VR (Figure 66). The average daily ER for the two houses during downtime was 0.21 ± 0.20 US-ton/d-house (0.19 ± 0.18 metric ton/d-house).

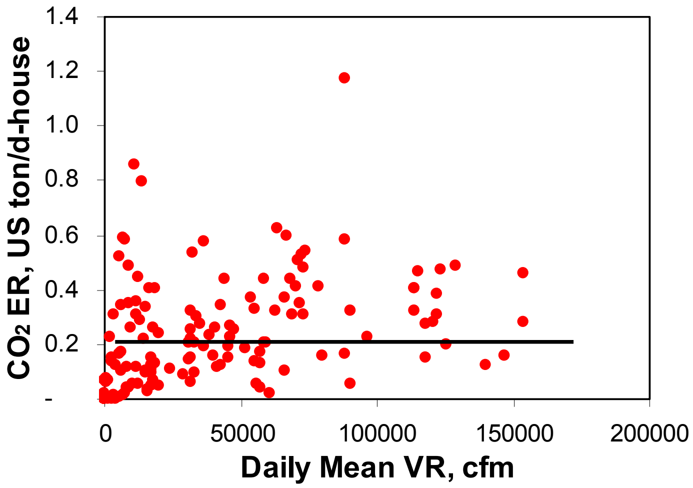
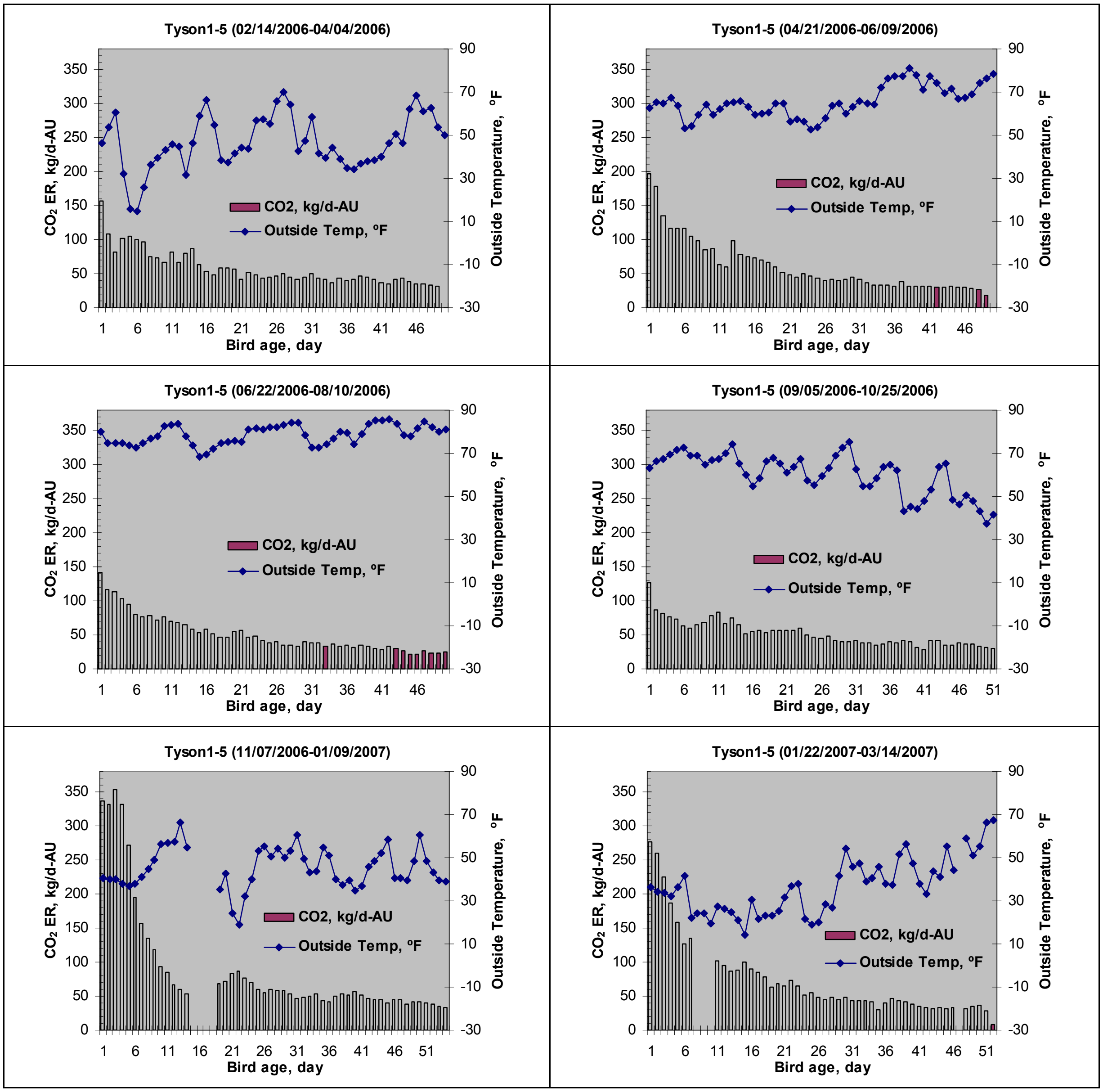


Figure 66. CO_2 emission rate(ER) vs. ventilation rate (VR) during downtime.

CO_2 ER per Animal Unit (AU)

Figures 67 and 68 present CO_2 ER in terms of 500 kg animal unit (kg/AU-d) for 11.4 flocks from the two houses. The ER per AU versus bird age showed that the ER decreased with the bird growth and became relatively stable after 30 d. The ER was higher during wintertime than during summertime due to additional CO_2 contribution from the brooder and space heaters. There was no significant difference between Tyson 1-5 and Tyson 3-3 in ER per AU (P=0.96). The daily ER per AU was 58.9 ± 37.1 and 63.3 ± 41.2 kg/d-AU for Tyson 1-5 and Tyson 3-3, respectively. The overall ER per AU was 61.9 ± 40.1 kg/ d-AU.


Tyson1-5 (02/14/2006-04/04/2006)

Tyson1-5 (04/21/2006-06/09/2006)

Tyson1-5 (06/22/2006-08/10/2006)

Tyson1-5 (09/05/2006-10/25/2006)

Tyson1-5 (11/07/2006-01/09/2007)

Tyson1-5 (01/22/2007-03/14/2007)

Figure 67. Tyson 1-5 CO_2 emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

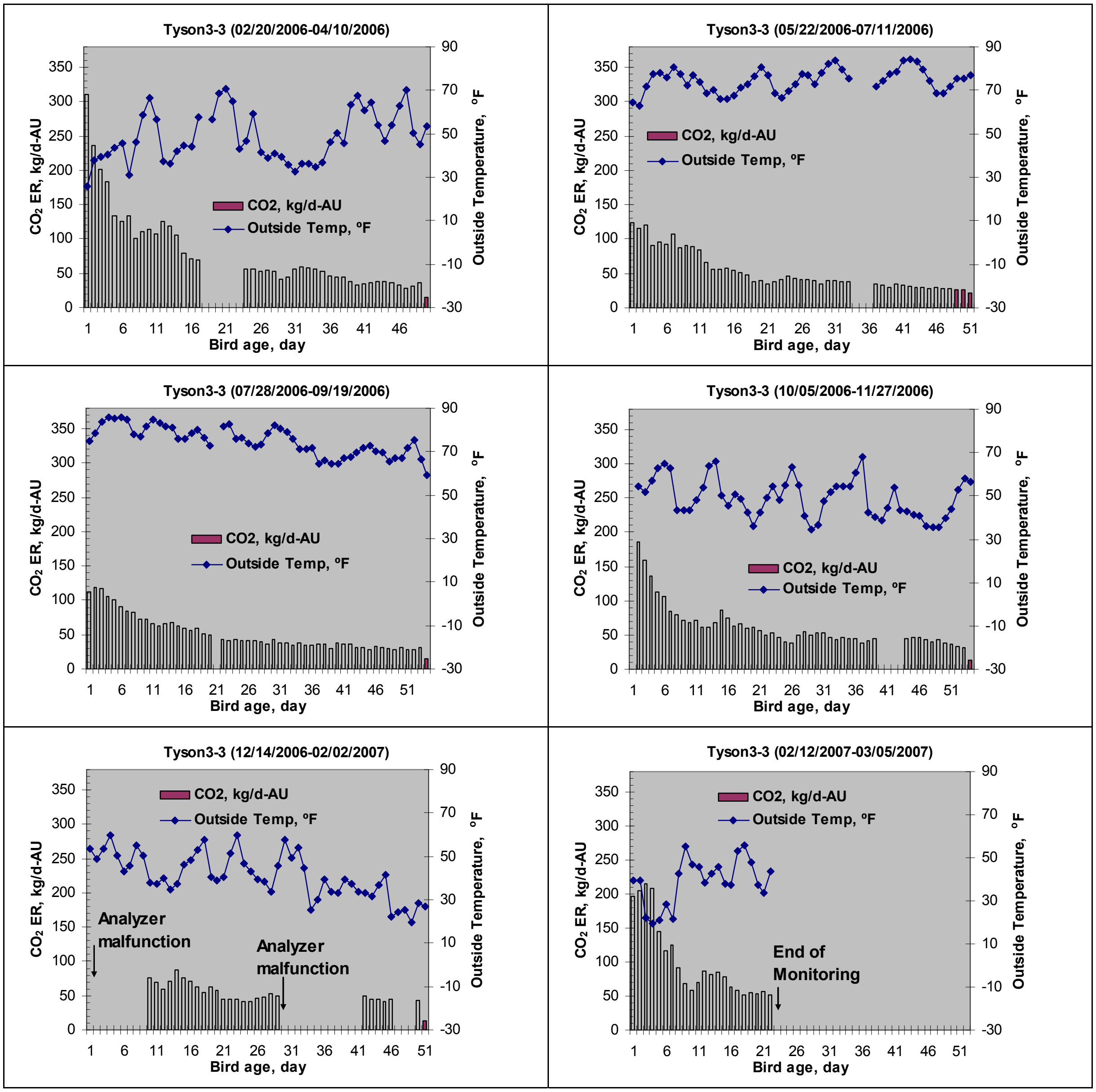


Figure 68. Tyson 3-3 CO_2 emission rate (ER) per animal unit (AU, 500 kg) and mean outside temperature vs. bird age.

Effects of Environmental Variables on CO_2 ER

To assess the impact of environmental variables on the CO_2 emission from the broiler houses, a multiple regression analysis was performed to relate CO_2 ER to bird age (d), outside temperature (^oF), RH (%), VR (cfm/bird) and litter status (0 for new bedding; 1 for built-up litter). The results of the regression analysis are shown in Table 18. The outside temperature and VR had significant effect on CO_2 ER at $\alpha = 0.05$. As outside temperature and VR increased, the CO_2 ER (ton/d-house) decreased because less CO_2 were from supplemental heating devices. During the cold season CO_2 emissions increased because additional CO_2 was generated by the brooder heaters and space heaters.

Table 18. Multiple regression analysis of CO_2 emission to bird age (d), ventilation rate (VR, cfm/bird), and litter status (LS) (R^2=0.93)

$$CO_2\ ER\ us\text{-}ton\ d^{-1}\ house^{-1} = \beta_0 + \beta_1 x\ Age + \beta_2\ x\ T_o + \beta_3\ x\ RH_i + \beta_4\ x\ VR + \beta_5\ x\ LS$$

Term	Estimate	S.E	t Ratio	Prob>|t|
β_0= Intercept	0.73	0.099	7.41	<.0001
β_1= Bird age, d	0.099	0.002	51.3	<.0001
β_2= Outside Temp, °F	-0.0087	0.0017	-5.21	<.0001
β_3= Inside RH, %	N/S			
β_4= VR, cfm/bird	-0.169	0.0262	-6.45	<.0001
β_5= LS, 0 or 1	N/S			

Annual CO_2 Emission

The annual CO_2 emission from each house is the accumulation of daily ERs over 365 days. Based on the regression of the ER on bird age from Equation [2], the average flock ER was 132.8 US tons per house per flock (120.5 metric ton per house per flock). The annual CO_2 emission rate (± S.E.) was 718 ± 21.6 US tons per house per year (651 ± 9.8 metric ton per house per flock). The annual mean emission of 5.49 ± 0.16 US tons per 1,000 birds marketed (including downtime emissions) obtained from this study is equivalent to an ER (± S.E.) of 4.98 ± 0.15 kg/bird-marketed.

Comparison of ER Values with Literature Data

Comparison of the reported ammonia ER (g/bird-d) for broiler production houses (occupied with birds) in the United States is given in Table 19. The data from this study tend to be on the lower side of all values reported, but match closely with the earlier Kentucky data obtained for different farms and with different instrumentation. Table 20 lists comparison of PM_{10} emissions from broiler operations, with data from this study being nearly double that of the only other published data (1.3 vs. 2.52 g/bird-marketed). There is currently a lack of published emission data for the comparison of H_2S and NMHC.

Table 19. Comparison of ammonia emission rates (ER, g/bird-d) of commercial broiler houses among various U.S. studies

Reference	Growth Period, d	Stocking Density, birds/m^2	Stocking Density, birds/ft^2	Flocks	Litter	Mean ER, g/bird-d	Location
This study	52	12.7	1.18	3	New	0.49 ± 0.37	Kentucky
This study	52	12.2	1.13	9	Built-up	0.62 ± 0.38	
Wheeler et al. (2006)	42	14.7	1.37	10	New	0.47	Kentucky and Pennsylvania
	42	14.7	1.37	12	Built-up	0.65	
	49	13.4	1.24	24	Built-up	0.76	
	63	10.8	1.00	20	Built-up	0.98	
Burns et al. (2003)	42	16.1	1.50	9	Built-up	0.92	Tennessee
Lacey et al. (2003)	49	13.5	1.25	12	Built-up	0.63	Texas
Seifert et al. (2004)	42	20	1.86	1	Built-up	1.18	Delaware

Table 20. Comparison of PM_{10} emission rate (ER) of commercial broiler houses among various U.S. studies

Reference	Growth Period, d	Vent.	Stocking Density, birds/ft^2	Flocks	Litter	Mean ER, mg/bird-d	ER, g/bird - marketed	Location
Lacey et al. (2003)	49	Tunnel	1.25	12	Built-up	26.5	1.3	Texas
This study	52	Cross + Tunnel	1.15	12	Mixed	48.2	2.52	Kentucky

Summary and Conclusions

Gaseous and particulate matter (PM) emissions from two representative broiler houses in western Kentucky were continuously measured for 12.5 to 13 months, involving a total of 11 complete and two partial grow-out flocks. Each house had 5.4 straight-run flocks per year and averaged 24,200 birds grown on new or built-up litter to 52 days of age. The gaseous and PM emissions were expressed in various units to meet different purposes of the data application, as following: a) annual total emission per house, b) daily mean emission per house, c) daily maximum emission per house, d) annual average emission per bird marketed, and e) annual average emission per animal unit (AU = 500 kg or 1,100 lb live body weight) marketed. All values included downtime emission, presented as mean ± standard error (S.E.) or standard deviation (S.D.). The data from this comprehensive and extensive monitoring of production houses are expected to enhance the national emissions inventory on animal feeding operations.

The following conclusions and observations were made from this study:

- There exist functional relationships between the gaseous and PM emissions and bird age. Empirical regression equations were developed to delineate the relationships.

- Annual total emission per house (mean ± S.E.): 5.1 ± 0.19 US tons (4620 ± 171 kg) NH_3, 42.3 ± 2.1 lb (19.2 ± 0.92 kg) H_2S, 510 lb ± 59.6 (231 ± 27 kg) NMHC, 1731 ± 58.6 lb (785 ± 26.6 kg) TSP, 727 ± 93.4 lb (330 ± 42.3 kg) PM_{10}, 71.7 ± 4.4 lb (32.5 ± 2.0 kg) $PM_{2.5}$, and 718 ± 21.6 US ton (651 ± 9.8 metric ton) CO_2.

- Annual average emission per 1,000 birds marketed (mean ± S.E.): 78.1 ± 3.1 lb NH_3, 0.32 ± 0.01 lb H_2S, 3.9 ± 0.45 lb NMHC, 13.2 ± 0.46 lb TSP, 5.56 ± 0.71 lb PM_{10}, 0.55 ± 0.04 lb $PM_{2.5}$, and 5.49 ± 0.16 US ton CO_2. Expressed on a per-bird-marketed basis, the annual average emissions were: 35.4 ± 1.32 g NH_3, 0.147 ± 0.01 g H_2S, 1.77 ± 0.21 g NMHC, 6.01 ± 0.21 g TSP, 2.52 ± 0.33 g PM_{10}, 0.25 ± 0.01 g $PM_{2.5}$, and 4.98 ± 0.15 kg CO_2.

- Annual average emission per AU marketed (mean ± S.E.): 6.25 ± 0.23 kg of NH_3, 26.0 ± 1.26 g of H_2S, 0.29 ± 0.03 kg NMHC, 1.06 ± 0.04 kg TSP, 0.45 ± 0.06 kg PM_{10}, 0.044 ± 0.003 kg $PM_{2.5}$, and 881 ± 26.5 kg CO_2.

- Daily mean emission per house (mean ± S.D.): 31.4 ± 14.9 lb (14.2 ± 6.8 kg) NH_3, 0.14 ± 0.09 lb (65.7 ± 42 g) H_2S, 1.68 ± 0.94 lb (0.8 ± 0.4 kg) NMHC, 6.13 ± 4.13 lb (2.78 ± 1.87 kg) TSP, 2.57 ± 1.88 lb (1.16 ± 0.85 kg) PM_{10}, 0.25 ± 0.22 lb (0.11 and 0.10 kg) $PM_{2.5}$, 2.55 ± 1.32 us-ton (2.31 ± 1.2 mton) CO_2. For the downtime between flocks, the daily mean emission per house were: 18.5 ± 17.8 lb (8.39 ± 8.1 kg) NH_3, 0.020 ± 0.028 lb (9.0 ± 12.5 g) H_2S, 0.45 ± 0.64 lb (0.2 ± 0.3 kg) NMHC, 0.12 ± 0.19 lb (0.05 ± 0.086 kg) TSP, 0.052 ± 0.085 lb (0.024 ± 0.039 kg) PM_{10}, 0.03 ± 0.06 lb (0.014 ± 0.027 kg) $PM_{2.5}$, 0.21 ± 0.20 US-ton (0.19 ± 0.18 metric ton) CO_2.

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APPENDIX E

Federal Register Notice

Animal Feeding Operations Consent Agreement and Final Order

NATIONAL ARCHIVES AND RECORDS ADMINISTRATION
1985

Federal Register

Monday,
January 31, 2005

Part IV

Environmental Protection Agency

Animal Feeding Operations Consent Agreement and Final Order; Notice

ENVIRONMENTAL PROTECTION AGENCY

[OAR–2004–0237; FRL–7864–4]

Animal Feeding Operations Consent Agreement and Final Order

AGENCY: Environmental Protection Agency (EPA).

ACTION: Notice of consent agreement and final order, and request for public comment.

SUMMARY: The EPA is offering animal feeding operations (AFOs) an opportunity to sign a voluntary consent agreement and final order (henceforth referred to as the ''Air Compliance Agreement'' or the ''Agreement''). A copy of the Air Compliance Agreement is attached as an Appendix to this notice. The sign-up period for eligible AFOs to sign the Agreement will run for 90 days from the date of this notice.

AFOs that choose to sign the Air Compliance Agreement will share responsibility for funding an extensive, nationwide emissions monitoring study. The monitoring study will lead to the development of methodologies for estimating emissions from AFOs and will help AFOs to determine and comply with their regulatory responsibilities under the Clean Air Act (CAA); the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA); and the Emergency Planning and Community Right-To-Know Act (EPCRA). Once applicable emission estimating methodologies have been published by EPA, the Agreement will also require each participating AFO to certify that it is in compliance with all relevant requirements of the CAA, CERCLA and EPCRA.

EPA is requesting comment on the Air Compliance Agreement, with particular emphasis on implementation of the Agreement. All comments should be submitted within 30 days of the date of this notice.

DATES: Comments must be received on or before March 2, 2005.

ADDRESSES: Submit your comments, identified by Docket ID No. OAR–2004–0237, by one of the following methods:

- Agency Web site: *http://www.epa.gov/edocket.* EDOCKET, EPA's electronic public docket and comment system, is EPA's preferred method for receiving comments. Follow the on-line instructions for submitting comments.
- E-mail: *a-and-r-docket@epa.gov.*
- Fax: (202) 566–1741.
- Mail: Air Docket, Environmental Protection Agency, Mailcode: 6102T, 1200 Pennsylvania Ave., NW., Washington, DC 20460. Please include a total of two copies.
- Hand Delivery: Environmental Protection Agency, 1301 Constitution Avenue, NW., Room B102, Washington, DC 20460. Such deliveries are only accepted during the Docket's normal hours of operation, and special arrangements should be made for deliveries of boxed information.

Instructions: Direct your comments to Docket ID No. OAR–2004–0237. The EPA's policy is that all comments received will be included in the public docket without change and may be made available online at *http://www.epa.gov/edocket,* including any personal information provided, unless the comment includes information claimed to be Confidential Business Information (CBI) or other information whose disclosure is restricted by statute. Do not submit information that you consider to be CBI or otherwise protected through EDOCKET, regulations.gov, or e-mail. The EPA EDOCKET and the Federal regulations.gov Web sites are ''anonymous access'' systems, which means EPA will not know your identity or contact information unless you provide it in the body of your comment. If you send an e-mail comment directly to EPA without going through EDOCKET or regulations.gov, your e-mail address will be automatically captured and included as part of the comment that is placed in the public docket and made available on the Internet. If you submit an electronic comment, EPA recommends that you include your name and other contact information in the body of your comment and with any disk or CD–ROM you submit. If EPA cannot read your comment due to technical difficulties and cannot contact you for clarification, EPA may not be able to consider your comment. Electronic files should avoid the use of special characters, any form of encryption, and be free of any defects or viruses.

Docket: All documents in the docket are listed in the EDOCKET index at *http://www.epa.gov/edocket.* Although listed in the index, some information is not publicly available, *i.e.,* CBI or other information whose disclosure is restricted by statute. Certain other information, such as copyrighted materials, is not placed on the Internet and will be publicly available only in hard copy form. Publicly available docket materials are available either electronically in EDOCKET or in hard copy form at Docket ID No. OAR–2004–0237, EPA/DC, EPA West, Room B102, 1301 Constitution Ave., NW., Washington, DC. The Public Reading Room is open from 8:30 a.m. to 4:30 p.m., Monday through Friday, excluding legal holidays. The telephone number for the Public Reading Room is (202) 566–1744, and the telephone number for the Air Docket is (202) 566–1742.

FOR FURTHER INFORMATION CONTACT: For information on the Air Compliance Agreement, contact Mr. Bruce Fergusson, Special Litigation and Projects Division, Office of Enforcement and Compliance Assurance, U.S. EPA, Ariel Rios Building, Washington, DC 20460, telephone number (202) 564–1261, fax number (202) 564–0010, and electronic mail: *fergusson.bruce@epa.gov.*

For information on the monitoring study, contact Ms. Sharon Nizich, Organic Chemicals Group, Emission Standards Division, Office of Air Quality Planning and Standards, U.S. EPA, Research Triangle Park, NC 27711, telephone number (919) 541–2825, fax number (919) 541–3470, and electronic mail: *nizich.sharon@epa.gov.*

SUPPLEMENTARY INFORMATION:

Overview of the Air Compliance Agreement: By offering AFOs this opportunity to sign an Air Compliance Agreement, the Agency will help participating AFOs pool their resources to lower the cost of measuring emissions and ensure that they comply with all applicable environmental regulations in the shortest amount of time. While EPA has the authority on a case-by-case basis to require AFOs to monitor their emissions and to come into compliance with applicable Federal laws, that process has proven to be difficult and time consuming, partly due to the uncertainty regarding emissions from AFOs, which was reiterated in a recent report by the National Academy of Sciences (NAS).[1] Moreover, even when EPA has reached a successful resolution of an enforcement case, only the facilities that are the subject of the enforcement action were directly affected. Consequently, EPA believes that the Air Compliance Agreement will be the quickest and most effective way to address the current uncertainty regarding emissions from AFOs and to bring all participating AFOs into compliance with all applicable regulatory requirements.

The Air Compliance Agreement will not affect in any way EPA's ability to respond to an imminent and substantial endangerment to public health, welfare or the environment. Nor will participation in the Agreement provide protection for criminal violations of

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[1] NAS, ''Air Emissions From Animal Feeding Operations: Current Knowledge, Future Needs,'' National Research Council, 2003.

environmental laws. Finally, the Air Compliance Agreement is not intended to affect compliance by AFOs with any requirements of the Clean Water Act (CWA) and the implementing regulations applicable to concentrated animal feeding operations.

AFOs that choose not to sign an Air Compliance Agreement will be subject to potential enforcement action by the Federal Government for any CAA, CERCLA, or EPCRA violations, as would any AFO that signs the Agreement but later drops out by not complying with the terms of the Agreement.

EPA recognizes that AFOs can have a negative impact on nearby residents, particularly with respect to objectionable odors and other nuisance problems that can affect their quality of life. EPA also recognizes that concerns have been raised recently regarding the possible health impacts from AFO emissions. It is important to note, however, that under existing Federal laws, EPA has an important but limited role in dealing with many of the potential impacts from AFOs. To the extent that certain pollutants from AFOs are regulated under the CAA and are emitted in quantities that exceed regulatory thresholds, EPA can and will require AFOs to comply with all applicable CAA requirements, including limiting those emissions where appropriate. However, many of the negative impacts resulting from AFOs, such as odor, are not currently regulated under Federal laws, but are addressed by State and local laws. EPA supports local and State efforts in those areas and relies on them to enforce their State and local laws for odor and nuisance problems, health code violations, and zoning challenges posed by AFOs. The Air Compliance Agreement will explicitly require participants to comply with final State nuisance orders. In addition, the Agreement will not affect the ability of States or citizens to enforce compliance with nonfederally enforceable State laws, existing or future, that are applicable to AFOs.

Sources may also emit fugitive emissions, but this notice does not address fugitive emissions. Guidance on fugitive emissions will be issued along with other appropriate guidance/and or regulations after the conclusion of the monitoring study.

Relevant Air Pollutants and Applicable Laws: AFOs emit several air pollutants, including ammonia (NH_3), hydrogen sulfide (H_2S), particulate matter (PM), and volatile organic compounds (VOC). NH_3 and H_2S are hazardous substances under CERCLA and EPCRA, and the release of these gases may need to be reported under CERCLA and EPCRA if released in sufficient quantities. H_2S, PM, and VOC are all regulated under the CAA and subject to various requirements under that statute and the implementing Federal and State rules and regulations. Emissions of these pollutants come from many different areas at AFOs, including animal housing structures (*e.g.,* barns, covered feed lots) and manure storage areas (*e.g.,* lagoons, covered manure piles). An important issue that arises under the CAA is whether emissions from different areas at AFOs should be treated as fugitive or nonfugitive. The Agency plans to issue regulations and/or guidance on this issue after the conclusion of the monitoring study.

Applicability: The Air Compliance Agreement is being offered to AFOs in the egg, broiler chicken, turkey, dairy and swine industries that meet the definition of an AFO under the CWA. The Agreement will address emissions coming from buildings or structures that house agricultural livestock, and from lagoons or similar structures that are used for storage and/or treatment of agricultural livestock waste at participating AFOs. The Air Compliance Agreement will not address AFOs that only have open-air feedlots, such as cattle feedlots. Nor will it address emissions from sources other than animal housing structures or agricultural livestock waste storage and treatment units.

Major Terms of the Air Compliance Agreement: The Air Compliance Agreement establishes specific obligations that will apply to all participating AFOs and includes limited, conditional covenants not to sue and liability releases from EPA. AFOs that choose to participate will agree to pay a civil penalty which is based on the size of the AFO. The penalty ranges from $200 to $1,000 per AFO, depending upon the number of animals at the AFO. The threshold ranges depend upon the species of animal. The total penalty is capped and ranges from $10,000 for a participant having 10 or fewer farms to $100,000 for a participant having over 200 farms. Participation in the Air Compliance Agreement and payment of a penalty will not be an admission of liability by an AFO.

In addition, participating AFOs, except for certain contract growers, will be responsible for the payment of approximately $2,500 per farm into a fund to conduct a nationwide emission monitoring study and for making their facilities available for emissions testing under the nationwide monitoring study. In general, the monitoring study, which is described more fully below and in Attachment B to the Air Compliance Agreement (included as an appendix to this notice), will undertake over a 2-year period, emissions monitoring at a representative sample of animal housing structures and manure storage and treatment units across the country. At the end of the monitoring study, EPA will use the data from the monitoring study and any other relevant, available data to develop emissions estimating methodologies. These emissions estimating methodologies will then be used by the AFO industry to estimate their annual emissions.

EPA's publication of the emissions estimating methodologies will trigger the obligation of participating AFOs to determine their emissions and to comply with all applicable CAA requirements, including applying for all required permits, and to make any requisite hazardous release notices under CERCLA and EPCRA. EPA expects to apply these emission estimating methodologies to all AFOs, whether or not they participate in the Air Compliance Agreement.

Please note that the Air Compliance Agreement does not define the scope of the term ''source'' as it relates to animal agriculture and farm activities. The Agency plans to provide guidance on this issue at the conclusion of the monitoring study.

Any AFO that fails to comply with the requirements as described will not receive the limited conditional release and covenant not to sue described later in this notice. Any conditional release and covenant not to sue offered as part of the Air Compliance Agreement will be revoked, and the AFO will remain liable for all past and ongoing violations.

AFOs that choose to participate in the Air Compliance Agreement and meet all its conditions will receive from EPA a limited release and covenant not to sue from liability for certain past and on-going CAA, CERCLA and EPCRA violations. The release and covenant not to sue will cover an AFO's liability for failing to comply with certain provisions of CERCLA, EPCRA, and the CAA up to the time the AFO reports its releases under CERCLA or EPCRA and applies for and receives the requisite CAA permits.

Participating AFOs will also be obligated to comply with all final actions and final orders issued by the State or local authority that address a nuisance arising from air emissions at the AFO. Failure to comply with the final action or order to correct the nuisance will void the conditional release and covenant not to sue offered in the Air Compliance Agreement.

Some very large AFOs will be required to immediately report estimated releases of NH_3, solely for purposes of the Air Compliance Agreement and not for purposes of reporting under CERCLA or EPCRA.

Finally, AFOs that install waste-to-energy systems that convert animal manure into electricity will get an extra 180 days to apply for CAA permits and to make the requisite hazardous release notifications under CERCLA and EPCRA.

Terms Applicable to Contract Growers and Integrators: Many AFOs, particularly in the swine, broiler chicken, and turkey industry, raise livestock for separate corporations that usually own the animals, provide feed and medical services, and that process and market the meat products. In those cases, the AFO that grows the animals is referred to as a ''contract grower,'' and the separate corporation that processes and markets the meat products is referred to as an ''integrator.''

The Air Compliance Agreement includes provisions that will allow both integrators and contract growers to participate. Among other things, a contract grower will not be responsible for the payment of monies into the monitoring fund if an integrator has already agreed to be responsible for the payment of such monies. The contract grower/integrator provisions in the Agreement will also apply to AFOs that produce milk under contract with a cooperative or that supply heifers to dairy herds owned by a separate entity.

Emissions Monitoring Study: The purpose of the monitoring study is to: collect data and aggregate it with appropriate existing emissions data; analyze the monitoring results; and create tools (*e.g.,* tables and/or emission models) that AFOs could use to determine whether they emit pollutants at levels that require them to apply for permits under the CAA or submit notifications under CERCLA or EPCRA. The monitoring study is designed to generate scientifically credible data to provide for the characterization of emissions from all major types of AFOs in all geographic areas where they are located. To provide a framework for the monitoring study and to generate a comprehensive field sampling plan from representative farms in the United States, a protocol (Attachment B to the Air Compliance Agreement, included as part of the Appendix to this notice) was developed through the collaborative efforts of industry experts, university scientists, government scientists, and other stakeholders knowledgeable in the field. Although the protocol development was facilitated by the U.S. EPA and the U.S. Department of Agriculture (USDA), it represents the opinions of the scientists, government experts, and stakeholders involved. In addition, there was extensive internal review and input by representatives from U.S. EPA's Office of Enforcement and Compliance Assurance, Office of Air and Radiation, and Office of Research and Development.

As recommended in the NAS 2003 report, ''Air Emissions From Animal Feeding Operations,'' and paraphrased here, EPA and USDA should for the short term, initiate and conduct a coordinated research program designed to produce a scientifically sound basis for measuring and estimating air emissions from AFOs. Specific recommendations being addressed with the protocol that were discussed in the NAS 2002 Interim Report[2] are related to direct measurements at sample farms by utilizing information on the relationships between air emissions and animal types, nutrient outputs, and manure handling practices; conducting studies to evaluate the extent to which ambient atmospheric concentrations of the various pollutants of interest are consistent with estimated emissions; and using scientifically sound and practical protocols for measuring pollutant concentration emission rates. EPA's longer-term strategy involves additional recommendations from the NAS which entail developing a process-based model that considers the entire animal production process. The data collected in the monitoring study will lay the groundwork for developing these more process-related emission estimates. However, as with any large and complex effort, this work must be conducted over a period of years.

Under the Air Compliance Agreement, the participating AFOs will set up an umbrella nonprofit entity (referred to here as the nonprofit organization or NPO) to handle the funds contributed by the individual participating facilities. The NPO will then subcontract to a Science Advisor and independent monitoring contractor (the ''IMC'') to run the nationwide monitoring study. The IMC will submit a proposed plan for review and approval by EPA that is consistent with the monitoring protocol outlined in Attachment B to the Air Compliance Agreement. The proposed plan would also include a list of recommended candidate facilities to be monitored.

EPA will review and approve or disapprove the proposed plan within 30 days of receiving it from the IMC. If the proposed plan is disapproved, EPA will specifically state why the plan is being disapproved and what changes need to be made. The IMC will then have 30 days to modify the proposed plan to address the changes required by EPA and to submit the modified plan to EPA for review and approval. Once the plan is approved, all participating AFOs, through the NPO, will be obligated to fully fund the nationwide emission monitoring study and to establish a binding contract with the IMC to carry out the approved plan.

Monitoring will be conducted pursuant to EPA protocols and be done by a fleet of mobile labs purchased by the NPO and overseen by the IMC hired to run the study. Emissions at the facilities will be monitored at both buildings and waste lagoons and will include H_2S, VOC, PM and NH_3. Monitoring will occur at facilities across the country to get a representative sample of the facility types in major geographic regions. EPA expects that the monitoring will begin in 2005 and continue for 2 years. Two years of monitoring is the minimum time needed because emissions from AFOs can vary greatly over the course of a year and may vary significantly from year to year. The data generated during the monitoring study will be made fully available to the general public.

Technical experts on emissions monitoring at EPA and from a number of universities believe that monitoring the farms described in the attached protocol will provide sufficient data to get a valid sample that is representative of the vast majority of the participating AFOs. Significantly increasing the number of farms to be monitored would be prohibitively expensive and would not add substantially to the value of the data collected.

Throughout the course of the monitoring study, EPA will review and analyze the data as they are generated. EPA will use the data generated from the monitoring and all other available, relevant data to develop methodologies for estimating annual emissions from swine, dairy, egg laying, broiler chicken, and turkey AFOs. Within 18 months after the conclusion of the nationwide emissions monitoring study, EPA expects that it will publish on its Web site, on a rolling basis as work is completed, the methodologies for estimating emissions for the vast majority of AFOs in the eligible animal groups.

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[2] NAS, ''The Scientific Basis For Estimating Air Emissions From Animal Feeding Operations.'' Interim Report, National Research Council, 2002.

Relationship Between the Air Compliance Agreement and Other Actions the Agency May Take To Address AFO Air Emissions

In September 2001, EPA's Office of Air and Radiation (OAR) and the USDA jointly commissioned the NAS to prepare a report recommending approaches for characterizing emission profiles and identifying emission mitigation techniques, including:

- Review industry characterization and use of model farms;
- Evaluate emission factors, measurement methods, and modeling approaches;
- Recommend fate and transport methodologies;
- Identify mitigation technologies and management practices; and
- Identify critical research needs.

The NAS concluded its report in 2003 with a number of key findings, some of which are quoted here from the report:

> * * * EPA and USDA should use process-based mathematical models with mass balance constraints for nitrogen-containing compounds, methane, and hydrogen sulfide to identify, estimate, and guide management changes that decrease emissions for regulatory and management programs.
>
> * * * measurement protocols, control strategies and management techniques must be emission and scale specific * * *
>
> * * * There is a general paucity of credible scientific information on the effects of mitigation technologies on concentrations, rates, and fates of air emissions from AFOs. However, the implementation of technically and economically feasible management practices (*e.g.,* manure incorporation into soil) designed to decrease emissions should not be delayed.
>
> * * * scientifically sound and practical protocols for measuring air concentrations, emission rates, and fates are needed for the various elements (nitrogen, carbon, sulfur), compounds (*e.g.,* ammonia [NH_3], CH_4, H_2S) and particulate matter.

The EPA is planning to proceed in a manner that is consistent with the recommendations of the NAS. EPA's plan is focused on the achievement of real environmental benefits to protect public health and the environment while supporting a sustainable agricultural sector. EPA plans to continue to work with USDA and others to:

- Collect data and information related to operations at AFOs;
- Determine emissions from individual AFOs; and
- Identify appropriate regulatory and nonregulatory (*e.g.,* best management practices, environmental management systems, etc.) responses for each farm.

The Air Compliance Agreement with individual AFOs is an integral component of the data collection and emissions determinations of this effort. As discussed earlier in this notice, as part of the Air Compliance Agreement, AFOs will fund a 2-year nationwide emissions monitoring study to gather emissions data and mass balance information from AFOs. It is anticipated that emissions monitoring will be conducted at farms that represent the major animal sectors, types of operations, and different geographic locations.

The information gathered during the emissions monitoring study will be used to more adequately characterize emissions from individual farms. Individual farm emissions estimates will be used, along with other relevant information, to determine appropriate regulatory and nonregulatory responses to address the emissions. As recommended in the NAS report, EPA will then move forward to develop a process-based model which entails considering the entire animal feeding process. Similar to other large and complex efforts, the work must be conducted in stages over a period of years. The monitoring study, and the resulting emission estimating methodology, is a critical first step in this multiyear effort.

Conclusion: EPA believes that the Air Compliance Agreement will be the quickest and most effective way to address the current uncertainties regarding air emissions from AFOs and to bring the entire AFO industry into compliance with the CAA, section 103 of CERCLA, and section 304 of EPCRA. The Air Compliance Agreement's terms, conditions, and protections will be available only to those facilities that are eligible, that elect to participate, and that comply with the terms of the agreement. As appropriate, nonparticipants, and those who sign up but later drop out due to noncompliance with the Air Compliance Agreement, will be subject to enforcement actions in which significant penalties and injunctive relief could be sought for violations of the CAA, section 103 of CERCLA, and section 304 of EPCRA.

This notice describes an Air Compliance Agreement that EPA is offering certain types of AFOs and requests public comment on that Agreement. No new rights or obligations on behalf of EPA or any other party are created beyond what is contained in a fully executed and approved Agreement.

This notice provides a general description of the Air Compliance Agreement. Interested parties are encouraged to carefully read the Air Compliance Agreement and its Attachments (included as an Appendix to this notice) to fully understand what is being offered to AFOs. To the extent that provisions of the Air Compliance Agreement and its Attachments are inconsistent with this notice, the provisions of the Agreement will prevail.

Participation in the Air Compliance Agreement is voluntary. The Agreement is not intended to affect in any way EPA's ability to respond to an imminent and substantial endangerment to public health, welfare or the environment. Participation in the Agreement will not provide protection for criminal violations of environmental laws. In addition, the Agreement is not intended to affect the ability of States or citizens to enforce compliance with nonfederally enforceable State laws applicable to AFOs.

EPA recognizes that State and local agencies are undertaking efforts to improve emissions estimation methodologies for AFOs. EPA supports continued action to improve emissions information for all source categories and will use the best information available as we implement our programs. EPA also supports State and local efforts to demonstrate improved emissions reduction strategies and recognizes the value of State or local control requirements tailored to the needs of specific geographic areas. For these reasons, nothing in the Air Compliance Agreement will be used to delay or otherwise interfere with the implementation and enforcement of existing State statutes that eliminate exemptions to CAA requirements for agricultural sources of air pollution.

Request for Public Comment: As stated above, EPA is requesting comment on the Air Compliance Agreement, with particular emphasis on implementation of the Agreement. All comments should be submitted within 30 days of the date of this notice.

Earlier drafts of the Air Compliance Agreement have been circulated publicly. EPA requested and received comments on those drafts from, among others, representatives of state governments, environmental groups, local citizens' groups, and the AFO industry. Those comments were considered, and, where appropriate, changes were made to the draft agreement. In addition, the emission monitoring protocol for the nationwide emission monitoring program (Attachment B to the Agreement, included in the Appendix to this notice) was developed by a group of 30 leaders in the area of AFO air emissions, including scientists from EPA, the AFO industry, environmental groups, and several colleges and universities.

Sign Up Procedures: To participate in the Air Compliance Agreement, eligible AFOs should sign the Air Compliance Agreement and fill out Attachment A to the Agreement (the Farm and Emission Unit Information Sheets). A copy of the Agreement and all attachments can be downloaded from EPA's Web site at: *http://www.epa.gov.* The signed Agreement should be returned to EPA during the 90-day sign-up period that commences on the date of this notice. EPA will not sign the Agreement and forward it to EPA's Environmental Appeals Board for approval until after the conclusion of the public comment period.

Owners and operators of AFOs who want to sign Air Compliance Agreements with EPA will need to provide all of the following information on the Farm and Emission Unit Information Sheets for each AFO they would like to be covered by the Compliance Agreement:

- The name and address of the Respondent signing the Air Compliance Agreement;
- The name of each facility to be covered by the Agreement;
- The name of the owner and operator of each facility, including whether it is a contract grower facility;
- The location of all the covered facilities;
- The animal type and number of animals at each facility;
- The type of animal housing structure and number of structures at each facility;
- The type of manure handling system and the number of manure storage areas (*e.g.,* manure piles or lagoons) at each facility;
- The capacity and surface area, if applicable, of all manure storage areas at each facility; and,
- A description of any emission control technology or nontraditional manure treatment systems at each facility.

Signed Air Compliance Agreements, including all properly filled out attachments, should be sent to: Special Litigation and Projects Division (2248A), Attn: Air Compliance Agreements, Office of Regulatory Enforcement, Office of Enforcement and Compliance Assurance, U.S. EPA, 1200 Pennsylvania Ave., NW., Washington, DC 20460.

At the end of the sign-up period, EPA will determine whether a sufficient number of AFOs of each species have elected to participate. The determination will be based on whether the number of participants is sufficient to fully fund the monitoring study and whether the number of participants for each type of operation is sufficient to provide a representative sample to monitor. If the total number of participants is insufficient, EPA will not sign any Air Compliance Agreements and will not proceed with the monitoring study. If, however, the total number of participants is sufficient but there are an insufficient number of AFOs with a particular species or type of operation, EPA may decline to sign Air Compliance Agreements with those particular operations and decide not to proceed with the monitoring of that type of operation. No later than 30 days after the end of the sign-up period, EPA will decide whether to proceed with all, part, or none of the monitoring study and will sign the Air Compliance Agreements and forward them to EPA's Environmental Appeals Board (EAB) for final approval.

Additional Sources of General Information: To find out more about compliance with the CAA or section 103 of CERCLA, or EPCRA 304, please access the EPA Web site at *http://www.epa.gov/air/oaq_caa.html/* or *http://www.epa.gov/superfund/action/law/cercla.htm.*

Dated: January 21, 2005.

Thomas V. Skinner,

Assistant Administrator for Enforcement.

Jeffrey R. Holmstead,

Assistant Administrator for Air and Radiation.

Appendix 1—Air Compliance Agreement With Attachments A and B; Attachment A—Farm Information Sheet; Attachment B—National Air Emissions Monitoring Study Protocol

Appendix 1

In the Matter of [Participating Company]; Consent Agreement and Final Order; CAA–HQ–2005–XX; CERCLA–HQ–2005–XX; EPCRA–HQ–2005–XX

I. Preliminary Statement

1. The United States Environmental Protection Agency (EPA) and [Participating Company] (Respondent) voluntarily enter into this Consent Agreement and Final Order (Agreement) to address emissions of air pollutants and hazardous substances from certain animal feeding operation(s) that may be subject to requirements of the Clean Air Act, the hazardous substance release notification provisions of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) and the emergency notification provisions of the Emergency Planning and Community Right-to-Know Act (EPCRA).

2. The purpose of this Agreement is to ensure that [Participating Company] complies with applicable requirements of the Clean Air Act and applicable release notification provisions of CERCLA and EPCRA. To that end, this Agreement requires [Participating Company], among other things, to be responsible for the payment of funds towards a two-year national air emissions monitoring study that will lead to the development of Emissions-Estimating Methodologies that will help animal feeding operations determine and comply with their regulatory responsibilities under the Clean Air Act, CERCLA and EPCRA.

3. This Agreement is issued pursuant to section 113 of the Clean Air Act, 42 U.S.C. 7413 (federal enforcement of the Clean Air Act); sections 103 and 109 of CERCLA, 42 U.S.C. 9603 and 9609 (federal enforcement of notification provisions); section 325 of EPCRA, 42 U.S.C. 11045 (federal enforcement of EPCRA notification provisions); and 40 CFR 22.13(b) and 22.18(b)(2) and (3) (procedural requirements for the quick resolution and settlement of matters before the filing of an administrative complaint). Respondent's participation in this Agreement is not an admission of liability. At this time, Respondent neither admits nor denies that any of its Farms is subject to CERCLA or EPCRA reporting or Clean Air Act permitting requirements, or is in violation of any provision of CERCLA, EPCRA or the Clean Air Act. The execution of this Agreement by Respondent is not an admission that any of its agricultural operations has been operated negligently or improperly, or that any such operation is or was in violation of any federal, state or local law or regulation.

4. As described more specifically in paragraphs 26 and 35 below, this Agreement resolves Respondent's civil liability for certain potential violations of the Clean Air Act, CERCLA and/or EPCRA at [Participating Company's] Farm(s) listed in Attachment A. The release and covenant not to sue found in paragraph 26 resolves only violations identified and quantified by applying the Emissions-Estimating Methodologies developed using data from the national air emissions monitoring study described herein.

5. This Agreement is one of numerous identical agreements between EPA and animal feeding operations across the nation. Through these agreements, EPA and participating animal feeding operations aim to assist in the development of improved Emissions-Estimating Methodologies for air emissions from animal feeding operations and to ensure that all animal feeding operations are in compliance with applicable Clean Air Act, CERCLA and EPCRA requirements. Notwithstanding any other provision, this Agreement shall not delay or interfere with the implementation or enforcement of State statutes that eliminate exemptions to Clean Air Act requirements for agricultural sources of air pollution.

6. EPA may decline to enter into this Agreement with animal feeding operations (and their successors and assigns) that have been notified by EPA or a State that they currently may be subject to a Federal or State Clean Air Act, CERCLA section 103 or EPCRA section 304(a) enforcement action.

II. Definitions

7. Unless otherwise defined herein, terms used in this Agreement shall have the same meaning given to those terms in the Clean

Air Act, 42 U.S.C. 7401 *et seq.*; the Comprehensive Environmental Response, Compensation, and Liability Act, 42 U.S.C. 9601 *et seq.*; the Emergency Planning and Community Right-to-Know Act, 42 U.S.C. 11001 *et seq.,* and the implementing regulations promulgated thereunder. For purposes of this Agreement only, the following terms shall have the following meanings.

8. The term ''Agricultural Waste'' or ''Agricultural Livestock Waste'' means Livestock manure, wastewater, litter including bedding material for the disposition of manure, and egg washing or milking center waste treatment and storage. ''Agricultural Livestock'' or ''Livestock'' include dairy cattle, swine and/or poultry among others.

9. The term ''Contract Grower'' means the owner or operator of a Farm that raises Livestock or produces milk or eggs under a contract with Respondent.

10. The term ''Emissions-Estimating Methodologies'' means those procedures that will be developed by EPA, based on data from the national air emissions monitoring study and any other relevant data and information, to estimate daily and total annual emissions from individual Emission Units and/or Sources. These methodologies will be published on EPA's Web site (*http://www.epa.gov*).

11. The term ''Emission Unit'' means any part of a Farm that emits or may emit Volatile Organic Compounds (VOCs), Hydrogen Sulfide (H_2S), Ammonia (NH_3), or Particulate Matter (TSP, PM10 and PM2.5) and is either: (a) A building, enclosure, or structure that permanently or temporarily houses Agricultural Livestock; or (b) a lagoon or installation that is used for storage and/or treatment of Agricultural Waste.

12. The term ''Environmental Appeals Board'' or ''EAB'' means the permanent body with continuing functions designated by the Administrator of EPA under 40 CFR 1.25(e) whose responsibilities include approving administrative settlements commenced at EPA Headquarters.

13. The term ''Facility'' shall mean ''CERCLA Facility and/or EPCRA Facility.'' The term ''CERCLA Facility'' shall have the meaning given that term under section 101(9) of CERCLA, 42 U.S.C. 9601(9). The term ''EPCRA Facility'' shall have the meaning given that term under section 329(4) of EPCRA, 42 U.S.C. 11049(4).

14. The term ''Farm'' shall mean the production area(s) of an animal feeding operation, adjacent and under common ownership, where animals are confined, including animal lots, houses or barns; and Agricultural Waste handling and storage facilities. ''Farm'' does not include land application sites for Agricultural Waste. This definition is limited exclusively to this Agreement and establishes no precedent for the interpretation of any statute, regulation or guidance.

15. The term ''Nuisance'' is defined according to State and local common law, statutes, regulations, ordinances or usage.

16. The term ''Permitting Authority'' means the local, State or Federal government entity with jurisdiction to require compliance with the permitting requirements of the Clean Air Act.

17. The term ''Independent Monitoring Contractor'' means a person or entity that is not affiliated with Respondent or any other animal feeding operation, that has sufficient experience and expertise to fully implement the national air emissions monitoring study described herein, that meets the qualifications set forth in Attachment B to this Agreement, and that is approved by EPA.

18. The term ''Qualifying Release'' means a release that triggers a reporting requirement under section 103 of CERCLA or section 304 of EPCRA.

19. The term ''Respondent'' means [Participating Company].

20. The term ''Source'' shall have the meaning given to the term ''stationary source'' in the implementing regulations of the Clean Air Act at 40 CFR 52.21(b)(5) through (6), as interpreted by applicable guidance issued by EPA.

21. The term ''State or Local Authority'' means a state or local government entity with jurisdiction over Respondent's Farm(s).

III. Consent Agreement

22. EPA and Respondent have agreed to resolve this matter by executing this Agreement, as further set forth herein.

23. Respondent asserts that it either owns, operates or otherwise controls, or contracts with Contract Growers who own, operate or otherwise control, the Farm(s) listed in Attachment A to this Agreement. Respondent agrees that this Agreement applies only to the Farm(s) that are listed in Attachment A and contain one or more Emission Unit(s) as defined in paragraph 11 and described in Attachment A.

24. For the purpose of this proceeding, Respondent does not contest the jurisdiction of the Environmental Appeals Board.

25. As specified more fully below, Respondent consents to pay a civil penalty, to be responsible for the payment of funds to the national air emissions monitoring study, and to facilitate implementation of the monitoring study, including making certain Farms available for monitoring.

26. In consideration of Respondent's obligations under this Agreement and subject to the limitations and conditions set forth in paragraphs 27–30, 33, 34, 36, 37 and 43, EPA releases and covenants not to sue Respondent, with respect to the listed Emission Units located at the Farm(s) in Attachment A, for:

(A) Civil violations of the permitting requirements contained in Title I, Parts C and D, and Title V of the Clean Air Act, and any other federally enforceable State implementation plan (SIP) requirements for major or minor sources based on quantities, rates, or concentrations of air emissions of pollutants that will be monitored under this Agreement, namely Volatile Organic Compounds (VOCs), Hydrogen Sulfide (H_2S), Particulate Matter (TSP, PM10 and PM2.5), and Ammonia (NH_3); and

(B) civil violations of CERCLA section 103 or EPCRA section 304 from air emissions of Hydrogen Sulfide (H_2S) or Ammonia (NH_3) that are not singular unexpected or accidental releases such as those caused by an explosion, fire or other abnormal occurrence.

27. (a) The releases and covenants not to sue described in paragraphs 26 and 35 extend only to violations of the requirements identified in those paragraphs and apply only to emissions from Agricultural Waste at Emission Units (as defined in paragraph 11). They do not extend to any other requirements including but not limited to: (i) Any possible requirements that relate to emissions generated by other equipment or activities co-located at the Farm, including waste-to-energy systems; (ii) activities at open cattle feedlots for beef production; (iii) Clean Air Act permitting requirements triggered by an expansion of a Farm beyond its design capacity as of the date this Agreement is executed; or (iv) requirements that are not triggered by the quantity, concentration or rate of emission of Volatile Organic Compounds (VOCs), Hydrogen Sulfide (H_2S), Particulate Matter (TSP, PM10 and PM2.5) or Ammonia (NH_3), including work practice requirements and equipment specifications.

(b) The release and covenants not to sue in paragraphs 26 and 35 shall apply to the liability of a Contract Grower with respect to a Farm if and only if the Contract Grower executes an Agreement with EPA covering that Farm.

28. The release and covenant not to sue described in paragraph 26 covers Respondent's liability for violations with respect to an Emission Unit located at a Farm listed in Attachment A if and only if Respondent complies with all applicable requirements of this Agreement and, with respect to that Emission Unit:

(A) Within 120 days after receiving an executed copy of this Agreement, for any Farm that confines more than 10 times the ''large Concentrated Animal Feeding Operation'' threshold of an animal species,[3] the animal feeding operation provides to the National Response Center (NRC) and to the relevant local and state emergency response authorities written notice describing its location and stating substantially as follows:

This operation raises [species] and may generate routine air emissions of Ammonia in excess of the reportable quantity of 100 pounds per 24 hours. A rough estimate of those emissions is [__] pounds per 24 hours, but this estimate could be substantially above or below the actual emission rate, which is being determined through an ongoing monitoring study in cooperation with the U.S. Environmental Protection Agency. When that emission rate has been determined by this study, we will notify you of any reportable releases pursuant to CERCLA section 103 or EPCRA section 304. In the interim, further information can be obtained by contacting [insert contact information for a person in charge of the operation].

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[3] This definition is being used in this Agreement solely for the purpose of determining the penalty assessed, and for certain limited reporting purposes. ''Large Concentrated Animal Feeding Operation'' is defined as: (a) 2,500 swine weighing more than 55 pounds; (b) 10,000 swine weighing less than 55 pounds; (c) 82,000 laying hens; (d) 125,000 broilers; (e) 55,000 turkeys; or (f) 700 mature dairy cows or 1000 dairy heifers.

Respondent shall provide to EPA, at the address in paragraph 64, a copy of any written notice given pursuant to this subparagraph. This interim notice shall be provided to satisfy the terms of this Agreement only and is not intended to establish a precedent or standard for reporting under CERCLA or EPCRA.

(B) Where application of the Emissions-Estimating Methodologies establishes that no Clean Air Act requirements or that no CERCLA or EPCRA notifications are required for a Source or Facility, Respondent shall so certify to EPA in writing within 60 days after EPA publishes Emissions-Estimating Methodologies applicable to the Emission Units at the Source or Facility. Any such certification shall identify each Source or Facility covered by the certification and the Emissions-Estimating Methodology used to calculate its emissions. If EPA notifies Respondent that this certification is not correct because application of the Emissions-Estimating Methodologies indicates that the Source or Facility is subject to such requirements, Respondent shall have 90 days from notification by EPA to comply with the provisions in paragraph 28(C) or submit, in writing, clear and convincing proof to EPA that Respondent's certification is correct.

(C) Respondent complies with all of the applicable requirements set forth below:

(i) Within 120 days after EPA has published Emissions-Estimating Methodologies applicable to the Emission Units at Respondent's Source, Respondent submits all Clean Air Act permit applications required by the Permitting Authority for the Source, based on application of those Emissions-Estimating Methodologies.

(a) For a Source whose emissions exceed the major source threshold in Title I, Part C or D, based on the area's attainment status (*e.g.,* in an attainment area, more than 250 tons per year of a regulated pollutant), this requirement includes:

(1) Applying for and ultimately obtaining a permit that contains a federally enforceable limitation or condition that limits the potential to emit of the Source to less than the applicable major source threshold for the area where the Source is located; or,

(2) Installing best available control technology (BACT) in an attainment area, or technology meeting the lowest achievable emission rate (LAER) if the Source is located in a nonattainment area, as determined by and in accordance with the schedule provided by the Permitting Authority for the Source, and obtaining a federally enforceable permit that incorporates an appropriate BACT or LAER limit. For the purposes of this Agreement, compliance with the requirements found in 40 CFR 52.21(k) through (p) is not a condition of the release and covenant not to sue described in paragraph 26. Nothing in this paragraph is intended to limit a state or local government's authority to impose applicable permitting requirements. Emission reductions that result from installing BACT or LAER may not be used in netting calculations to offset emissions from a future modification to the Source.

(b) The annual emissions from a particular Source shall be determined based on Respondent's current operating methods and on the maximum number of animals housed at the Source at any time over the 24 months prior to EPA's publication of the applicable Emissions-Estimating Methodologies.

(c) Respondent promptly and fully responds to any notices of deficiency (or other equivalent notification that the permit application is incomplete or incorrect) issued by the Permitting Authority with respect to the permit application(s).

(d) As described in paragraph 34, below, Farms installing waste-to-energy systems will have an additional 180 days to submit the above-referenced permit applications.

(ii) Within 120 days after EPA has published Emissions-Estimating Methodologies applicable to Emission Units at Respondent's Facility, Respondent reports all Qualifying Releases of Hydrogen Sulfide (H_2S) and Ammonia (NH_3) in accordance with section 103 of CERCLA and section 304 of EPCRA.

(iii) Respondent timely installs all emission control equipment and implements all practices required by this Agreement or contained in the Clean Air Act permits issued in response to the applications submitted in accordance with subparagraph (i) of this paragraph.

(iv) Respondent provides EPA with written certification that it has timely installed all emission control equipment and implemented all practices required by this Agreement or contained in the Clean Air Act permits issued in response to the applications submitted in accordance with subparagraph (i) of this paragraph, within 30 days of meeting those requirements or within 30 days of acknowledgment of compliance by the Permitting Authority if such acknowledgment is required.

(D) Respondent's failure to comply with any of the above requirements in this paragraph at any particular Source shall affect the release and covenant not to sue for the noncompliant Source only and shall not affect the release and covenant not to sue for Respondent's complying Sources. In addition, Respondent's failure to comply with any of the above requirements in this paragraph at any particular Facility shall affect the release and covenant not to sue for the noncompliant Facility only and shall not affect the release and covenant not to sue for Respondent's complying Facilities.

29. For any Farm listed in Attachment A that is owned and operated by a Contract Grower, Respondent is not responsible for complying with paragraphs 28, 30 and 60. However, the release and covenant not to sue described in paragraph 26 covers Respondent's liability for violations with respect to the Emission Units located at such Farm if, and only if, the Contract Grower complies with all the requirements of paragraph 28. The Contract Grower's liability for violations with respect to the Emission Units located at that Farm is not covered by any of the releases and covenants not to sue set forth in this Agreement. However, the Contract Grower may enter its own agreement with EPA (thus becoming a respondent in its own agreement) and obtain similar conditional releases and covenants not to sue with respect to the emission units at its farm.

30. In addition, the release and covenant not to sue described in paragraph 26 covers violations with respect to the Emission Units located at a Farm listed in Attachment A if, and only if, Respondent complies with the following requirements, with respect to that Farm:

(A) During the period in which potential violations at the Farm are covered by the release and covenant not to sue as described in paragraph 26, Respondent complies with all final actions and final orders issued by the State or Local Authority that address a Nuisance arising from air emissions at the Farm and that are:

(i) Issued after Respondent has been given notice and opportunity to be heard (including any available judicial review) as required by applicable state or local law; and,

(ii) Issued during the time period in which potential violations at the Farm are covered by the release and covenant not to sue as described in paragraph 26.

(B) Within 60 days of coming into compliance with the final action or order of the State or Local Authority, Respondent provides EPA with written certification that Respondent has complied with the final action or final order and within the time schedule approved by the State or Local Authority.

31. Respondent agrees that the statute of limitations for all claims covered by the release and covenant not to sue in paragraph 26 will be tolled from the date this Agreement is approved by the EAB and until the earlier of: (a) 120 days after Respondent files the required certifications in accordance with paragraph 28(B) or paragraph 28(C)(iv), or (b) December 31, 2011. This time period can be extended by written agreement of both parties.

32. EPA will publish Emissions-Estimating Methodologies within 18 months of the conclusion of the monitoring period and will publish such Methodologies on a rolling basis as soon as they are developed. If EPA's Science Advisory Board determines that EPA is unable to publish Emissions-Estimating Methodologies applicable to a particular type of Emission Unit in Attachment A within 18 months of the conclusion of the monitoring period because of inadequate data, EPA will attempt to resolve such data problems as soon as possible. EPA's inability to publish an Emissions-Estimating Methodology for a particular type of Emission Unit in Attachment A within 18 months shall have no effect on any other deadline or provision of this Agreement for any other type of Emission Unit listed in Attachment A.

33. As a condition of its participation in this Agreement, Respondent agrees to accept, regardless of any collateral proceeding, the study protocols employed in and the emissions data developed by, the national air emissions monitoring study conducted under the plan described in paragraphs 53 through 63 below. If Respondent challenges the protocols employed or the data developed, the release and covenant not to sue described in paragraph 26 of this Agreement will become null and void and will have no effect on Respondent's past or future liability.

34. Respondent may choose to install and operate one or more systems that process

Agricultural Livestock Waste to produce electricity (a waste-to-energy system). If Respondent selects this option, it will have, with respect to a Farm at which such a system will be installed, an additional 180 days to comply with the requirements of paragraph 28 provided the following requirements are met, with respect to that Farm:

(A) Within 120 days after EPA has published Emissions-Estimating Methodologies applicable to the Emission Units at Respondent's Source, Respondent provides EPA with a written certification that it intends to install a waste-to-energy system, identifies each Farm at which such a system is or will be installed, and describes the type of waste-to-energy system installed and the percentage by volume of Agricultural Waste processed by the system at each Farm.

(B) The waste-to-energy system processes at least 50 percent of the Agricultural Waste by volume produced at the Farm.

(C) Respondent makes each Farm at which a waste-to-energy system is installed available for inspection by EPA.

(D) Respondent agrees to operate the waste-to-energy system for 24 months from the first date of operation or the date EPA publishes Emissions-Estimating Methodologies for the Emission Units at Respondent's Source, whichever is later. If during that 24-month period Respondent has to shut down the waste-to-energy system, the benefits of this paragraph will still be applicable if Respondent has made all reasonable efforts to maintain and operate the system.

(E) Respondent obtains, within applicable time limits, all required federal and state permits needed to construct and operate the waste-to-energy system at the Farm.

35. Subject to paragraphs 27, 37 and 43, if during the pendency of the nationwide monitoring study, Respondent promptly reports and corrects a civil violation of a federally approved SIP or an approved Federal implementation plan (FIP) resulting from emissions of Volatile Organic Compounds (VOCs), Hydrogen Sulfide (H_2S), Ammonia (NH_3), or Particulate Matter (TSP, PM10, and PM2.5) from a Farm listed in Attachment A that causes or contributes to a violation of any provision of the federally approved SIP that requires compliance with an ambient air quality standard at the Farm's property line, EPA releases and covenants not to sue Respondent for the reported and corrected violation if, and only if, the conditions set forth below are met:

(A) Unless Respondent first learned of the violation through a notice from EPA, Respondent provides notice of the violation to EPA and the applicable Permitting Authority within 21 days of Respondent's discovery of the violation or the final order of the EAB approving this Agreement, whichever is later;

(B) Respondent corrects the violation, including making any necessary adjustments to its operations at the Farm to prevent the violation from happening again, within 60 days after notice is given by Respondent or EPA as described in subparagraph (A) above. If the violation cannot reasonably be corrected within 60 days, Respondent must, before the end of the 60-day time period, submit a plan that is ultimately approved by EPA and the applicable Permitting Authority to correct the violation and must comply with the approved plan in accordance with the specified schedule. Within 30 days of correcting the violation, Respondent shall submit a written certification to EPA indicating that it has corrected the violation in accordance with the approved plan; and,

(C) The violation is not a repeated violation that Respondent previously reported to EPA pursuant to this paragraph. Respondent may rectify the loss of the above release and covenant not to sue for the first instance of a repeat violation; however, if it pays a stipulated penalty of $500 a day for each day that the Farm exceeds the ambient air quality standard, and it meets the requirements of subparagraphs (A) and (B), except that the time to correct the violation shall be 30 days instead of 60 days.

36. All certifications that Respondent must submit to comply with this Agreement shall include the following statement:

I certify under penalty of law that the information contained in this submittal to EPA is accurate, true, and complete. I understand that there are significant civil and criminal penalties for making false or misleading statements to the United States government.

The above statement shall be signed by a responsible official for the Respondent (*i.e.,* the owner if Respondent is a sole proprietorship, the managing partner if Respondent is a partnership, or a responsible corporate official if Respondent is an incorporated entity).

37. The releases and covenants not to sue described in paragraphs 26 and 35 do not cover Respondent's liability for any violation with respect to an Emission Unit located at a Farm if Respondent fails to comply with any of the applicable requirements of this Agreement with respect to that Emission Unit, including the limitations and conditions in paragraphs 26–29 and 33–34 above. The releases and covenants not to sue described in paragraphs 26 and 35 cover only violations with respect to the Emission Units located at the Farm that occur before the earlier of: (a) The date Respondent submits the last required certification covering those Emission Units; or (b) 2 years after Respondent submits any permit applications pursuant to paragraph 28(C)(i). This time period can be extended by a period not to exceed 6 months upon written agreement of both parties provided the Respondent's action or inaction is not the cause of any delay in obtaining a permit.

38. EPA will notify Respondent if EPA has determined that it cannot develop Emissions-Estimating Methodologies for any Emission Units listed in Attachment A.

(A) This notice shall identify (individually or by category) Emission Units, Sources and/or Facilities for which Emissions-Estimating Methodologies cannot be developed.

(B) For the Emission Units identified in such a notice:

(i) No certification under paragraph 28 shall be required for those Emission Units and any other related Emission Units that comprise the Source or Facility; and,

(ii) The releases and covenants not to sue described in paragraphs 26 and 35 shall cover potential violations that occur on or before 120 days after the date the notice is mailed, but shall not cover potential violations that occur more than 120 days after that date.

(C) Notice required under this paragraph will be deemed proper if sent via U.S. mail postage prepaid to the address listed in Attachment A.

39. The execution of this Agreement is not an admission of liability by Respondent, and Respondent neither admits nor denies that it has violated any provisions of the Clean Air Act, CERCLA or EPCRA.

40. Respondent waives its right to request an adjudicatory hearing on this Agreement, and its right, created by Clean Air Act section 113(a)(4), to confer with the Administrator before this Agreement takes effect. Respondent further waives its right to seek judicial review of the penalty assessed in paragraph 48.

41. Respondent and EPA represent that they are duly authorized to execute this Agreement, and that the persons signing this Agreement on their behalf are duly authorized to bind Respondent and EPA, respectively, to the terms of this Agreement.

42. Respondent agrees not to claim or attempt to claim a federal income tax deduction or credit covering all or any part of the civil penalty paid to the United States Treasurer. Any payments made in connection with the national air emissions monitoring study do not constitute a fine or penalty and are not paid in settlement of any actual or potential liability for a fine or penalty.

43. This Agreement is without prejudice to all rights of EPA against Respondent with respect to any claims not expressly covered by the releases and covenants not to sue contained in paragraphs 26 and 35. This Agreement does not limit in any way EPA's authority to restrain Respondent or otherwise act in any situations that may present an imminent and substantial endangerment to public health, welfare or the environment. In addition, the releases and covenants not to sue in paragraphs 26 and 35 do not cover any criminal liability.

44. With respect to any claims not expressly released herein, in any subsequent administrative or judicial proceeding initiated by the United States for injunctive relief, penalties, recovery of response costs or other relief relating to a Farm listed in Attachment A, Respondent shall not assert, and may not maintain, any defense or claim based upon the principles of waiver, res judicata, collateral estoppel, issue preclusion, claim-splitting or other defenses based upon any contention that the claims raised by the United States in the subsequent proceeding were or should have been brought in the instant proceeding.

45. Respondent recognizes that EPA may not execute this Agreement if EPA determines that there will be inadequate funding for the national air emissions monitoring study or if EPA determines that there is inadequate representation of eligible animal groups and types of Farms, Facilities or Emission Units.

46. Respondent and EPA stipulate to the issuance of the proposed Final Order below.

[Participating Company], Respondent

By: ________________
(Print Name): ________________
Title: ________________
Dated: ________________

U.S. Environmental Protection Agency, Complainant

By: ________________
Title: ________________
Dated: ________________

IV. Final Order

It is hereby ordered and adjudged as follows:

Compliance

47. Respondent shall comply with all terms of this Agreement.

Penalty

48. Respondent is hereby assessed a penalty based on the number and size of the Farms listed in Attachment A as follows:

(A) If Respondent has only one Farm and that Farm is below the ''large Concentrated Animal Feeding Operation'' threshold for that animal species,[4] Respondent is assessed a penalty of $200.

(B) All other Respondents are assessed a penalty of $500 per Farm, unless the Farm contains more than 10 times the total number of animals that defines the ''large Concentrated Animal Feeding Operation'' threshold. For those Farms, Respondent is assessed a penalty of $1,000 per Farm.

(C) The total penalty paid by Respondent shall not exceed:

$10,000 if Attachment A lists 1–10 Farms
$30,000 if Attachment A lists 11–50 Farms
$60,000 if Attachment A lists 51–100 Farms
$80,000 if Attachment A lists 101–150 Farms
$90,000 if Attachment A lists 151–200 Farms
$100,000 if Attachment A lists more than 200 Farms.

49. Respondent shall pay the assessed penalty no later than 30 calendar days from the date an executed copy of this Agreement is received by Respondent (hereinafter referred to as the ''Agreement Date'').

50. All penalty assessment monies under this Agreement shall be paid by certified check or money order, payable to the United States Treasurer, and mailed to: U.S. Environmental Protection Agency (Washington, DC Hearing Clerk), P.O. Box 360277, Pittsburgh, Pennsylvania 15251–6277. A transmittal letter, indicating Respondent's name, complete address, and this case docket number must accompany the payment. Respondent shall file a copy of the check and of the transmittal letter by mailing it to: Headquarters Hearing Clerk, US EPA, 1921 Jefferson Davis Hwy, Crystal Mall #2, Room 104, Arlington, VA 22202.

51. Failure to pay the penalty assessed under this Agreement may subject Respondent to a civil action pursuant to section 113(d)(5) of the Clean Air Act, 42 U.S.C. 7413(d)(5), to collect any unpaid portion of the monies owed, together with interest, handling charges, enforcement expenses, including attorney fees and nonpayment penalties. In any such collection action, the validity, amount or appropriateness of this Order or the penalty assessed hereunder is not subject to review.

52. Pursuant to 42 U.S.C. 7413(d)(5) and 31 U.S.C. 3717, Respondent shall pay the following amounts:

(A) *Interest.* Any unpaid portion of the assessed penalty shall bear interest at the rate established pursuant to 26 U.S.C. 6621(a)(2) from the date an executed copy of this Agreement is received by Respondent; provided, however, that no interest shall be payable on any portion of the assessed penalty that is paid within 30 days of the Agreement Date.

(B) *Attorney Fees, Collection Cost, Nonpayment Penalty.* Should Respondent fail to pay on a timely basis the amount of the assessed penalty, Respondent shall be required to pay, in addition to such penalty and interest, the United States' enforcement expenses, including but not limited to attorney fees and costs incurred by the United States for collection proceedings, and a quarterly nonpayment penalty for each quarter during which such failure to pay persists. Such nonpayment penalty shall be 10 percent of the aggregate amount of Respondent's outstanding penalties and nonpayment penalties accrued from the beginning of such quarter.

(C) *Payment.* Interest, attorney fees, collection costs, and nonpayment penalties related to Respondent's failure to timely pay the assessed penalty shall be made in accordance with subparagraphs (A) and (B) of this paragraph.

Monitoring Fund

53. Respondent has a shared responsibility for funding and implementing the national air emissions monitoring study described in paragraphs 53 through 63.

(A) Respondent individually shall be responsible for paying the lesser of: (a) $2,500 for each Farm listed in Attachment A to this Agreement; or (b) Respondent's pro rata share of the amount needed to fully fund the monitoring study (''Full Funding Level''), including any unfunded balance of the monitoring study, consistent with the provisions of paragraph 62. Respondent's pro rata share shall be based on the number of Farms listed in Attachment A divided by the total number of discrete Farms of the same species that share responsibility for funding the national monitoring study. The Full Funding Level is the amount of money actually needed to fully and adequately fund the monitoring study described in this Agreement. The Full Funding Level shall be initially estimated within 60 days of the Agreement date and shall be included as part of the proposed plan to conduct the monitoring described in paragraph 55. The estimated Full Funding Level shall be used to determine the pro rata share of the monitoring fund payment for which Respondent is initially responsible. Any shortfalls that occur because the estimated Full Funding Level was less than the actual Full Funding Level shall be handled in accordance with this paragraph and paragraph 62.

(B) Respondent shall have no obligation to contribute money to the national monitoring study on behalf of a Farm listed in Attachment A if: (a) That Farm has been listed as a contract farm in another agreement that is identical to this agreement except for the respondent involved, and (b) the respondent to the other Agreement has agreed to be responsible for the payment of monies into the monitoring study for that Farm.

54. Respondent shall have met its shared responsibility for funding and implementing the national air emissions monitoring study, including any individual payments by Respondent under paragraph 53 or 62 if, and only if: (a) A nonprofit entity is established for the purposes set forth below; (b) the monitoring fund obligations to the nonprofit entity are fully satisfied; (c) the nonprofit entity enters into a contract with an Independent Monitoring Contractor (the ''IMC'') that obligates the IMC to fulfill the requirements set forth in paragraphs 55 through 59 and 62 of this Agreement; and, (d) Respondent grants access to Farms listed in Attachment A in accordance with paragraphs 60 and 61. The purposes of the nonprofit entity shall include: collecting and holding Respondent's contributions to the national air emissions monitoring study, purchasing and holding title to research equipment, contracting with an IMC to conduct the monitoring study, and other responsibilities.

55. The contract identified in paragraph 54 shall require the IMC to submit to EPA, within 60 days of the Agreement date, a detailed plan to conduct the nationwide monitoring study set forth in Attachment B. The proposed plan shall:

(A) Identify the IMC and its qualifications, including the qualifications of any subcontracted science advisors, for implementing the national air emissions monitoring study;

(B) Be consistent with, expand the explanation of, and include all of the elements of the monitoring study outline set forth in Attachment B to this Agreement, including the requirements that: (1) All monitoring be completed within 2 years of EPA's approval of the monitoring study; (2) a comprehensive quality assurance program be implemented as part of the study; and (3) the emissions to be monitored will be Particulate Matter (TSP, PM10, and PM2.5), Hydrogen Sulfide (H_2S), Ammonia (NH_3), and Volatile Organic Compounds (VOCs);

(C) Identify the Farms to be monitored and the justification for including those Farms based on the specifications for the monitoring set forth in Attachment B; and,

(D) Require the IMC to submit detailed quarterly reports to EPA and to the entity described in paragraph 54. Those reports shall discuss the IMC's progress in implementing the approved monitoring plan, including what it did during the previous 3 months and what it intends to do during the next three months. The IMC shall submit quarterly reports starting with the end of the first calendar quarter (*i.e.,* March 31, June 30, September 30 or December 31) after the proposed monitoring plan is approved by EPA, unless the plan is approved by EPA with less than 30 days left in the current

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[4] Ibid.

calendar quarter. If that occurs, the IMC shall submit the first quarterly report at the end of the next calendar quarter. The quarterly reports shall continue through the end of the calendar quarter during which the national monitoring study is completed.

56. EPA will review and approve or disapprove the proposed plan within 30 days of receiving it from the IMC. If the proposed plan is disapproved, EPA will specifically state why it is being disapproved and what changes need to be made. The IMC shall then have 30 days from the date EPA disapproves the proposed plan to modify it and to submit the modified plan to EPA for review and approval. If the IMC does not submit a plan that is ultimately approved by EPA, the releases and covenants not to sue set forth in paragraphs 26 and 35 of this Agreement shall be null and void.

57. Once the plan is approved, the contract between the nonprofit entity identified in paragraph 54 and the IMC shall require the IMC to fully implement the approved plan in accordance with the approved schedule. Failure of the IMC to implement the approved plan in accordance with the approved schedule, unless specifically excused by EPA in writing, shall nullify the releases and covenants not to sue set forth in paragraphs 26 and 35 of the Agreement. The estimated Full Funding Level monies shall be transferred to the nonprofit entity described in paragraph 54 within 60 days of EPA's approval of the monitoring plan.

58. The contract identified in paragraph 54 shall require the IMC to schedule periodic meetings (either by phone or in person) with EPA, and additional meetings upon request by EPA or the IMC, to discuss progress in implementing the approved plan. The IMC shall be required to promptly inform EPA of any problems in implementing the approved plan that have occurred or are anticipated to occur or of any adjustments that may be needed. No changes may be made to the approved plan without the written consent of EPA.

59. All emissions data generated and all analyses of the data made by the IMC during the nationwide monitoring study shall be provided to EPA as soon as possible in a form and through means acceptable to EPA. The parties agree that all emissions data will be fully available to the public, and that Respondent waives any right to claim any privilege with respect to such data.

60. Respondent agrees to make the Farms listed in Attachment A available for emissions monitoring under the national air emissions monitoring study if the Farm is chosen as a monitoring site under the approved plan. As stated in paragraph 29, if the Farm is owned by a Contract Grower, this requirement does not apply. However, a Contract Grower who enters into its own agreement with EPA (thus becoming a respondent in its own agreement) is subject to this requirement.

61. Respondent also agrees to give EPA or its representative access to those Farms for the purpose of verifying their suitability for monitoring or to observe monitoring conducted under the approved nationwide monitoring plan. EPA agrees that prior to entering a Farm, it will comply with proper biosecurity measures as are normal and customary. Nothing in this Agreement is intended in any way to limit EPA's inspection, monitoring, and information collection authorities under the Clean Air Act, CERCLA or EPCRA.

62. If, prior to completion of the national air emissions monitoring study, it appears that there will be insufficient funds to complete the study, the IMC shall notify EPA of this problem within 30 days of making this determination. The notice shall contain a detailed explanation of why there are insufficient funds, account for all money spent, and identify how much more money is needed to complete the monitoring study. If Respondent is not required under paragraph 53 to contribute or secure the contribution of additional money to the national monitoring study that will be sufficient to complete the monitoring study, the IMC or the nonprofit entity described in paragraph 54 shall make all reasonable efforts to find additional funding to complete the monitoring study. The IMC or the nonprofit entity described in paragraph 54 shall advise EPA of the efforts to locate additional funding and shall not commit to the use of additional funding sources without the prior approval of EPA. If, despite the best efforts of Respondent or its representative, the IMC, or the nonprofit entity described in paragraph 54, the national monitoring study cannot be completed due to lack of funding, then the releases and covenants not to sue set forth in paragraphs 26 and 35 of this Agreement will no longer be in effect. For Farms with animal types for which sufficient funds were provided to fully and adequately fund their portion of the national monitoring study, EPA shall make reasonable efforts to avoid terminating the releases and covenants not to sue set forth in paragraphs 26 and 35.

63. If, after completion of the national monitoring study, there is unspent money in the national monitoring fund, the IMC shall notify EPA within 90 days of completion of the monitoring study. The notice shall contain a detailed explanation of why there are unspent funds, including an accounting of all money spent to implement the national monitoring study and how much is left unspent. The notice shall also include a proposed plan for distribution of the leftover money.

64. All certifications required by this Agreement shall be submitted to: Special Litigation and Projects Division (2248A), Attn: AFO/CAFO certifications, Office of Regulatory Enforcement, 1200 Pennsylvania Ave., NW., Washington, DC 20460.

65. Except for a Farm for which Respondent, or the Contract Grower, is able to certify under paragraph 27(B), this document constitutes an "enforcement response" as that term is used in the Clean Air Act Penalty Policy and an "enforcement action" as that term is used in the EPCRA/CERCLA Penalty Policy.

66. Each party shall bear its own costs, fees, and disbursements in this action, except where explicitly stated as otherwise in this Agreement.

67. The provisions of this Agreement shall be binding on Respondent, its officers, directors, employees, agents, successors and assigns.

68. This Agreement is not binding and without legal effect unless and until approved by the Environmental Appeals Board.

It is so ordered.

Dated this__________ day of __________, 2005.

____

Environmental Appeals Judge
Environmental Appeals Board
U.S. Environmental Protection Agency

Attachment A to the Consent Agreement

This Attachment identifies and describes the Farms and Emission Units covered by this Agreement. This Agreement has no effect on any Farm or Emission Unit not specifically listed on this Attachment. The terms used in this Attachment shall have the meaning given to those terms in the Agreement.

The attached Farm Information Sheets and Emission Unit Information Sheets provide information about each Farm and Emission Unit(s) to be covered by this Agreement. A separate form for each Farm and each Emission Unit covered by the Agreement is attached below and as such is an integral part of this Attachment. By identifying a Farm for coverage under the Agreement, Respondent is asserting that the Farm meets the definition of a Farm in the Agreement and contains at least one Emission Unit as defined in the Agreement. Also by identifying an Emission Unit at a Farm for coverage under the Agreement, Respondent is asserting that the Emission Unit meets the definition of an Emission Unit in the Agreement. Unless Respondent identifies a Contract Grower for a Farm, Respondent is also asserting it owns, operates or otherwise controls the Farm.

I certify under penalty of law that the information contained in this submittal to EPA is accurate, true, and complete. I understand that there are significant civil and criminal penalties for making false or misleading statements to the United States Government.

[Signature] __________________________

[Name] [Title] [Date]
[Participating Company]
[Participating Company's Address]

Farm Information Sheet (Example) (Fill Out One Sheet for Each Farm)

Name of Farm: ______________________

Is the Farm owned and operated by a Contract Grower or is otherwise a contract farm?

______yes ______no

Name of Contract Grower (if applicable): ____

Location: ____________________________

(street address, city, county, state)

Animal Type (check all that apply):
______Poultry (layers)
______Poultry (broilers)
______Poultry (turkeys)
______Dairy Cattle (heifers or milking cattle)
______Swine (nursery, sow or finisher)
______Other (please identify)

For all Farms that Respondent owns and/or operates, provide a Farm sketch/diagram that numbers or otherwise identifies all Emission Units listed on this Farm Information Sheet.

Emission Unit Information Sheet (Example) (Fill Out One Sheet for Each Emission Unit)

Name of Farm where Emission Unit is located: ______________________________

Unit name and/or number: ______________

Date placed in service: ______________

Design capacity (No. of animals or No. of gallons): ______________________________

If the Emission Unit is a manure storage and treatment system in use at the Farm, check all that apply:

______pull plug/flush/in-ground manure storage basin (if lagoon, specify type)
______deep pit/in-ground manure storage basin (if lagoon specify type)
______shallow pit/open manure storage
______shallow pit/closed manure storage
______deep pit/open manure storage
______deep pit/closed manure storage
______manure belt/closed manure storage
______manure belt/open manure storage
______flush/open manure storage
______flush/closed manure storage
______scrape/open manure storage
______scrape/closed manure storage
______other (briefly describe)

If the Emission Unit is a building, enclosure, or structure that permanently or temporarily houses Agricultural Livestock, check all that apply with respect to the ventilation type:

______natural
______mechanical
______other (please describe)

Emission Control Technology (please list type and briefly describe if applicable):

Attachment B—National Air Emissions Monitoring Study Protocol; Overview & Summary

Executive Summary

This document provides an overview and summary of a monitoring study protocol for collecting air emissions data from the egg, broiler chicken, turkey, dairy and swine industries. This protocol was developed through a collaborative effort of industry experts, university scientists, government scientists, and other stakeholders knowledgeable in the field. Although the effort was facilitated by the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA), this product represents the opinions of the scientists, government experts, and stakeholders involved. In addition, there was extensive internal review and input by representatives from U.S. EPA's Office of Enforcement and Compliance Assurance, Office of Air and Radiation, and Office of Research and Development.

This protocol is designed to provide a framework for development of a comprehensive field sampling plan for collecting quality-assured air emission data from representative livestock and poultry farms in the U.S. As recommended in the National Academy of Sciences (NAS) 2003 report,[5] and paraphrased here, * * * EPA and USDA should for the short term, initiate and conduct a coordinated research program designed to produce a scientifically sound basis for measuring and estimating air emissions from AFOs. Specific recommendations being addressed with this protocol are related to direct measurements at sample farms; utilizing information on the relationships between air emissions and animal types, nutrient outputs, manure handling practices, animal numbers, climate, and other factors, conducting these studies to evaluate the extent to which ambient atmospheric concentrations of the various pollutants of interest are consistent with estimated farm emissions; and using scientifically sound and practical protocols for measuring pollutant emission rates. The research program will involve additional recommendations from the NAS, which entails developing a process-based model that considers the entire animal production process. The data collected in the monitoring study will lay the groundwork for developing these more process-related emission estimates. However, as with any large and complex effort, this work must be conducted over a period of years.

In the development of this protocol, several alternate techniques were considered. The Science Advisor, in designing the monitoring study, may choose to use an alternate technique that is deemed most appropriate for a particular study unit. (A listing of alternate techniques can be found later in this protocol.) Thus, this protocol does not exclude use or consideration of any measurement methods or technologies that have been demonstrated to be scientifically sound and/or widely accepted for application to collecting air emissions data from the relevant farm sectors. However, the use of alternate techniques is dependent upon EPA approval of a comprehensive study design and budget.

The benchmark data collected and subsequent analyses and interpretation will allow EPA and livestock and poultry producers to reasonably determine which farms are subject to the regulatory provisions of the Clean Air Act and reporting requirements of CERCLA and EPCRA. Following sound scientific principles and using accepted instrumentation and methods, the monitoring study will collect new data from a number of farms across the country and will also evaluate existing emissions data from other selected studies that may meet EPA quality assurance criteria. Together, they will form a database to which additional studies of air emissions and the effectiveness control technologies can be compared.

EPA will review and approve (as described in the Consent Agreement) a comprehensive study design and plan, including a Quality Assurance Project Plan (QAPP), and a budget for all aspects of the monitoring study. The QAPP will outline appropriate procedures to ensure acceptable accuracy, precision, representativeness, and comparability of the data; and will specify the use of properly maintained and reliable instrumentation, sampling schedules, ready supply of spare parts, approved analytical methodologies and standard operation procedures, description of routine quality control (QC) checks, external validation of data, well-trained analysts, field blanks, electrical backups, audits, documentation and format of data submission, and other procedural requirements. Chain of custody documentation will be used for samples of particulate matter. Wetted materials for gas sampling will be Teflon®, stainless steel or glass. All sampling flow rates will be calibrated.

Monitoring Study Responsibilities

Several groups of management and technical staff will be responsible for success of the study. Their responsibilities are discussed here and graphically illustrated in the following flow chart.

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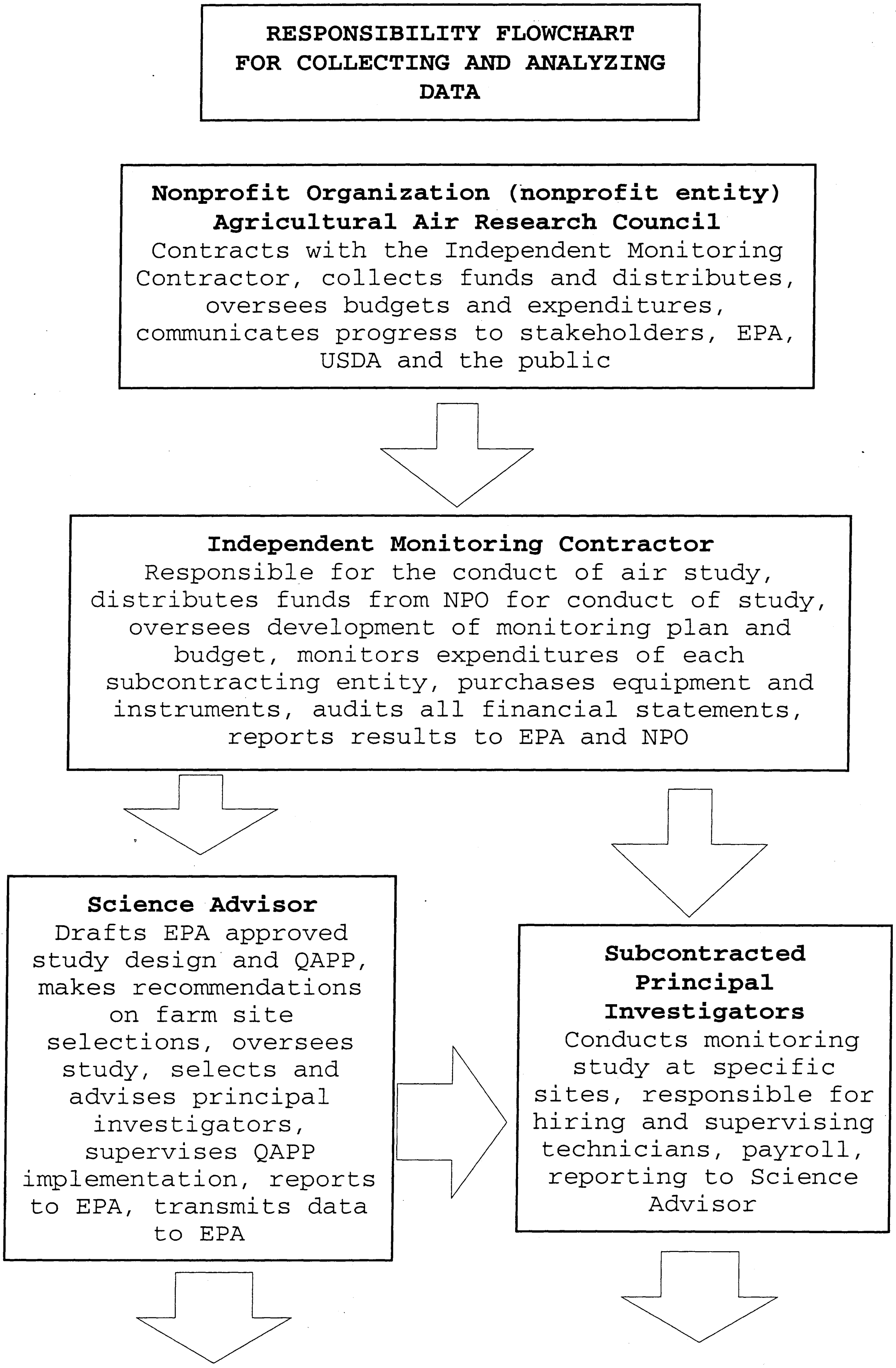
[5] NAS, ''Air Emissions From Animal Feeding Operations: Current Knowledge, Future Needs,'' National Research Council, 2003.



RESPONSIBILITY FLOWCHART FOR COLLECTING AND ANALYZING DATA

Nonprofit Organization (nonprofit entity) Agricultural Air Research Council
Contracts with the Independent Monitoring Contractor, collects funds and distributes, oversees budgets and expenditures, communicates progress to stakeholders, EPA, USDA and the public

Independent Monitoring Contractor
Responsible for the conduct of air study, distributes funds from NPO for conduct of study, oversees development of monitoring plan and budget, monitors expenditures of each subcontracting entity, purchases equipment and instruments, audits all financial statements, reports results to EPA and NPO

Science Advisor
Drafts EPA approved study design and QAPP, makes recommendations on farm site selections, oversees study, selects and advises principal investigators, supervises QAPP implementation, reports to EPA, transmits data to EPA

Subcontracted Principal Investigators
Conducts monitoring study at specific sites, responsible for hiring and supervising technicians, payroll, reporting to Science Advisor

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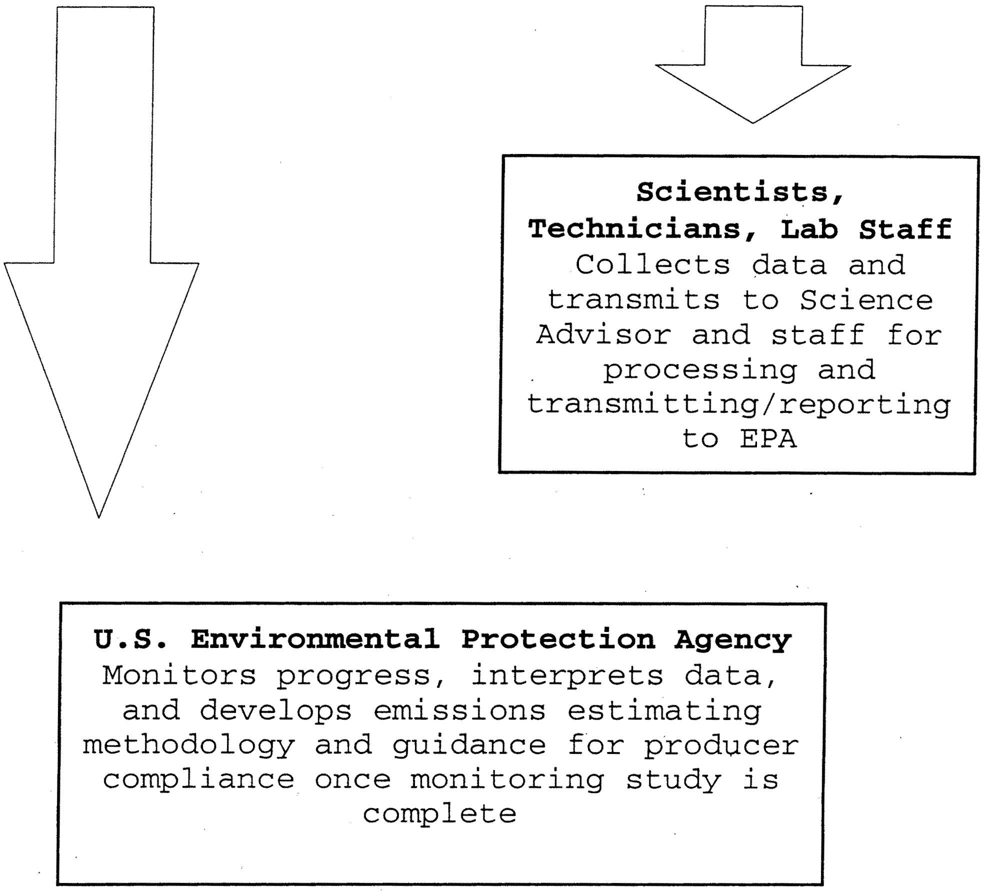
The Nonprofit Organization (NPO)

Industry has established a nonprofit entity (Agricultural Air Research Council, or AARC, and referred to as the nonprofit organization or NPO in the Consent Agreement) to handle the funds contributed by individual participating organizations. The NPO will operate like a company with voting members who elect a board of directors. The board of directors will meet regularly, receive reports on the progress of the study, approve the budget, and review audits of expenditures.



Scientists, Technicians, Lab Staff
Collects data and transmits to Science Advisor and staff for processing and transmitting/reporting to EPA

U.S. Environmental Protection Agency
Monitors progress, interprets data, and develops emissions estimating methodology and guidance for producer compliance once monitoring study is complete

The NPO will be responsible for:

- Selecting the Science Advisor and Independent Monitoring Contractor (IMC);
- Holding and disbursing to the Independent Monitoring Contractor the funds necessary to complete the study according to its approved schedule, protocol and budget; and
- Communicating progress of the study to livestock and poultry producers, the media and other interested parties.

Selection of the IMC and Science Advisor

The NPO will choose an IMC and a Science Advisor based on qualifications, experience and familiarity with all components of the subject matter. The IMC and the Science Advisor must be well staffed with accountants and contract managers who are well versed in fiduciary management. EPA will review the NPO's selection. If EPA believes the qualification criteria have not been met, the NPO will have to select an alternate candidate.

Role of Science Advisor

To be technically qualified, the Science Advisor must have an extensive background in animal agriculture, including expertise in air emissions from animal feeding operations, data processing, and engineering processes. The Science Advisor will be responsible for drafting the comprehensive study design and QAPP and will submit these to EPA for approval. He/She will also coordinate with the IMC to oversee the work of the subcontracted Principal Investigators on the study. The Science Advisor will be employed by the IMC.

Roles of the Independent Monitoring Contractor (IMC)

Technical & Administrative Oversight

The IMC will be contractually responsible for the conduct of the study, and will:

- Be a separate organization from the industry that funds the study;
- Oversee the performance of the Science Advisor;
- Work closely with the Science Advisor in purchasing and assembling equipment and developing contracts for principal investigators; and
- Directly administer all subcontracts, supervise budgets and monitor expenditures, report progress and audit all financial statements.

Reporting on Study Progress

The IMC will:

- Report to EPA and the NPO on financial status of the study;
- Report to EPA and the NPO on the study progress; and
- Create a Web site specifically for the monitoring study and regularly post updates so that the public can follow the study's progress.

Role of the Principal Investigators

Principal investigators will carry out the monitoring at each site. They will report to the Science Advisor and, in turn, to the IMC.

Site Selection

The NPO will be comprised of representatives from the various animal husbandry industries who are knowledgeable of actual farming operations as related to the farm sites proposed for monitoring. They will compile a list of candidate farms from those operations participating in the Consent Agreement and submit the list to the Science

Advisor. The Science Advisor will then facilitate a process to select farms for monitoring based on a set of pertinent factors (*e.g.,* differing regional and climatic conditions, number of animals, different manure handling practices, and types of ventilation (natural vs. forced air)). In addition, logistical issues will be considered to reduce problems associated with egress and convenience; such as, is there a principal investigator located within 3 hours of the site, are there housing accommodations available within 1 hour of the site, is there internet access at the farm, and is 220 V power available? After comprehensive site plans are approved by EPA, the Science Advisor will supervise the set up of equipment at those farms selected, advise the cooperating farmers of their responsibilities, verify utilities, arrange for high speed computer data transmission service, initiate the study and implement the quality assurance project plan. As the study progresses, some investigators may want to alter their approved plans due to interim findings (such as, collecting redundant data or discovering a need to change equipment location). Any changes must be sent to the Science Advisor, with EPA notification and concurrence, for approval or disapproval.

Monitoring Plans by Species

On the following pages, the swine, egg layer, meat bird (broiler and turkey) and dairy air emissions study components are summarized. These were developed over several months by a peer review team of scientists, industry and other stakeholders. While the study scope varies from species to species in line with their data needs, available funding, and industry characteristics, the technologies and measurement methodologies selected by the team are consistent across species.

1. Air Emission Monitoring Plan for Swine

Introduction: Swine production phases include sows (breeding, gestation, and farrowing), nursery pigs, and finishing pigs. The buildings are either naturally ventilated or mechanically ventilated but many buildings have a combination of the two ventilation types. Manure treatment and/or storage generally consists of either basins (earthen, clay or synthetic lined earthen, concrete, glass lined steel) that store manure collected from the barn, or clay/synthetic lined earthen anaerobic treatment lagoons that treat and store manure. Manure collection systems with external manure storage/treatment are generally scrape, flush or pull-plug.

Overall, the U.S. hog inventory is located in three general regions. The five top Midwest swine states, IA, MN, IL, MO, and IN represent about 54 percent of the total inventory in the U.S. In the Southeast, NC, AR, VA, KY, and MS represent about 19 percent, and in the West, OK, NE, KS, SD, and TX represent about 15 percent.

Farm Selection for New Measurements: Swine production farm types are identified by region, production phase, ventilation type, and manure storage/treatment in Table 1. Farms selected will be characterized by criteria such as facility age, size, design and management, local topography and meteorology, swine diet and genetics. The farm should be reasonably isolated from other potential air pollution sources. Producers/farm managers must be willing to attend a training session, make changes as needed to accommodate the project, and maintain and share certain production records to facilitate data analysis and interpretation. Farms to be monitored will be further characterized using farm management data and samples collected for analysis of water, feed and manure. Farms will provide vital management information regarding ventilation controls/management and scheduling of barn activities such as manure management, animal load out, animal treatment, or feeding. At a minimum, water, feed and manure samples will be collected and analyzed for total nitrogen and total sulfur content.

TABLE 1.—FARM SITES IDENTIFIED AND PROPOSED FOR MONITORING

[G = gestation, F = farrowing, FI = finishing, MV = mechanically ventilated]

Production phase	Ventilation type	Number of units	Location of measurements	
			Barns or rooms	Storage/lagoon treatment
SOUTHEAST:				
Sow	MV	4	G & F.	
		Single or double		Lagoon.
Finisher	MV	4	FI.	
		Single or double		Lagoon.
MIDWEST:				
Sow	MV	4	G & F.	
		2		Deep pit.
Finisher	MV	4	FI.	
		1		Basin.
WEST:				
Sow	MV	4	G & F.	
		Single or double		Lagoon.

Methods: The mass balance technique will be used for measuring emissions from mechanically ventilated barns. Micrometeorological techniques will be used for manure storage/treatment systems located outside the barn. Table 2 summarizes the methods and emissions that will be measured from barns and manure storage/treatment systems. A maximum of five farms will be selected for barn measurements and six farms for manure storage/treatment system measurements. If possible, at least one farm will have measurements conducted at both the barns and the manure storage/treatment system.

TABLE 2.—SUMMARY OF EMISSIONS MEASUREMENTS AND METHODOLOGIES

Source units	Methodology	Targeted emissions	Number of farms	Number of units to monitor
Barn	Mass balance	NH_3, PM10, PM2.5 VOC, H_2S, TSP, CO_2.	[1] 5	20
Manure storage/treatment system	Micromet and Water 9	VOC, H_2S, NH_3	[1] 6	6

[1] See Table 1.

Barn Measurements: An on-farm instrumentation shelter (OFIS) will house the equipment for measuring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn airflows, operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 seconds. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the shelter will draw air sequentially from representative locations (including outdoor air) at the barns and deliver selected streams to a manifold from which on-line gas monitors draw their subsamples. Concentration of constituents of interest will be measured using the following methods:

- Ammonia will be measured using chemiluminescence or photoacoustic ingrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared or equivalent.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- PM2.5 will be measured gravimetrically with a federal reference method for PM2.5 at least for 1 month per site. It will be shared among sites.
- PM10 will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn and ambient air.
- An initial characterization study of barn volatile organic compounds (VOC) will be conducted on 1 day during the first month at the first site (site 1). While total nonmethane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOC will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography-mass spectrometry (GC–MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC–MS or GC–FID speciation. This should account for the VOC that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOC.
- By the middle of the second month, the Science Advisor will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an ''as carbon'' basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC–MS evaluations during applicable intervals of time.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers. Specific processes that directly or indirectly influence barn emissions will be measured including pig activity, manure management/handling, feeding, and lighting. Environmental parameters including heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction, and solar radiation will be continuously monitored. Feed and water consumption, manure production and removal, swine mortalities, and animal production will also be monitored. As noted above, samples of feed, water, and manure will be collected and analyzed for total nitrogen and total sulfur. These data will enable the development and validation of process-based emission models in the future.

Table 1 identifies those types of farms where barn measurements will be taken to provide the needed data to complete the objectives of the monitoring study. A total of five farms will be selected as measurement sites. Two farms in the Southeast representing the sow and finishing phases of production with lagoon manure treatment will be selected. Two farms in the Midwest representing a finishing farm using an in-ground manure storage basin and a sow farm with a deep pit gestation barn will be selected. Finally, one farm in the West representing a sow farm with lagoon treatment will be selected. On each of the farms, four barns will have measurements taken simultaneously. Where applicable, the sow farms will have two farrowing rooms and two gestation barn emissions measured and on finishing farms, up to four barns will have emission measurements.

Lagoons: Micrometeorological techniques will be used to estimate emissions of NH_3, H_2S, and a limited number of VOC from lagoons. Fundamentally, this approach will use optical remote sensing (ORS) downwind and upwind of the lagoon coupled with 3-dimensional (3D) wind velocity measurements at heights of 2 and 12 meters (m). The concentrations of NH_3 and the various hydrocarbons will be made using open path Fourier transform infrared spectroscopy (FTIR). Measurements of H_2S (and NH_3) will be made using collocated open path UV differential optical absorption spectroscopy (UV–DOAS) systems. A team of two persons with two scanning FTIR systems, two single-path UV–DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.

Each of two ORS systems will be oriented parallel to the storage side and approximately 10m from the lagoon edge. Each monostatic FTIR system will scan five retroreflectors; three mounted at 1m height equally dividing the length of the open path along the lagoon side and two mounted on a tower at heights of 6 and 12m located at the corners down the adjacent sides of the lagoon, resulting in scan lines down each of the four sides of the lagoon. Two bistatic single-path UV–DOAS systems will be located at a nominal 2m height within 2m laterally of the FTIR scan lines on the two sides of the lagoon oriented most closely with prevailing winds.

Emissions will be determined from the difference in upwind and downwind concentration measurements using two different methods—a Eulerian Gaussian approach and a Lagrangian Stochastic approach. The Lagrangian approach is based on an inverse dispersion analysis using a backward Lagrangian stochastic method (bLS). This approach will be used to estimate NH_3 emissions from concentration measurements made using the FTIR and UV–DOAS systems and the H_2S emissions from concentration measurements made using the UV–DOAS systems. The emission rate for NH_3 will be the ensemble average of the estimated emissions for each of the five FTIR scans with a corresponding error of the emission estimate. The Eulerian approach is based on a computed tomography (CT) method using Eulerian Gaussian statistics and a fitted wind profile from the two 3D sonics. Measurements of air and lagoon temperatures, wind speed and direction, humidity, atmospheric pressure, and solar radiation will also be conducted.

The bLS and CT emission estimates will be quality assured using tests of instrument response, wind direction and wind speed, stability, turbulence intensity, differences between the lagoon and the surrounding surface temperatures, differences in the mean and turbulent wind components with height, and the temporal variability in emissions. Emission estimates using the CT method will be qualified by the measured fraction of the estimated plume. To estimate VOC emissions from lagoons, samples of the lagoon liquid will be collected and analyzed for VOC, and the EPA model WATER9 will be used to estimate emissions based on measured VOC concentrations, pH, and other factors.

Quality Assurance/Quality Control (QA/QC): QA/QC processes will be established before data collection commences. The QA/QC procedures will be based on EPA guidelines and will include the use of properly maintained and reliable instrumentation, ready supply of spare parts, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, field blanks, electrical backups, audits, and documentation. Calibration and maintenance logs will be maintained for each instrument.

2. Air Emission Monitoring Plan for Laying Hens

Introduction: Most U.S. layer housing types and manure management schemes fall under one of four categories: (1) High-rise houses with manure stored in the lower level and removed every 1 to 2 years, (2) belt houses with quasi-continuous manure transfer to an external storage/treatment facility, (3) shallow-pit houses with regular manure removal by scraping and temporary storage in uncovered piles, and (4) liquid-manure houses with manure flushed daily into a lagoon. The locations for four sites with specific housing types were recommended for the monitoring study with consideration of these four housing categories along with the potential impact of climatic differences and the geographical density of egg production (Table 3). Final site selections will also depend on site-specific factors including representativeness of facility age, size, design and management, and flock diet and genetics. The facility should be reasonably isolated from other air pollution sources and have potential for testing mitigation strategies. Producers/farm managers must be willing to attend a training session, make changes as needed to accommodate the project, and maintain and share certain production records to facilitate data analysis and interpretation.

TABLE 3.—RECOMMENDED TYPES AND LOCATIONS OF LAYING HEN HOUSES TO BE MONITORED IN THE MONITORING STUDY

Region/location	House 1—type	House 2—type
Midwest	High-rise with inside manure storage (2)	Manure belt (2) with manure storage.
West	Shallow pit with open manure storage	Manure belt with open manure storage.
South	High-rise with inside manure storage	High-rise with inside manure storage.
East	High-rise with inside manure storage	Flushing with anaerobic treatment lagoon

Methods: An on-farm instrument shelter (OFIS) will house the equipment for monitoring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn and manure shed airflows, and operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 seconds. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the OFIS will draw air sequentially from representative locations (including outdoor air) at the hen houses and manure sheds and deliver selected streams to a manifold from which gas analyzers draw their samples.

Selected pollutants will be evaluated as follows:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared or equivalent.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- PM2.5 will be measured gravimetrically with a federal reference method for PM2.5 at least for 1 month per site. It will be shared among sites.
- PM10 will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn, ambient air, and at manure storage exhaust (if manure is disturbed).
- An initial characterization study of barn VOC will be conducted on 1 day during the first month at the first site (site 1). While total nonmethane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOC will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography—mass spectrometry (GC–MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC–MS or GC–FID speciation. This should account for the VOC that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of unaccounted for VOC mass.
- By the middle of the second month, the Science Advisor will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an ''as carbon'' basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC–MS evaluations during applicable intervals of time.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers. Specific processes that directly or indirectly influence air emissions will be measured including hen activity, feeding, and lighting. Measured environmental parameters include cooling system status, manure temperatures, inside and outside air temperatures and humidities, wind speed and direction, and solar radiation. Feed and water consumption, egg production, manure production and removal, and bird mortalities will also be monitored with producer assistance. Samples of feed, eggs, water, and manure will be collected and analyzed for total nitrogen and total sulfur. These data will enable the development and validation of process-based emission models in the future.

Quality assurance/quality control (QA/QC): QA/QC processes will be established before data collection commences. The QA/QC procedures will be based on EPA guidelines and will include the use of properly maintained and reliable instrumentation, ready supply of spare parts, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, field blanks, electrical backups, audits, and documentation. Instrument calibration and maintenance logs will be maintained.

3. Air Emission Monitoring Plan for Meat Birds (Broiler Chickens and Turkeys)

Introduction: Meat birds include broilers and turkeys and are raised in confinement barns on dirt or concrete floors covered with litter. Broiler barns are typically mechanically ventilated and turkey barns are typically naturally ventilated. The locations for three sites with specific housing types were recommended for the monitoring study with consideration of the potential impact of climatic differences and the geographical density of poultry meat production (Table 4). The final site selections will depend on site-specific emission generating factors including representativeness of facility age, size, design and management; and flock diet and genetics. The facility should be reasonably isolated from other air pollution sources and have potential for testing mitigation strategies. Producers/farm managers must be willing to attend a training session, make changes as needed to accommodate the project, and maintain and share certain production records to facilitate data analysis and interpretation.

TABLE 4.—RECOMMENDED TYPES AND LOCATIONS OF MEAT BIRD HOUSES TO BE MONITORED

Region	Type	Ventilation type	Manure handling
Midwest	Turkey	Mechanical	Litter on floor.
West Coast	Broiler	Mechanical	Litter on floor.
Southeast	Broiler	Mechanical	Litter on floor.

Methods: An on-farm instrument shelter (OFIS) will house the equipment for monitoring pollutant concentrations at representative air inlets and outlets (primarily by air extraction for gases), barn airflows, and operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 seconds. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA for subsequent calculations of emission factors. A multipoint air sampling system in the OFIS will draw air sequentially from representative locations (including outdoor air) at the barns and deliver selected streams to a manifold from which gas analyzers draw their subsamples. The pollutants targeted for measurement will be evaluated as follows:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared or equivalent.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- PM2.5 will be measured gravimetrically with a federal reference method for PM2.5 at least for 1 month per site. It will be shared among sites.
- PM10 will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn, and ambient air.
- An initial characterization study of barn VOC will be conducted on 1 day during the first month at the first site (site 1). While total nonmethane hydrocarbons (NMHC) are continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOC will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography—mass spectrometry (GC–MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.
- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC–MS or GC–FID speciation. This should account for the VOC that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of the Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOC.
- By the middle of the second month, the Science Advisor will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an ''as carbon'' basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC–MS evaluations during applicable intervals of time.

Mechanically ventilated barn airflows will be estimated by continuously measuring fan operational status and building static pressure to calculate fan airflow from field-tested fan performance curves and by directly measuring selected fan airflows using anemometers. Specific processes that directly or indirectly influence barn emissions will be measured including bird activity, manure handling, feeding, and lighting. Measured environmental parameters include heating and cooling operation, floor and manure temperatures, inside and outside air temperatures and humidity, wind speed and direction, and solar radiation. Feed and water consumption, manure production and removal, bird mortalities and bird production will also be monitored with producer assistance. Samples of feed, water, and manure will be collected and analyzed for total nitrogen and total sulfur. These data will enable the development and validation of process-based emission models in the future.

Quality Assurance/Quality Control (QA/QC): QA/QC processes will be established before data collection commences. The QA/QC procedures will be based on EPA guidelines and will include the use of properly maintained and reliable instrumentation, ready supply of spare parts, approved analytical methodologies and standard operating procedures, external validation of data, well-trained analysts, field blanks, electrical backups, audits, and documentation. Instrument calibration and maintenance logs will be maintained.

Open Manure Piles: Micrometeorological techniques will be used to estimate emissions of NH_3, H_2S, and a limited number of VOC from open manure piles. Fundamentally, this approach will use optical remote sensing (ORS) downwind and upwind of the source coupled with 3-dimensional (3D) wind velocity measurements at heights of 2 and 12m. The concentrations of NH_3 and the various hydrocarbons will be made using open path Fourier transform infrared spectroscopy (FTIR). Measurements of H_2S (and NH_3) will be made using collocated open path UV differential optical absorption spectroscopy (UV–DOAS) systems. A team of two persons with two scanning FTIR systems, two single-path UV–DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.

Each of two ORS systems will be oriented parallel to the storage side and approximately 10m from the storage edge. Each monostatic FTIR system will scan five retroreflectors; three mounted at 1m height equally dividing the length of the open path along the storage side and two mounted on a tower at heights of 6 and 12m located at the corners down the adjacent sides of the source, resulting in scan lines down each of the four sides of the storage. Two bistatic single-path UV–DOAS systems will be located at a nominal 2m height within 2m laterally of the FTIR scan lines on the two sides of the manure storage area oriented most closely with prevailing winds.

Emissions will be determined from the difference in upwind and downwind concentration measurements using two different methods—an Eulerian Gaussian approach and a Lagrangian Stochastic approach. The Lagrangian approach is based on an inverse dispersion analysis using a backward Lagrangian stochastic method (bLS). This approach will be used to estimate NH_3 emissions from concentration measurements made using the FTIR and UV–DOAS systems and the H_2S emissions from concentration measurements made using the UV–DOAS systems. The emission rate for NH_3 will be the ensemble average of the estimated emissions for each of the five FTIR scans with a corresponding error of the emissions estimate. The Eulerian approach is based on a computed tomography (CT) method using Eulerian Gaussian statistics and a fitted wind profile from the two-3D sonics. Measurements of air and storage temperatures, wind speed and direction, humidity, atmospheric pressure, and solar radiation will also be conducted.

The bLS and CT emission estimates will be quality assured using tests of instrument response, wind direction and wind speed, stability, turbulence intensity, differences between the storage and the surrounding surface temperatures, differences in the mean and turbulent wind components with height, and the temporal variability in emissions. Emission estimates using the CT method will be qualified by the measured fraction of the estimated plume.

4. Air Emissions Monitoring Plan for Dairy

Introduction: Dairy operations are naturally ventilated buildings with different manure handling systems. Measurement of the emissions from these operations is to be conducted with a series of measurement systems that provide a concentration measurement along a path that would be representative of the emission plume from the building. In order to estimate the emissions rate, it is necessary to couple the concentration with a measurement of the wind flow through the building or facility.

Manure storage sites could be either liquid (lagoons or slurry store) or piles of solid materials. These sites represent a different source area for emissions than buildings and will have to be considered separately in the measurement scheme.

The protocols that are developed for these studies are based on the following assumptions.

- The buildings are naturally ventilated and require a measurement method that captures the entire plume leaving the building. Mechanically ventilated facilities are beginning to enter the industry.
- Manure storage is separate from the building and will have to be measured as a distinct entity as part of the farm emission factor.
- The primary emissions sources are the housing and feeding areas and manure storage.
- There is a large diversity among dairy operations across the U.S., and although there are similar characteristics in general structure, the difference in building design, management, and climate require measurements of facilities that represent these factors.
- Measurements will be conducted at facilities which represent a diversity of systems in three general areas: California and Southern U.S., Northeast U.S., and Upper Midwest.

Milk production facilities include cattle (dry cows, lactating cows, and replacement heifers) and calves. The partially open barns range from those with windows and flaps to fully open free stalls. The buildings are most typically naturally ventilated except for some mechanically ventilated free stall and tie stall houses. The naturally ventilated barns range from partially open barns with windows and flaps to fully open free stalls. External manure storages generally consist of either earthen basins that store undiluted manure collected from the barn, or anaerobic treatment lagoons that treat manure that is diluted by a factor of about 5:1. Manure collection systems generally are either scrape or flush. Four dairy sites that consider climate and types of ventilation, manure collection, and manure storage have been identified by the dairy industry for collecting the comprehensive air emission data required by the monitoring study (Table 5). Final site selections will also depend on site-specific factors including representativeness of facility age, size, design and management; and cow diet and genetics. The facility should be isolated from other potential air pollution sources and have potential for testing mitigation strategies. Producers should be willing to make changes and keep extra records to facilitate a quality study.

TABLE 5.—RECOMMENDED TYPES AND LOCATIONS OF DAIRY FACILITIES TO BE MONITORED IN THIS STUDY

Region	Site type	Ventilation **	Manure collection	Manure storage
Midwest	Free stall	Natural	Flush or scrape	Lagoon.
Northeast	Free stall	Natural	Scrape	Basin.
West	Open* free stall	Natural	Flush	Lagoon.
South	Open free stall	Natural	Scrape	Basin.

* Cattle are free to walk outside in open free stall barns.
** If warranted by current or future use, mechanically ventilated barns may be monitored.

Methods

Naturally Ventilated Buildings: To achieve the most representative measurements of the emissions of the gases, it is recommended that a FTIR system be used to quantify the concentration of NH_3, CO_2, and, at levels above 50 parts per billion (ppb), H_2S in various paths through the atmosphere. A variation of the horizontal gradient method utilizing multiple paths through the airflow from the building, called radial plume mapping, measures the concentrations. The FTIR method is selected because of the extreme turbulence adjacent to the building and the lack of a defined plume in this area of the facility. A scanning system rotates among the paths to provide a serial measurement of the paths utilizing horizontally and vertically located retro-reflectors. A computer calculates the concentration gradients in real time. FTIR measurements are coupled to two sonic anemometers positioned at two locations along the length of the building to provide the wind flow measurements needed to estimate the flux from the measured concentrations.

Particulate load would be sampled using a series of particle samplers located with a sampling height of 5m adjacent to one of the sonic anemometer towers. These units would be designed to collect 2.5µm, 10µm and TSP values.

VOC would be sampled at the same position as the particulate samples for the building emissions. VOC emissions from the manure storage would be sampled with a system located both upwind and downwind of the manure storage system. These units would be positioned at heights of 2 and 12m.

Mechanically Ventilated Buildings: Mechanically ventilated buildings have begun to be used in the dairy industry. If warranted by current or future use, a mechanically ventilated facility will be included in this project. An on-site instrument shelter (OSIS) will house the equipment for monitoring pollutant concentrations at representative air inlets and outlets (primarily by air extraction), barn airflows, and operational processes and environmental variables. Sampling will be conducted for 24 months with data logged every 60 seconds. Data will be retrieved with network-connected PCs, formatted, validated, and delivered to EPA as hourly averages for subsequent calculations of emission factors. A multipoint air sampling system in the OSIS will draw air sequentially from representative locations (including ambient) at the barns and deliver selected streams to a manifold from which on-line gas monitors draw their subsamples. The pollutants targeted for measurement will be evaluated as follows:

- Ammonia will be measured using chemiluminescence or photoacoustic infrared.
- Hydrogen sulfide will be measured with pulsed fluorescence.
- Carbon dioxide will be measured using photoacoustic infrared or equivalent.
- TSP will be measured using an isokinetic multipoint gravimetric method.
- PM2.5 will be measured gravimetrically with a federal reference method for PM2.5 at least for 1 month per site. It will be shared among sites.
- PM10 concentrations will be measured in real time using the tapered element oscillating microbalance (TEOM) at representative exhaust locations in the barn and ambient air.
- An initial characterization study of barn VOC will be conducted on 1 day during the first month at the first site (site 1). While total nonmethane hydrocarbons (NMHC) are

continuously monitored using a dual-channel FID analyzer (Method 25A) along with building airflow rate, VOC will be sampled with replication at two barns using Silcosteel canisters, and all-glass impingers (EPA Method 26A). Each sample will be evaluated using concurrent gas chromatography—mass spectrometry (GC–MS) and GC/FID for TO 15 and other FID-responding compounds. VOC mass will be calculated as the sum of individual analytes. The 20 analytes making the greatest contribution to total mass will be identified during the initial characterization study. A sampling method that captures a significant fraction of the VOC mass will be chosen for the remainder of the study.

- The Method 26A sampling train is suitable for collecting samples for analysis of formaldehyde and acetaldehyde using NCASI 94.02, requiring only the addition of spectrophotometry for the detection of formaldehyde. These compounds will be measured during the initial characterization study and, if not found, will not be analyzed during subsequent measurements.
- Total VOC mass may be estimated (scaled) by multiplying the total carbon as determined by Method 25A by the molecular weight/carbon weight ratio derived from GC–MS or GC–FID speciation. This should account for the VOC that are not identified by GC methods due either to sampling bias or the analytical procedures used, although some error is anticipated due to the imprecise response of Method 25A FID to oxygenated compounds. Acceptance of a scaling factor will depend on whether the Method 25A analyzer response is reasonable based on the manufacturer's stated response factors, bench-scale verification, or judgmental estimation of the mass of unaccounted for VOC.
- By the middle of the second month, the Science Advisor will report results of the initial VOC characterization to EPA with recommendations on the appropriateness and validity of the selected methodologies.
- Quarterly VOC samples using the selected VOC sampling method will occur at all sites, along with continuous Method 25A monitoring at site 1 throughout the study.
- Method 25A measurements will be corrected from an ''as carbon'' basis to a total VOC mass basis by multiplying them by the mean molecular weight per carbon atom established by GC–MS evaluations during applicable intervals of time.

Manure Storage Systems: Micrometeorological techniques will be used to estimate emissions of NH_3, H_2S, and a limited number of VOC from manure storage systems and storages. Fundamentally, this approach will use optical remote sensing (ORS) downwind and upwind of the storage coupled with 3-dimensional (3D) wind velocity measurements at heights of 2 and 12m. The concentrations of NH_3 and the various hydrocarbons will be made using open path Fourier transform infrared spectroscopy (FTIR). Measurements of H_2S (and NH_3) will be made using collocated open path UV differential optical absorption spectroscopy (UV–DOAS) systems. A team of two persons with two scanning FTIR systems, two single-path UV–DOAS systems, and two 3D sonics with supplementary meteorological instruments will move sequentially from farm to farm.

Each of two ORS systems will be oriented parallel to the storage side and approximately 10m from the storage edge. Each monostatic FTIR system will scan five retroreflectors; three mounted at 1m height equally dividing the length of the open path along the storage side and two mounted on a tower at heights of 6 and 12m located at the corners down the adjacent sides of the storage, resulting in scan lines down each of the four sides of the storage. Two bistatic single-path UV–DOAS systems will be located at a nominal 2m height within 2m laterally of the FTIR scan lines on the two sides of the storage oriented most closely with prevailing winds.

Emissions will be determined from the difference in upwind and downwind concentration measurements using two different methods—an Eulerian Gaussian approach and a Lagrangian Stochastic approach. The Lagrangian approach is based on an inverse dispersion analysis using a backward Lagrangian stochastic method (bLS). This approach will be used to estimate NH_3 emissions from concentration measurements made using the FTIR and UV–DOAS systems and the H_2S emissions from concentration measurements made using the UV–DOAS systems. The emission rate for NH_3 will be the ensemble average of the estimated emissions for each of the five FTIR scans with a corresponding error of the emission estimate. The Eulerian approach is based on a computed tomography (CT) method using Eulerian Gaussian statistics and a fitted wind profile from the two 3D sonics. Measurements of air and storage temperatures, wind speed and direction, humidity, atmospheric pressure, and solar radiation will also be conducted.

The bLS and CT emission estimates will be quality assured using tests of instrument response, wind direction and wind speed, stability, turbulence intensity, differences between the storage and the surrounding surface temperatures, differences in the mean and turbulent wind components with height, and the temporal variability in emissions. Emission estimates using the CT method will be qualified by the measured fraction of the estimated plume.

To estimate VOC emissions from lagoons, samples of the lagoon liquid will be collected and analyzed for VOC, and the EPA model WATER9 will be used to estimate emissions based on measured VOC concentrations, pH, and other factors.

Alternate Techniques

1. For the circuit rider system, an instrumental system such as the DustTrak by TSI could be used for continuous particle data for PM2.5 and PM10. These systems provide optical light scattering measurements of the concentration in mg/m3 and cost about $5,000 per point including an environmental shelter.

2. A radial plume mapping approach could be applied to the manure storage systems using a TDL system that has been approved by EPA for use in the aluminum industry in a single path mode. One upwind and three downwind paths provide the same type of data as the FTIR except for a single compound. The single laser is scanned via fiberoptic cables to the individual paths with a complete scan taking 40 seconds. It provides a fast, direct measurement of the flux of ammonia from these manure systems. A single 4-channel system costs $68,000.

3. It is recommended that one short-term (2-week) measurement of each facility be made with a LIDAR system to measure and quantify the plume dynamics of particles, water vapor, and ammonia surrounding the facility. This is recommended because the short-term measurements will be made at different times throughout the year and will be placed at a series of heights based on experience. These associated data of the plume structure will provide evidence of representativeness of the micrometeorological measurements for the emission rates.

4. It is recommended that each building site be instrumented with temperature and associated sensors to provide a continuous measurement record of the microclimate within and adjacent to the building. These systems can be linked with sensors to measure and record animal activity and floor temperature. A similar system would be located to measure the microclimate of the manure storage system and would include air temperature, wind speed, wind direction, surface temperature, and relative humidity of the manure storage system. The continuous record from these manure storage units and buildings would provide a reference for the short-term measurements made with the FTIR systems.

5. A Dynamic Flux Chamber Technique could be used for performing emission measurements from lagoons and/or a manure pile. Ammonia flux is measured over a surface (lagoon and/or soil) using a dynamic flux chamber system interfaced to an environmentally controlled mobile laboratory. This flux chamber system is interfaced to an environmentally controlled mobile laboratory in which two ammonia chemiluminescence analyzers, gas dilution/titration calibration system, and data logger with lap-top computer are located. The flux calculation of ammonia using the flow-through chamber system is given by the mass balance for ammonia in the chamber.

Typical Factors Used in Determining Farm Selection

Farm Characteristics

1. Did the producer sign up to the Consent Agreement and pay EPA?
2. Does the producer's farm fit the description of any of the farms listed?
3. Is there a principal investigator within 3 hours of the site?
4. Are there housing accommodations available within 1 hour of the site?
5. Does your site have mechanical or natural ventilation for barns? Do the fans blow out directly over the lagoon/ manure storage area?
6. Is the producer/farm manager cooperative to attend a training session and provide needed production information?
7. Is there internet access at the farm? Is 220 V power available?
8. What is the general topography on the farm? Describe the surrounding terrain

(rolling hills, flat, low lying, river bottom, etc.) specifically for areas near the barns and the manure storage/treatment system.

9. Is the farm free from large disturbances such as trees and other buildings?

10. What is the distance from a public road? Is it gravel?

11. Are there other potential air pollutant sources nearby? Explain type (other farms, industrial site, grain elevator/feedmill), distance and direction.

12. Are there other animal species housed on the site, or planned for housing on site?

13. How many barns are located on the site? How many animals in each barn? Please characterize the barns: Barn number/identifier, production phase, rate your barn cleanliness (1–5; 1 being the cleanest), age of barns, and air exchange rate.

14. How far are the land application fields from the lagoons and barns?

15. How often is manure removed from the manure treatment/storage system and land applied?

16. How often is manure removed from the buildings and sent to the outdoor treatment/storage system?

17. Describe (in general terms) the rations fed to the animals.

18. Are the animals hand-fed or is feed delivered through an automatic delivery system?

19. Is fat (vegetable or animal) added to the rations?

20. Are feed rations pelleted or ground?

INFLUENCES ON EMISSIONS

Influences	Producer provided	Collected by study
Climate	....	X
Air temperature	....	X
Manure temperature	....	X
Barn temperature	....	X
Wind speed	....	X
Solar radiation	....	X
Rainfall	....	X
Relative humidity	....	X
Wind direction	....	X
Feed conversion/efficiency	....	X
Feed analysis (N & P & S)	X	X
Phases	....	X
Feeding to recommendations	X	....
Manure production volume	X	X
Management cycle	X	....
Storage duration	X	....
Stocking density (actual)	....	X
Lagoon design	X	X
Swine genetics	X	....
Animal inventory	X	....
Feed usage	X	....
Water usage	X	....
Closeouts	X	....
Feed analysis	X	X
Water analysis	....	X
Manure analysis	X	X
Animal/barn activity	X	X

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BILLING CODE 6560–50–P

APPENDIX F

SUPPLEMENTAL FIGURES

DEVELOPMENT OF EMISSIONS-ESTIMATING METHODOLOGIES FOR BROILER CONFINEMENT OPERATIONS

APPENDIX F – SUPPLEMENTAL FIGURES

Section **Page**

LIST OF FIGURES

Figure **Page**

1.0 Supplemental Plots to Support EEM Development Decisions

Scatter plots were used to subset data to evaluate trends present in subsections of the data. The data in the plots were binned based on most predictive parameter. For all pollutants, bins were based on average mass (*avem*). Six bins were created that cover 0.5 kg each (e.g., mass bin 1 covers 0 to 0.5 kg, mass bin 2 covers 0.5 to 1.0 kg).

1.1 H_2S Functional Form Plots

Figure 1-1, Figure 1-2, and Figure 1-3 support the use of a cubic function of average bird mass in EEM development. Plots of all emissions values masked the emissions decrease because of large variances in emissions between the houses at that same time. Figure 1-1 contains scatter plots of H_2S emission versus the average bird mass for each of the 14 flocks that occurred over the study at CA1B House 10. Figure 1-2 contains the same plots for CA1B House 12. Figure 1-3 contains the plots for the six flocks that occurred at the KY1B-2 House 3 at the top half of the figure and KY1B-1 House 5 on the bottom half of the figure.

The remaining plots on the section plot the H_2S emission versus each of the predictor variables by average mass bin to assist in determining their functional forms.

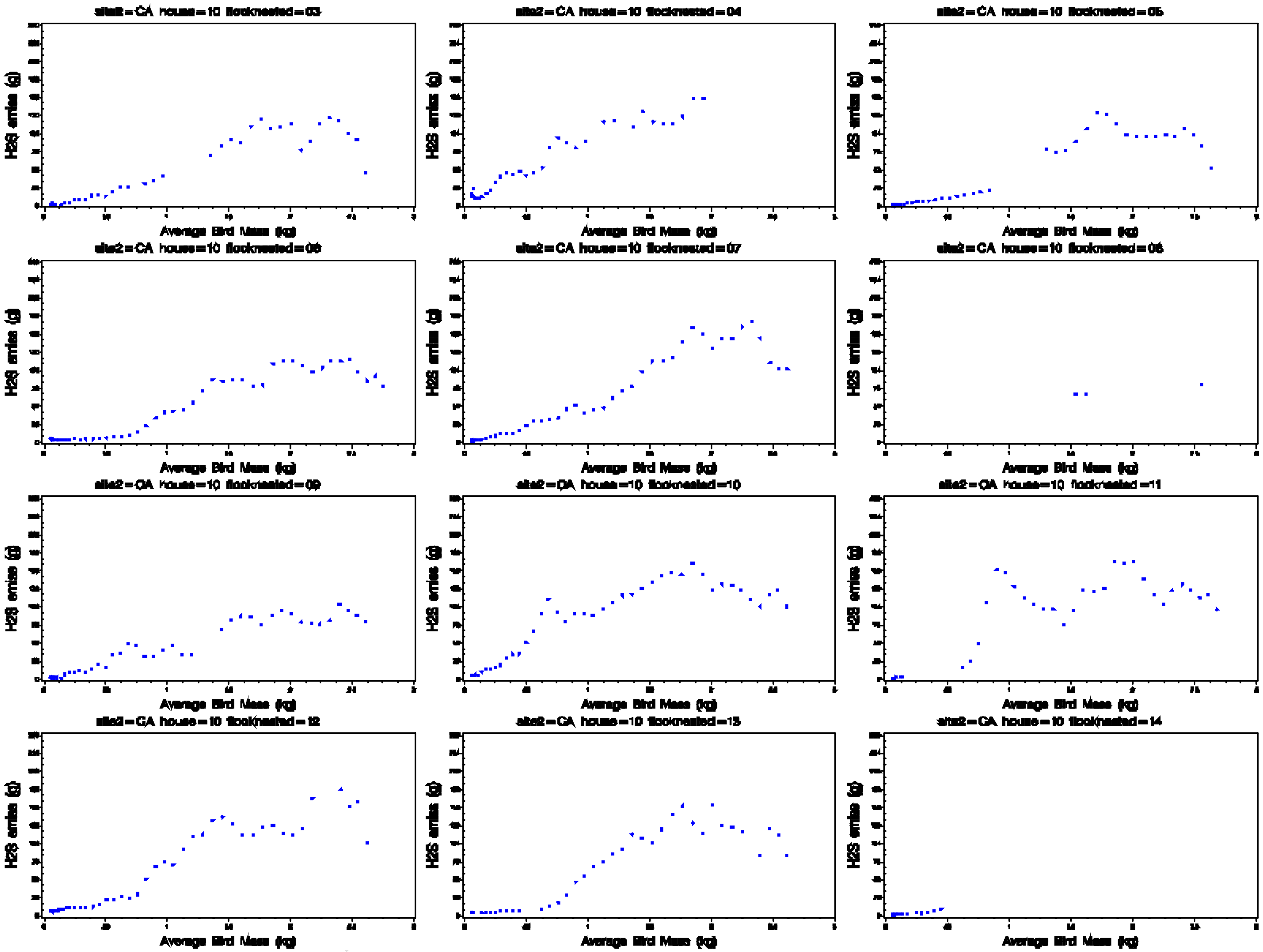

Figure 1-1. H_2S Emissions Vs. Average Bird Mass, for Each Flock at CA1B H10

**** Internal Draft – Do Not Quote or Cite ****

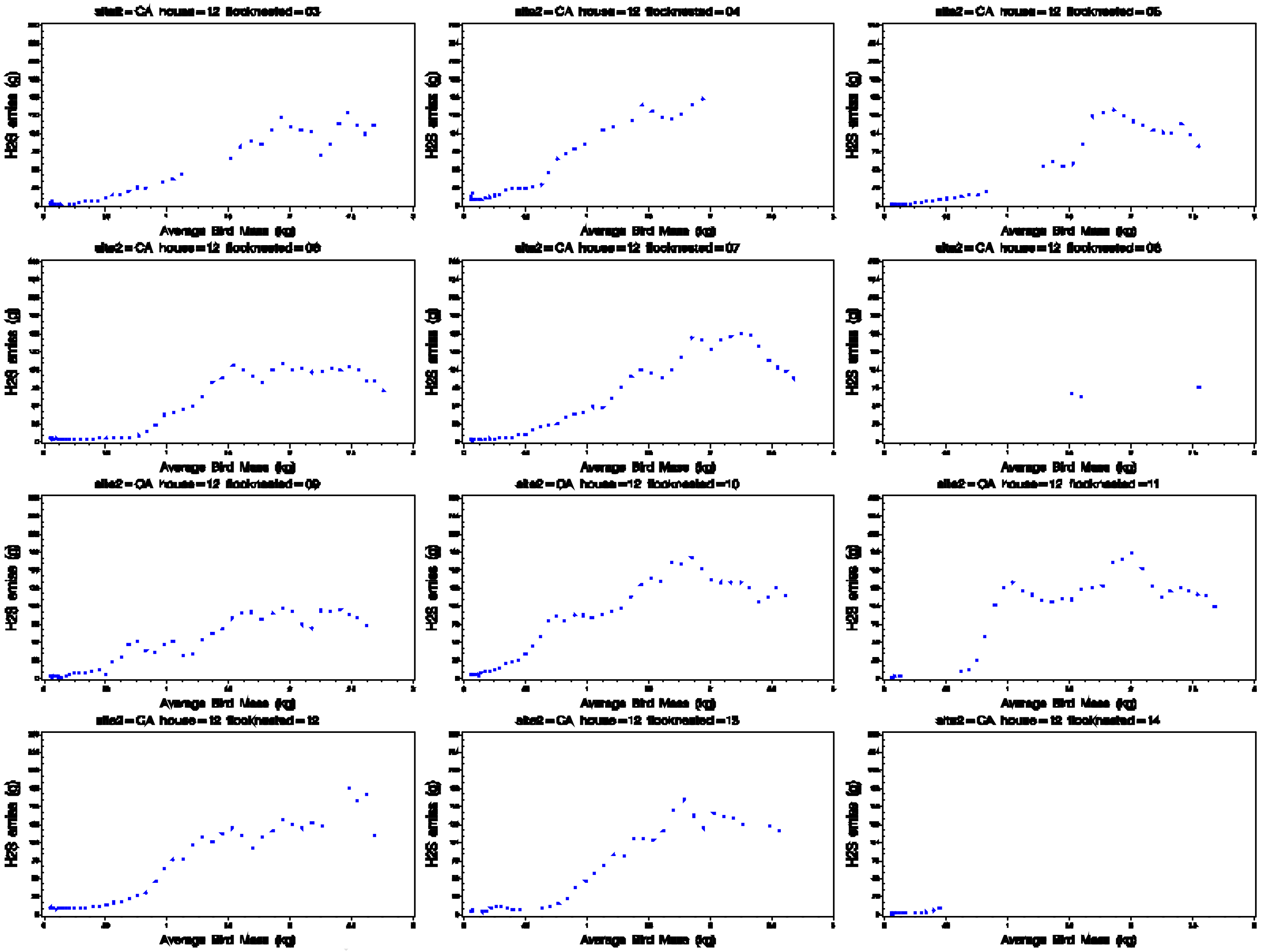

Figure 1-2. H_2S Emissions Vs. Average Bird Mass, for Each Flock at CA1B H12

**** Internal Draft – Do Not Quote or Cite ****

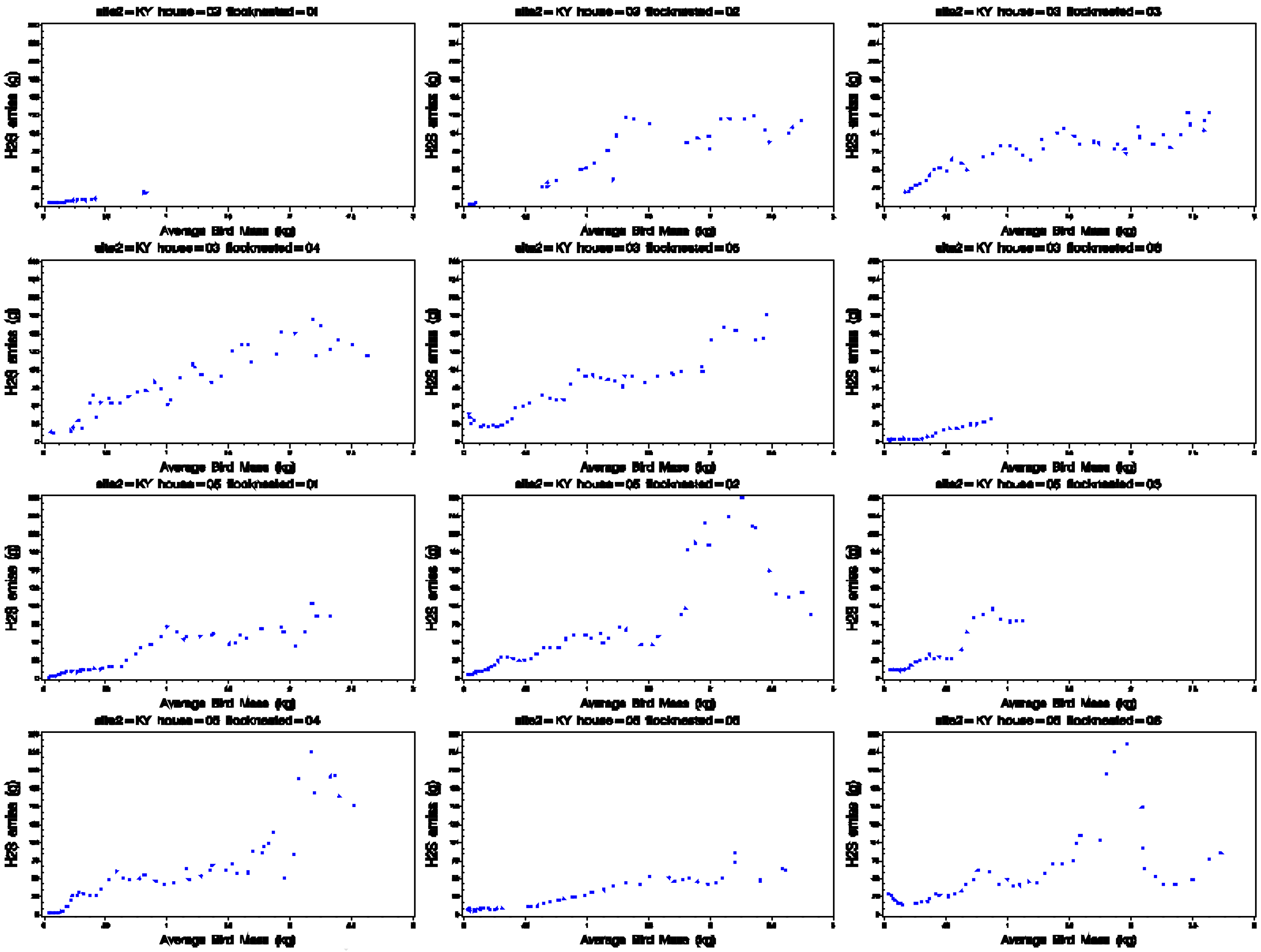

Figure 1-3. H_2S Emissions Vs. Average Bird Mass, for Each Flock at the Kentucky Sites

**** Internal Draft – Do Not Quote or Cite ****

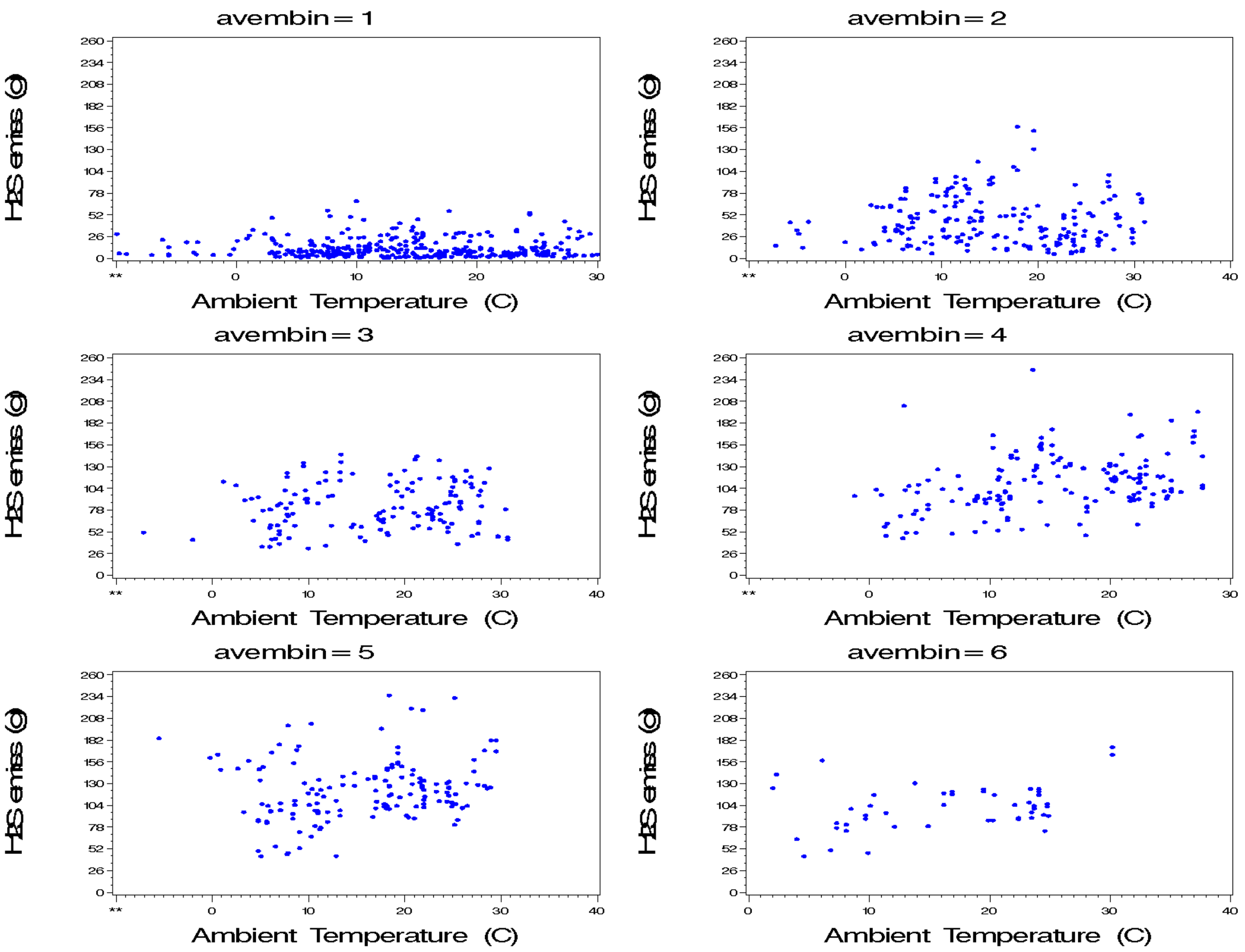

Figure 1-4. H$_2$S Emissions Vs. Ambient Temperature, for Each Average Mass Bin

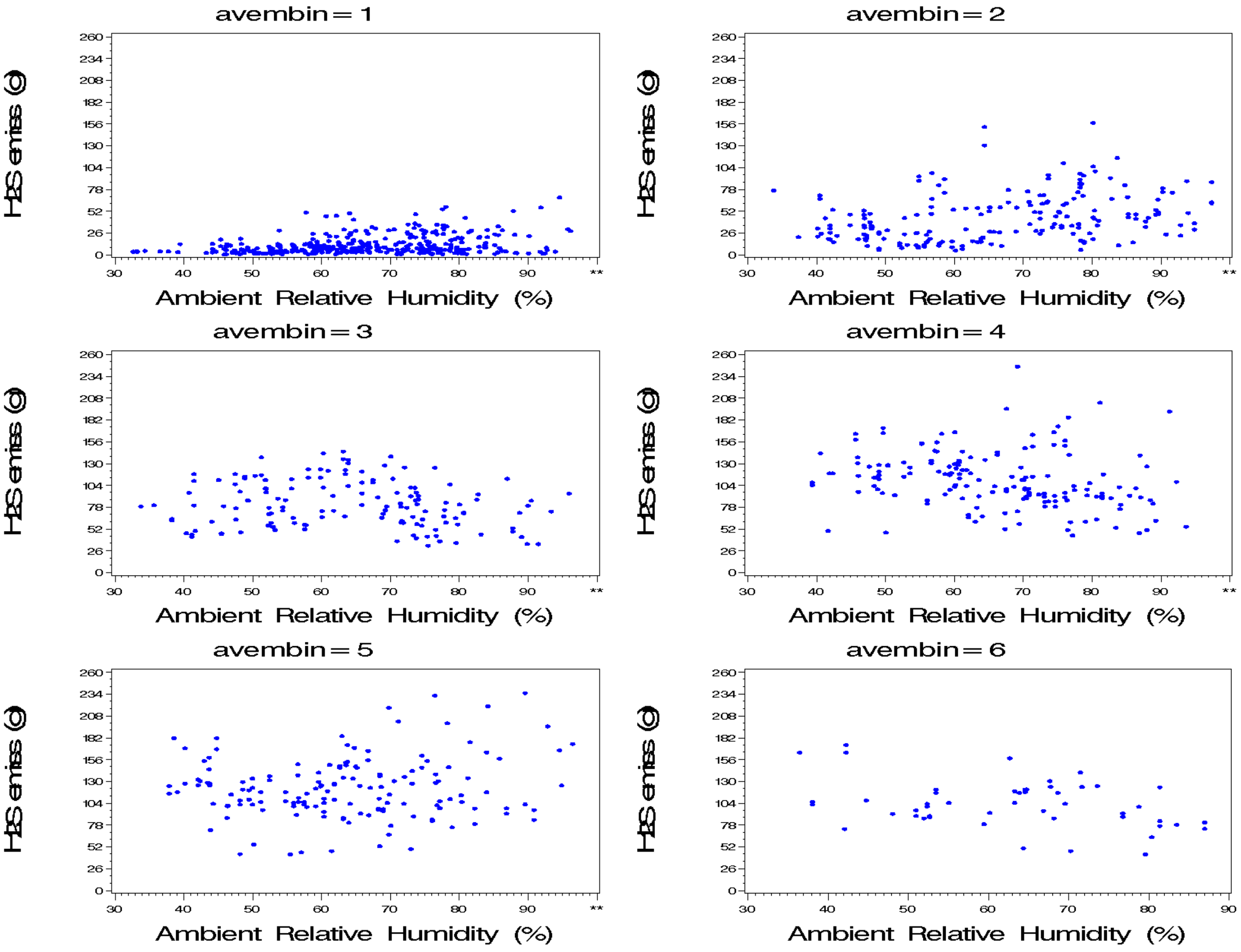

Figure 1-5. H_2S Emissions Vs. Ambient Relative Humidity, for Each Average Mass Bin

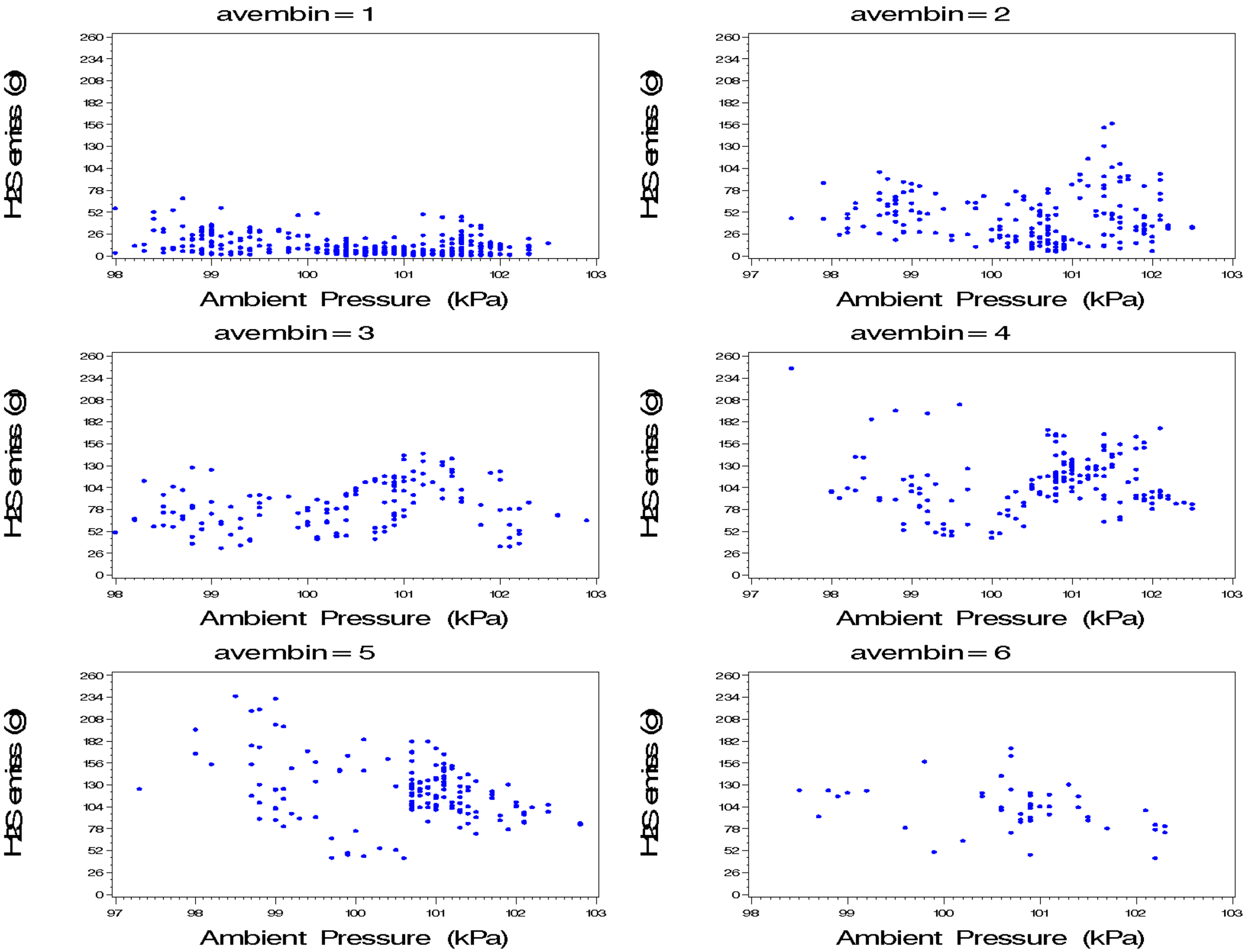

Figure 1-6. H_2S Emissions Vs. Ambient Pressure, for Each Average Mass Bin

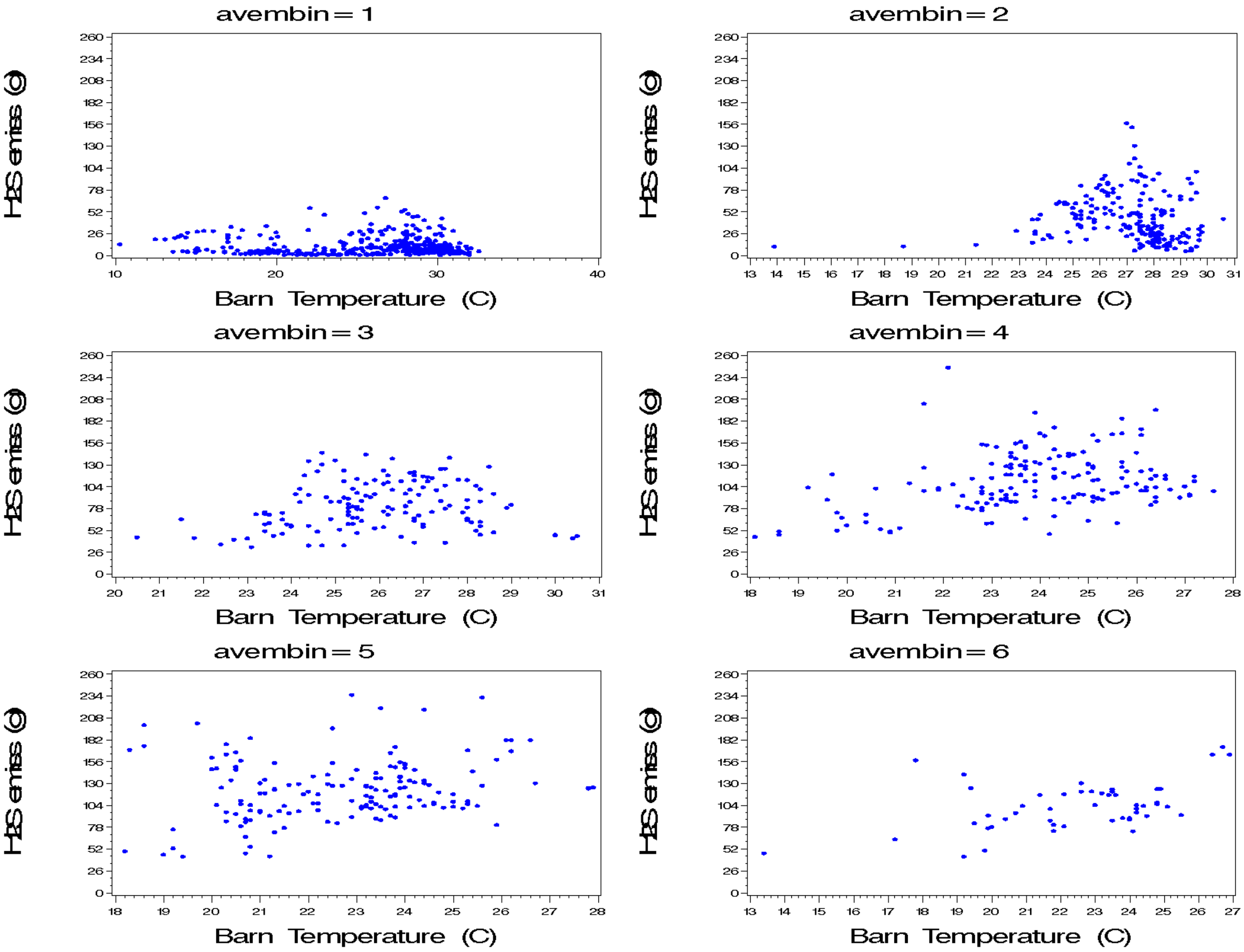

Figure 1-7. H_2S Emissions Vs. House Temperature, for Each Average Mass Bin

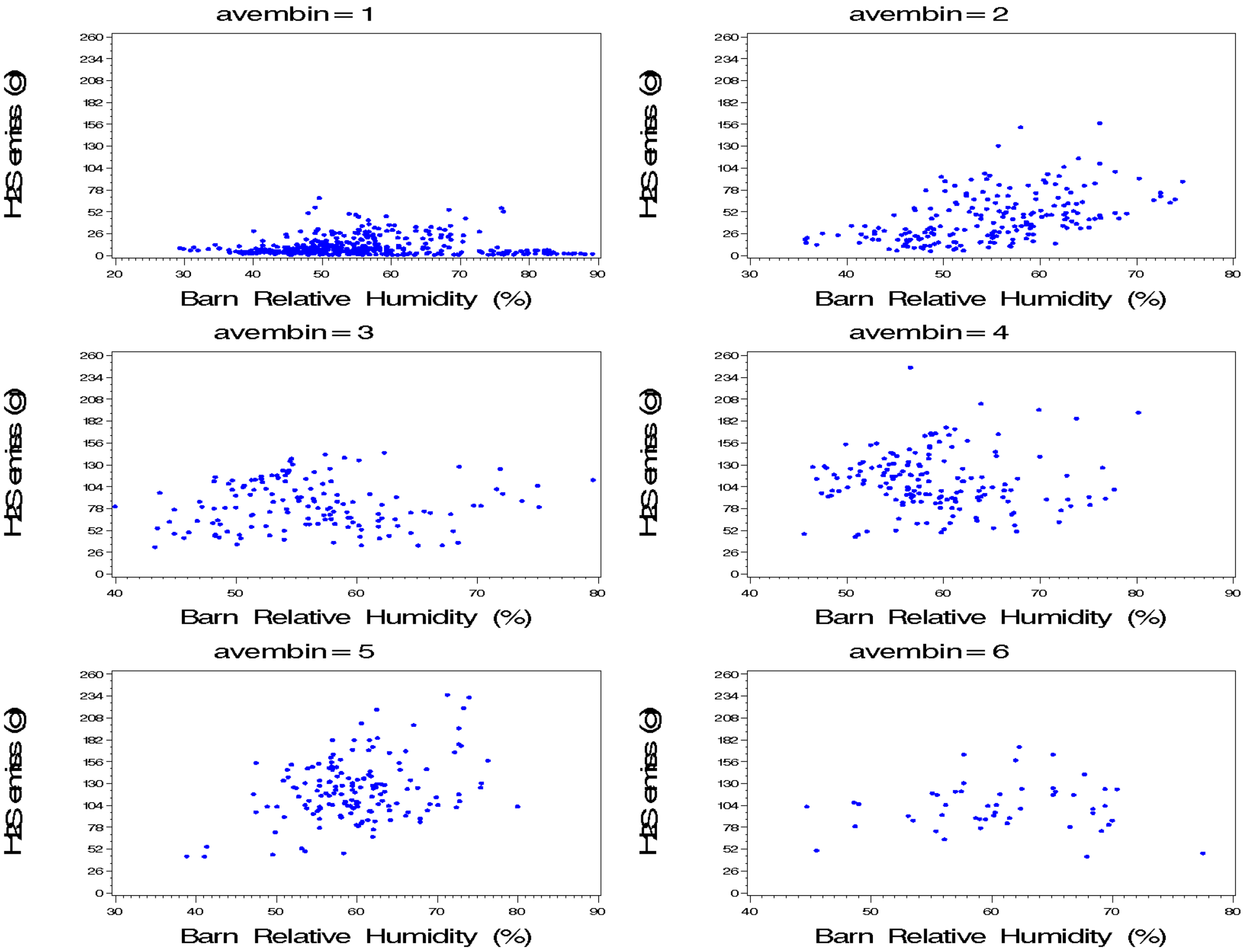

Figure 1-8. H_2S Emissions Vs. House Relative Humidity, for Each Average Mass Bin

1.2 PM_{10} Functional Form Plots

The plots presented in this section plot the PM_{10} emission versus each of the predictor variables by average mass bin to assist in determining their functional forms.

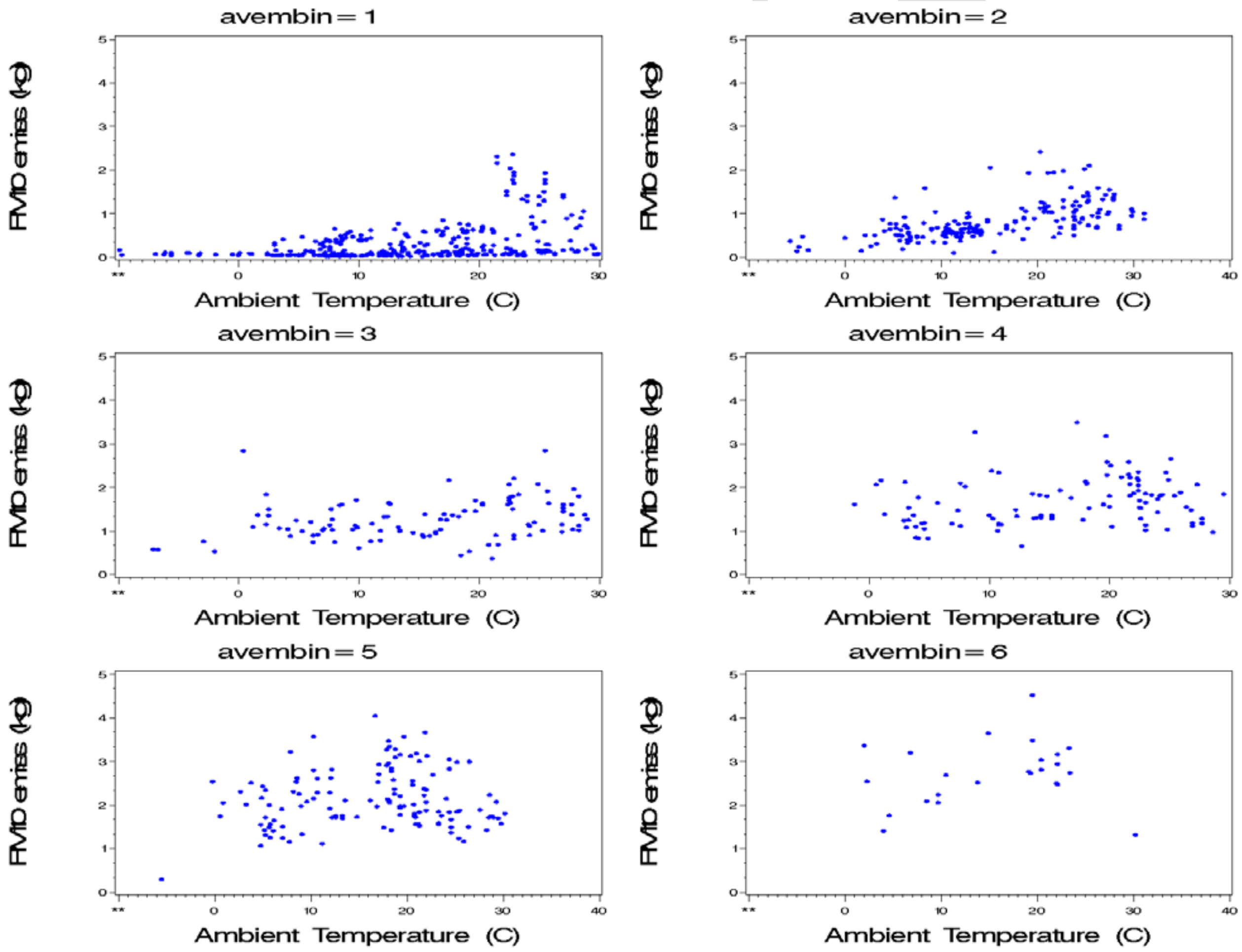

Figure 1-9. PM_{10} Emissions Vs. Ambient Temperature, for Each Average Mass Bin

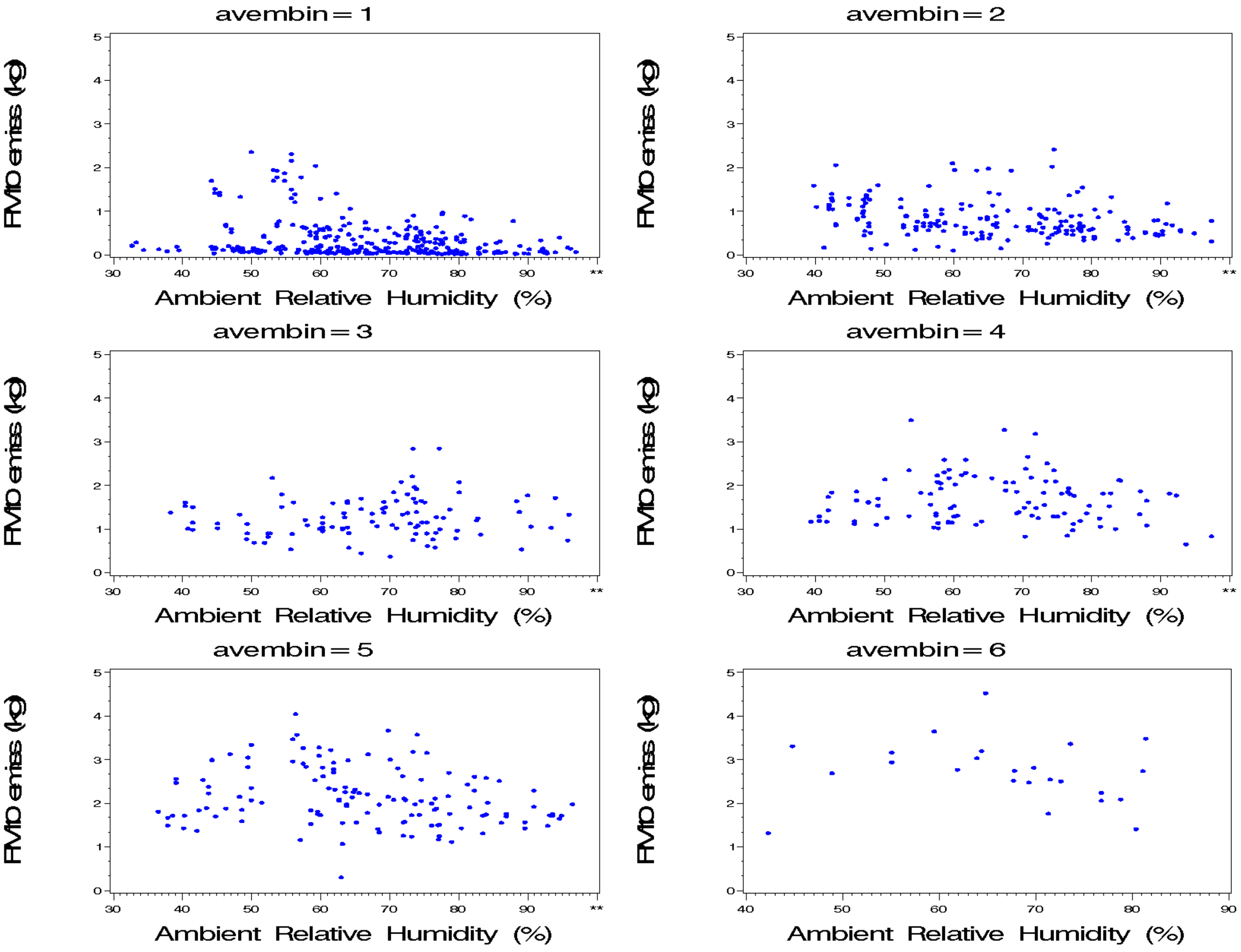

Figure 1-10. PM$_{10}$ Emissions Vs. Ambient Relative Humidity, for Each Average Mass Bin

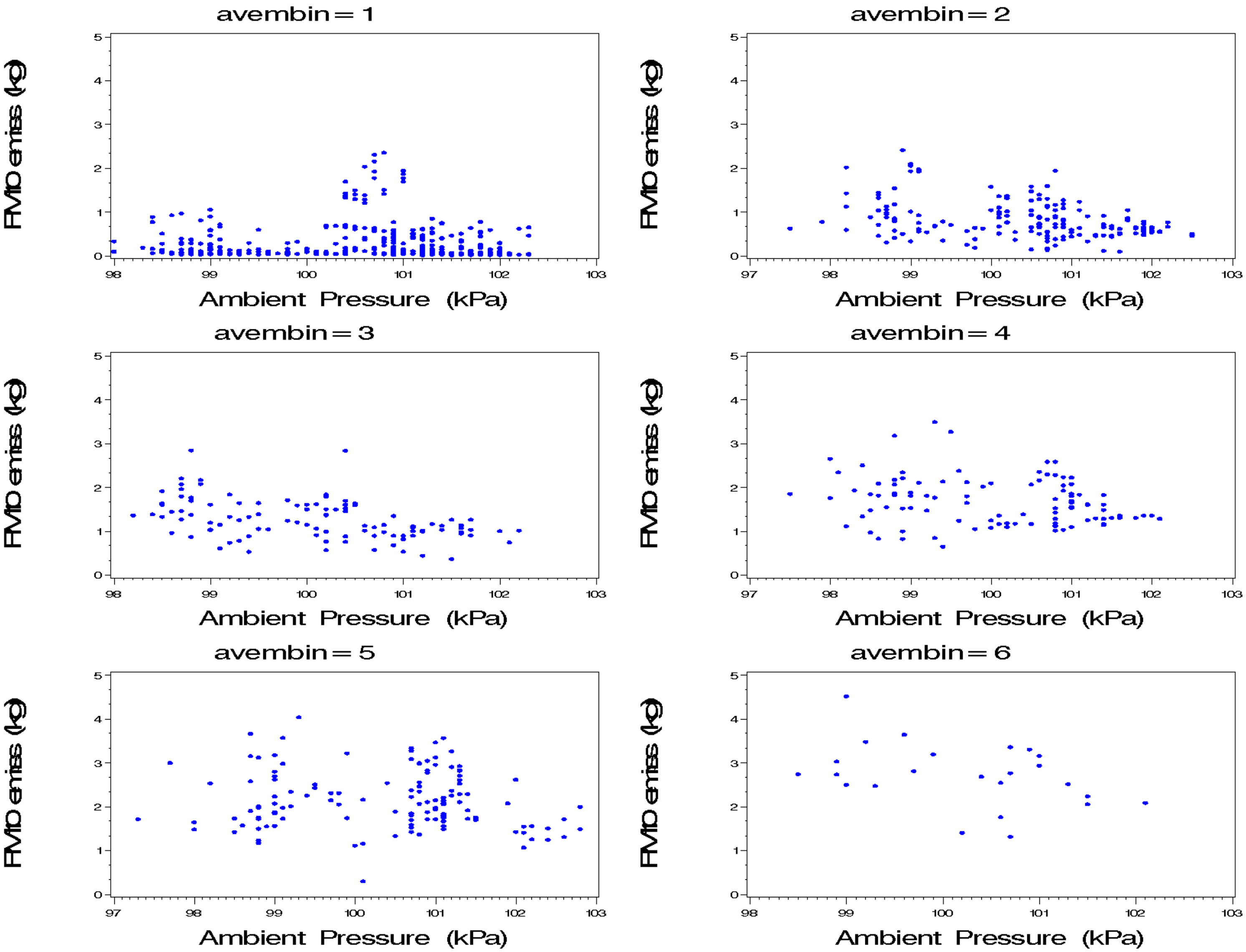

Figure 1-11. PM_{10} Emissions Vs. Ambient Pressure, for Each Average Mass Bin

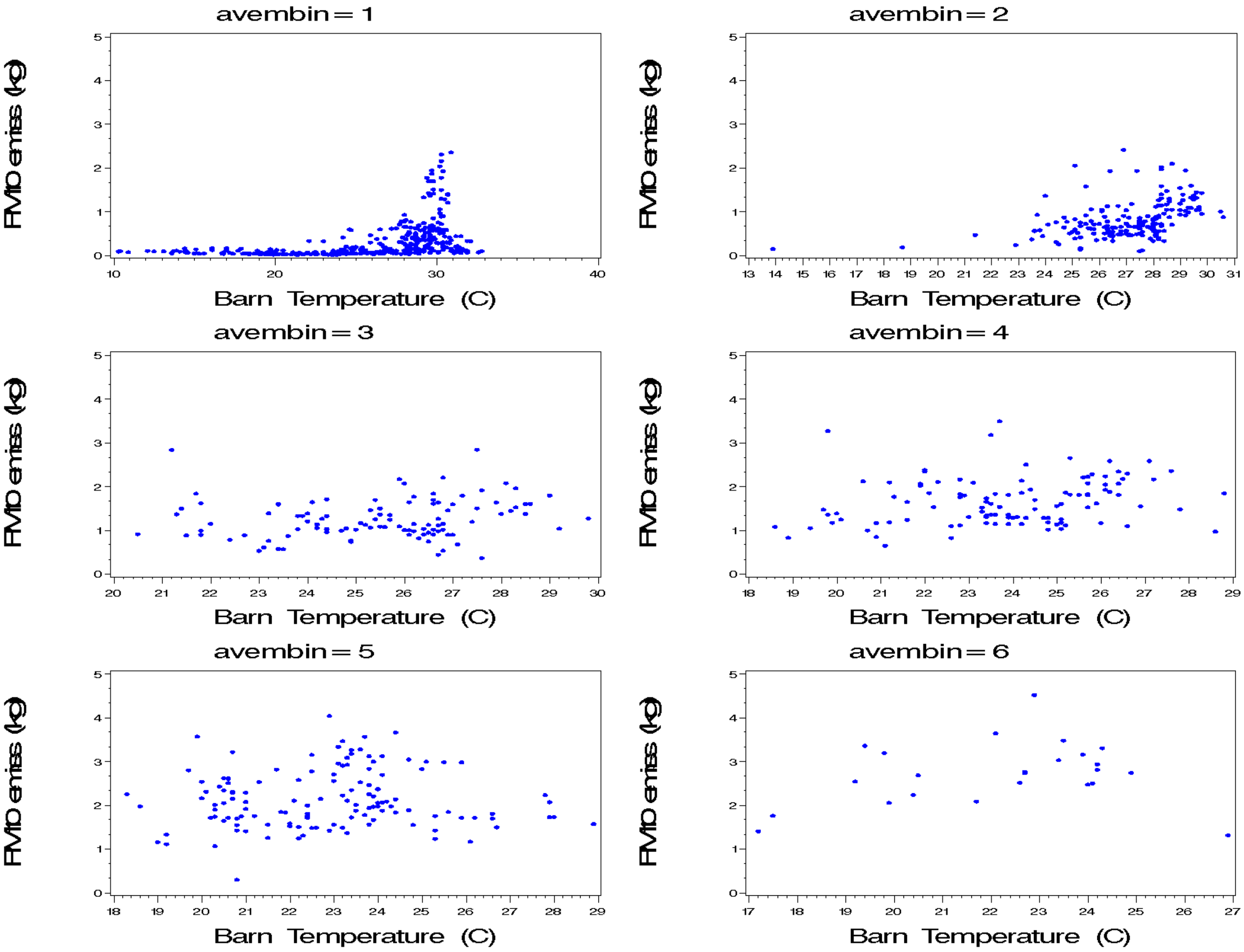

Figure 1-12. PM_{10} Emissions Vs. House Temperature, for Each Average Mass Bin

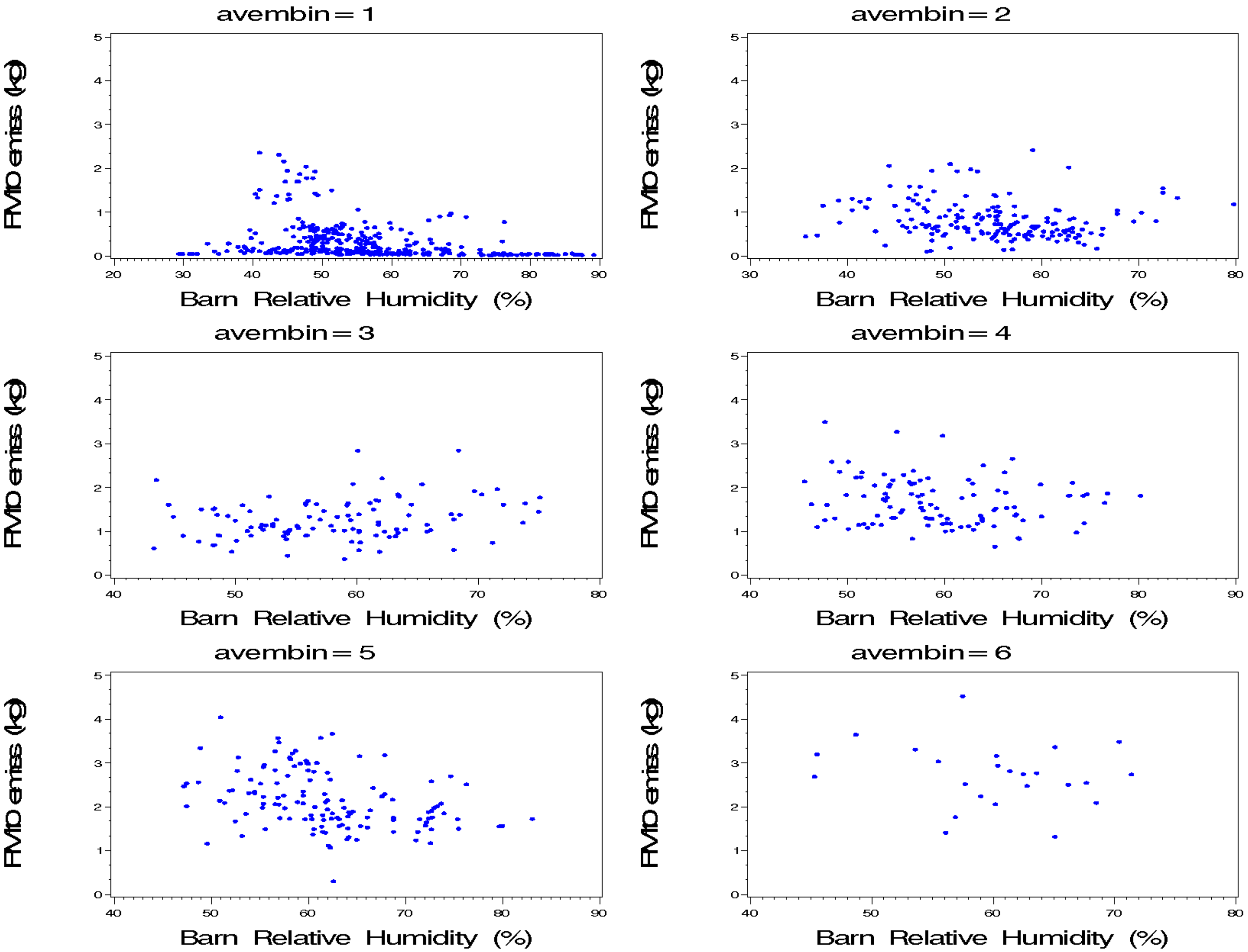

Figure 1-13. PM_{10} Emissions Vs. House Relative Humidity, for Each Average Mass Bin

**** Internal Draft – Do Not Quote or Cite ****

1.3 $PM_{2.5}$ Functional Form Plots

The plots presented in this section plot the $PM_{2.5}$ emission versus each of the predictor variables by average mass bin to assist in determining their functional forms.

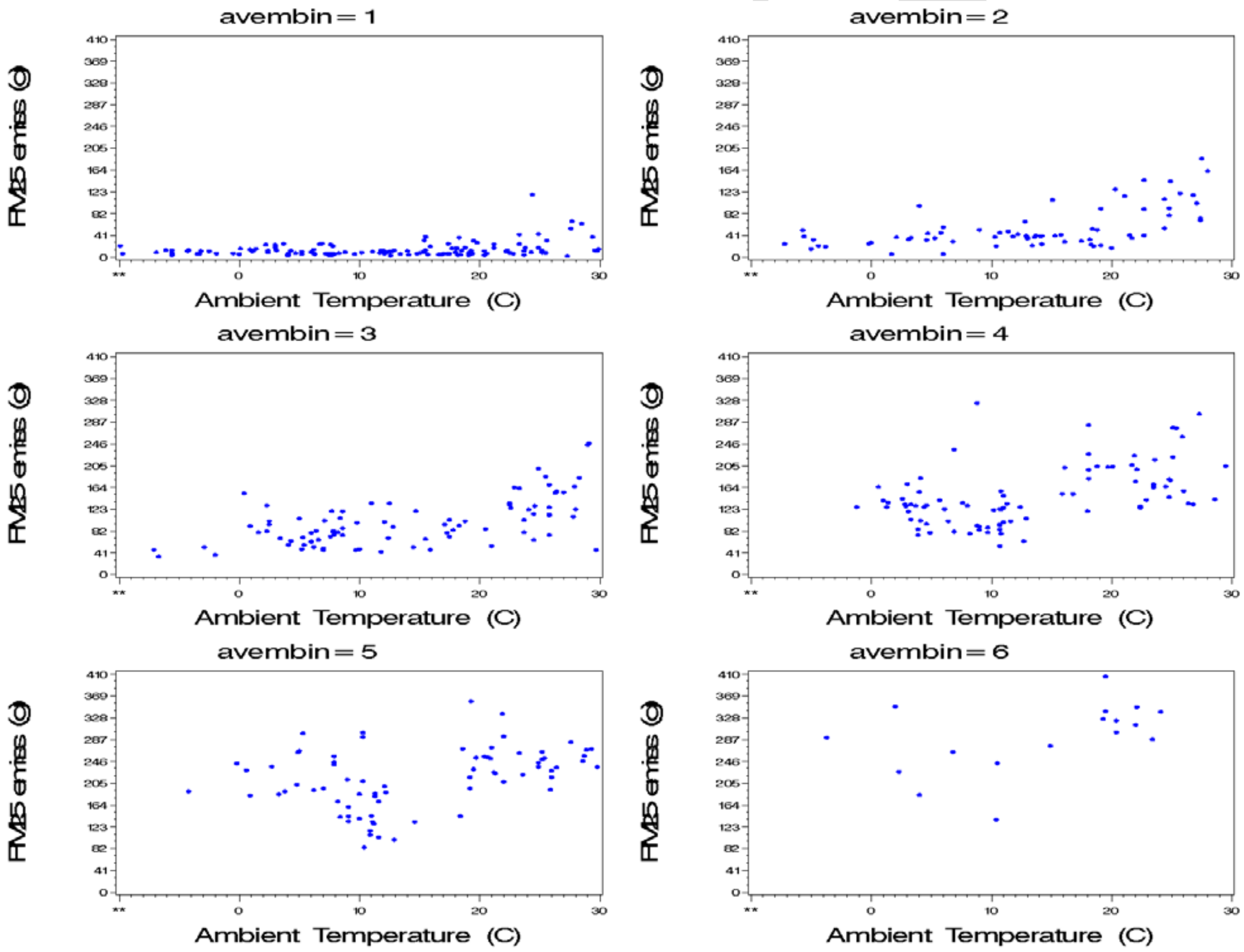

Figure 1-14. $PM_{2.5}$ Emissions Vs. Ambient Temperature, for Each Average Mass Bin

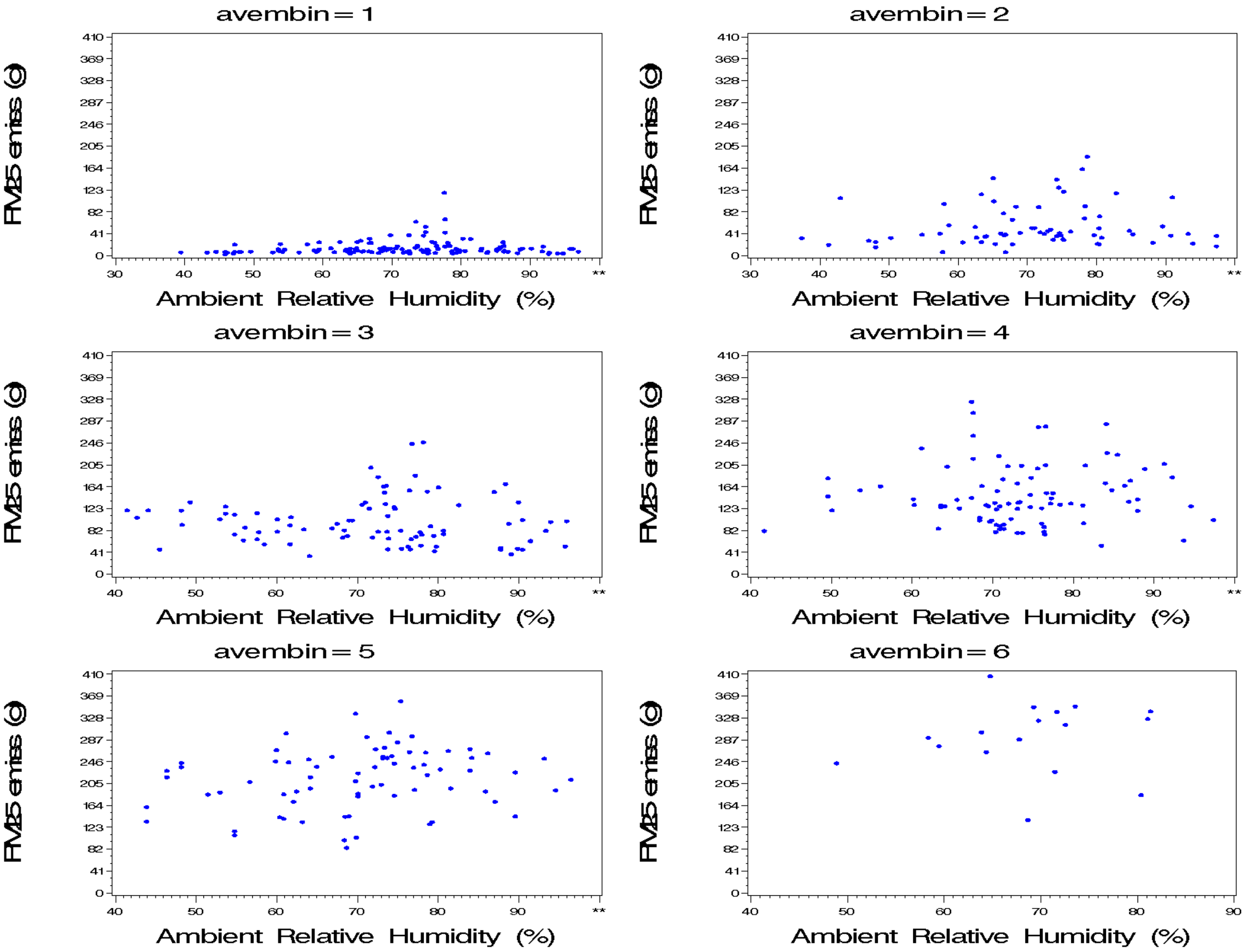

Figure 1-15. PM$_{2.5}$ Emissions Vs. Ambient Relative Humidity, for Each Average Mass Bin

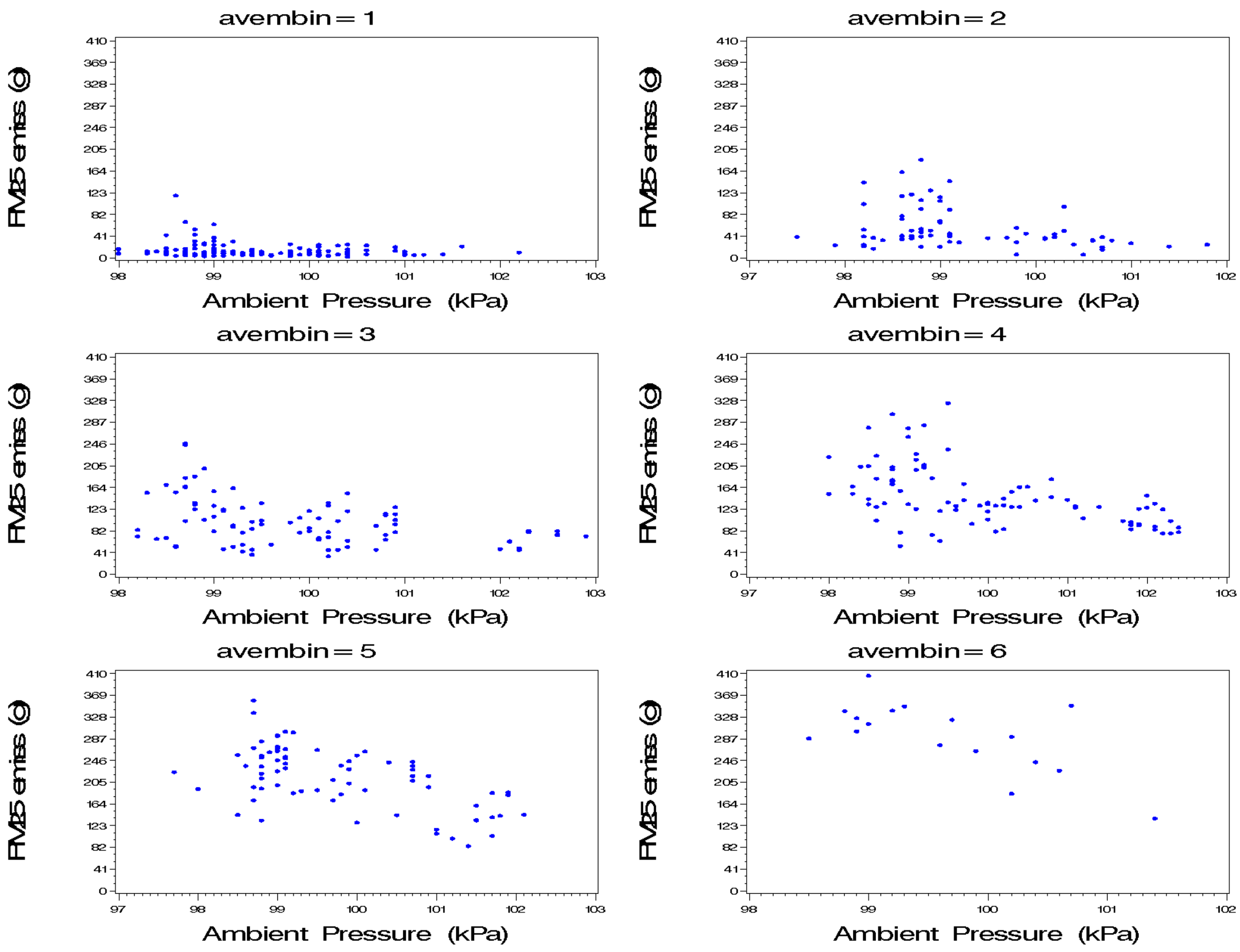

Figure 1-16. PM$_{2.5}$ Emissions Vs. Ambient Pressure, for Each Average Mass Bin

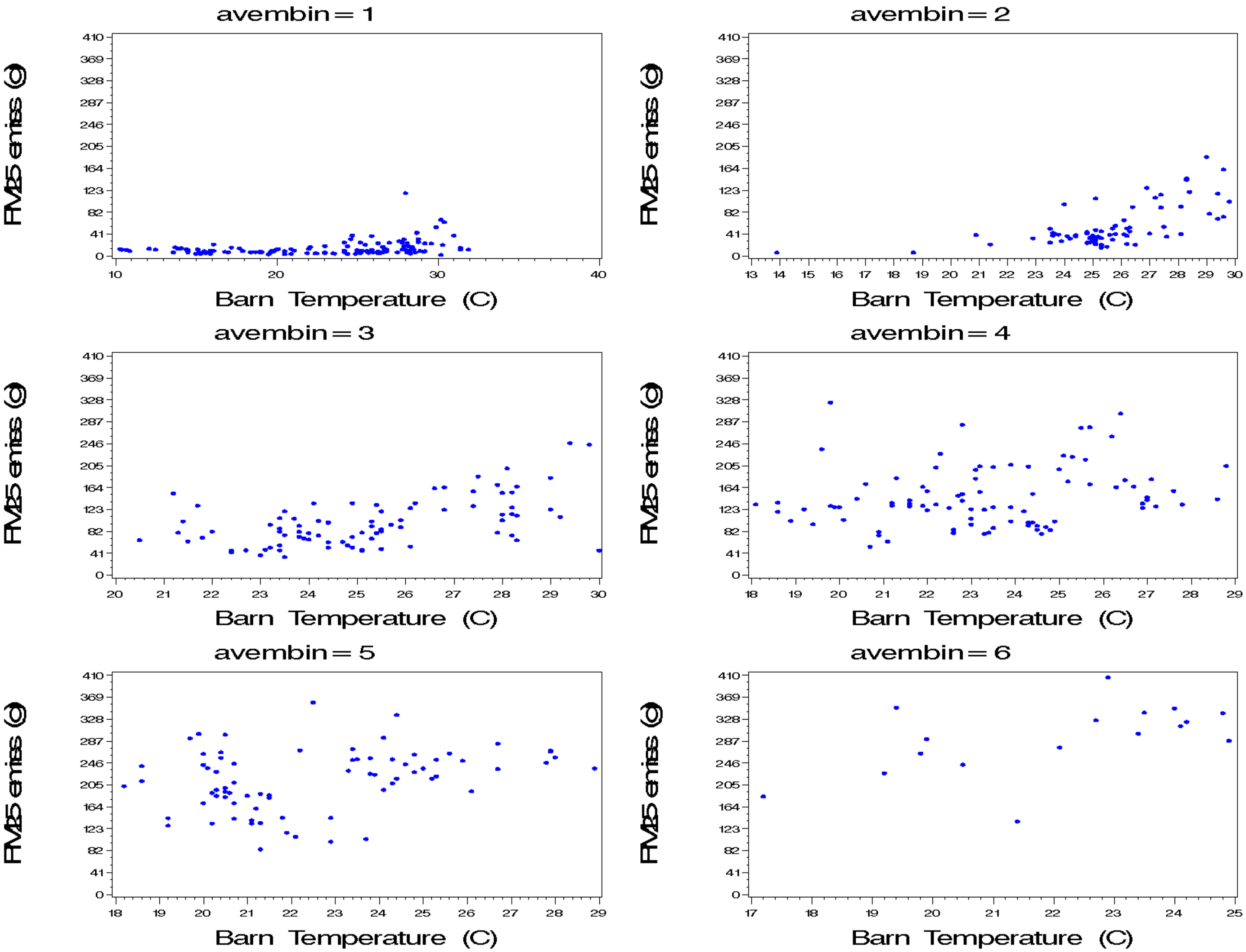

Figure 1-17. PM$_{2.5}$ Emissions Vs. House Temperature, for Each Average Mass Bin

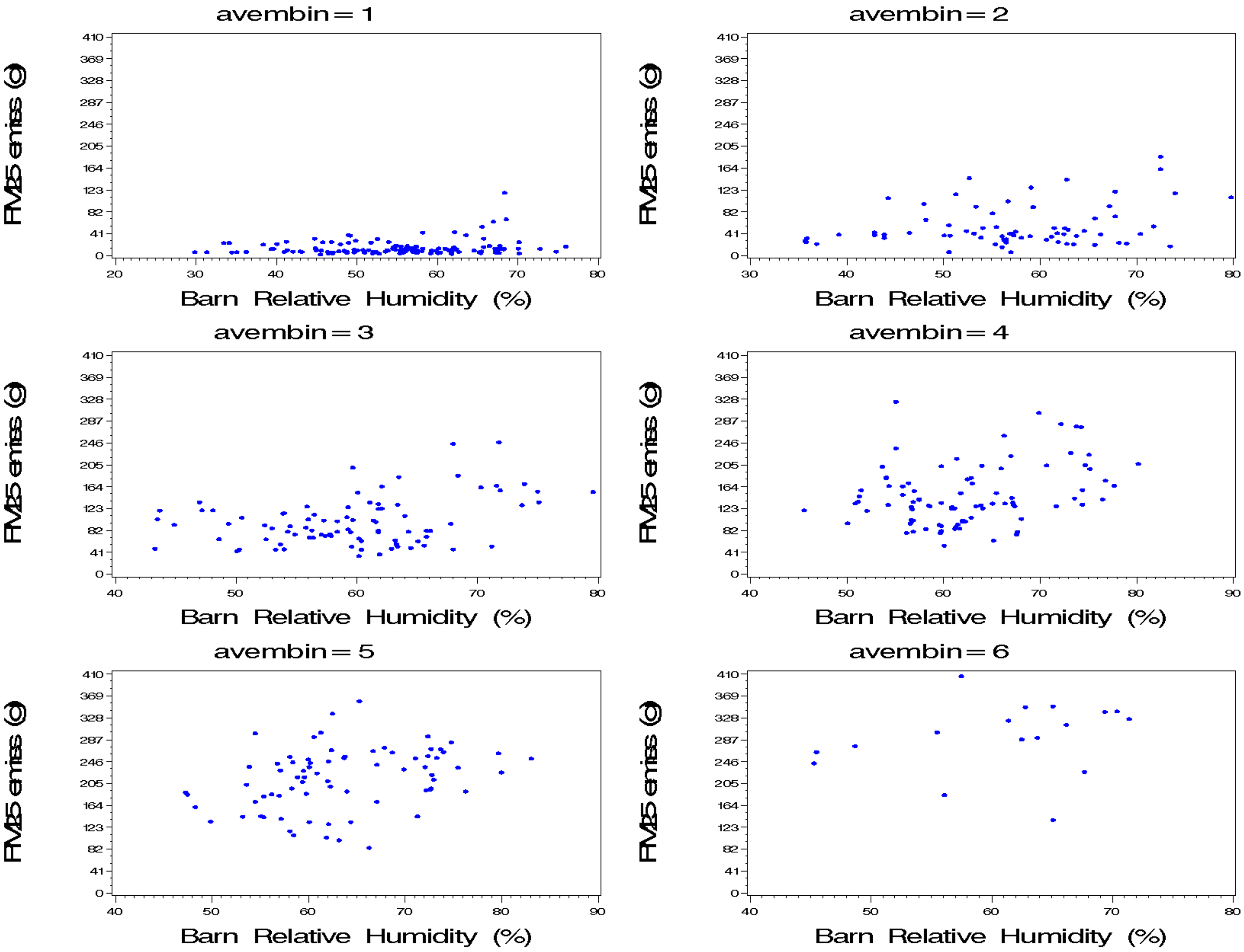

Figure 1-18. PM$_{2.5}$ Emissions Vs. House Relative Humidity, for Each Average Mass Bin

1.4 TSP Functional Form Plots

Figure 1-19 and Figure 1-20 support the use of a quadratic function of average bird mass in EEM development. Plots of all emissions values masked the emissions decrease because of large variances in emissions between the houses at that same time. Figure 1-19 contains scatter plots of TSP emission versus the average bird mass for each of the 9 flocks with TSP measurements that occurred over the study at CA1B House 10 and House 12. Figure 1-20 contains the plots for the six flocks that occurred at the KY1B-2 House 3 at the top half of the figure and KY1B-1 House 5 on the bottom half of the figure.

The remaining plots on the section plot the TSP emission versus each of the predictor variables by average mass bin to assist in determining their functional forms.

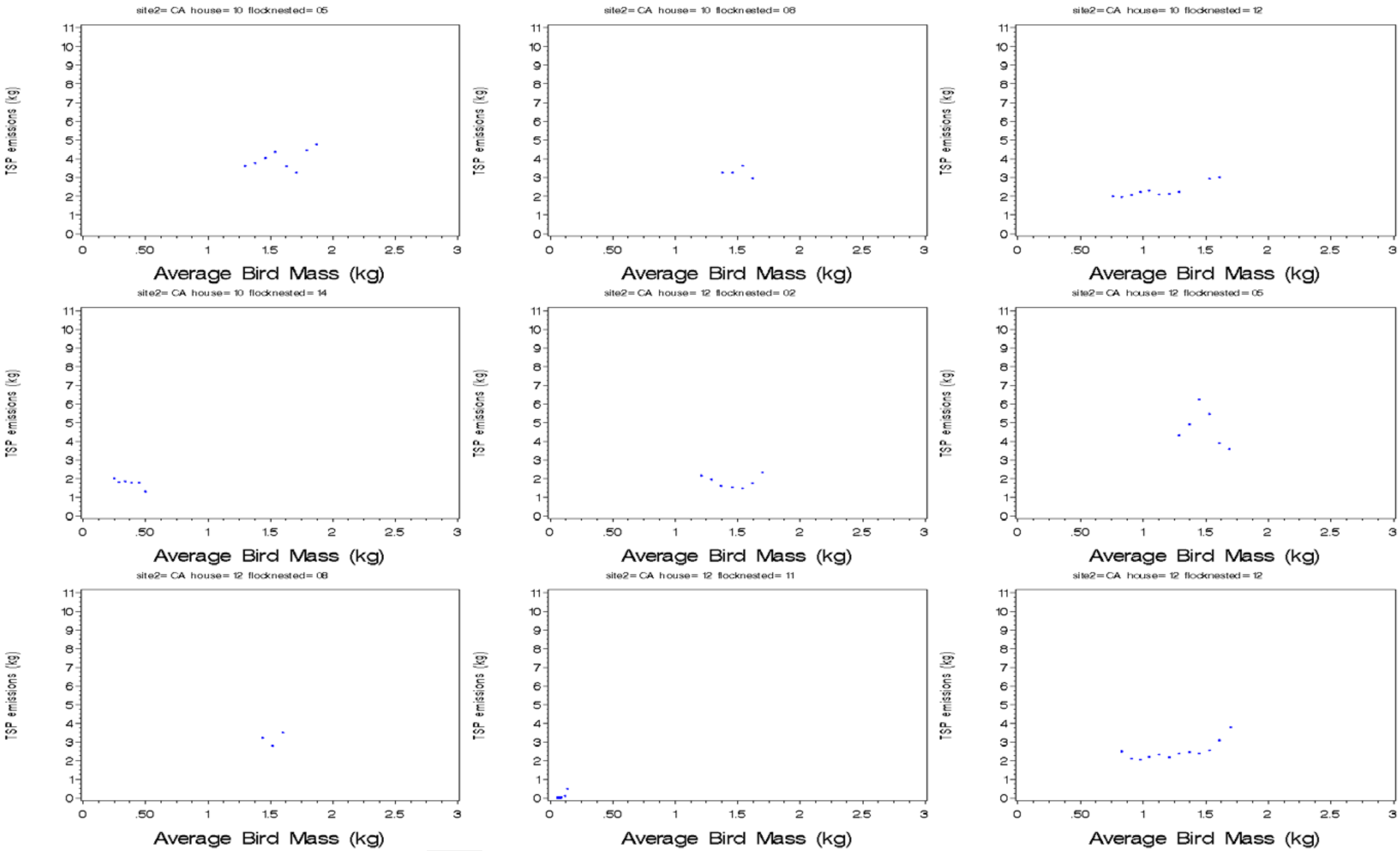

Figure 1-19. TSP Emissions Vs. Average Bird Mass, for Each Flock at CA1B Houses

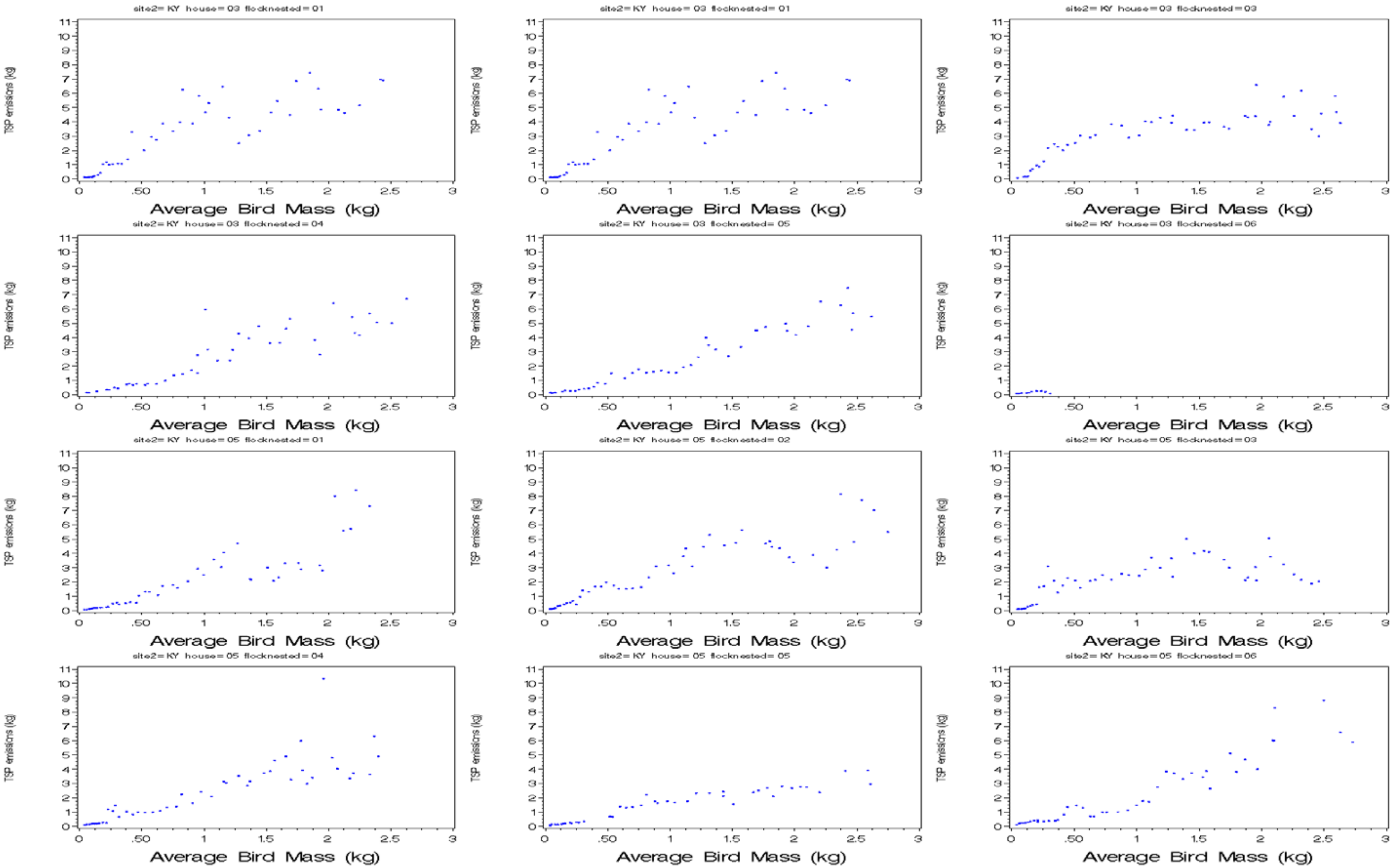

Figure 1-20. TSP Emissions Vs. Average Bird Mass, for Each Flock at the Kentucky sites

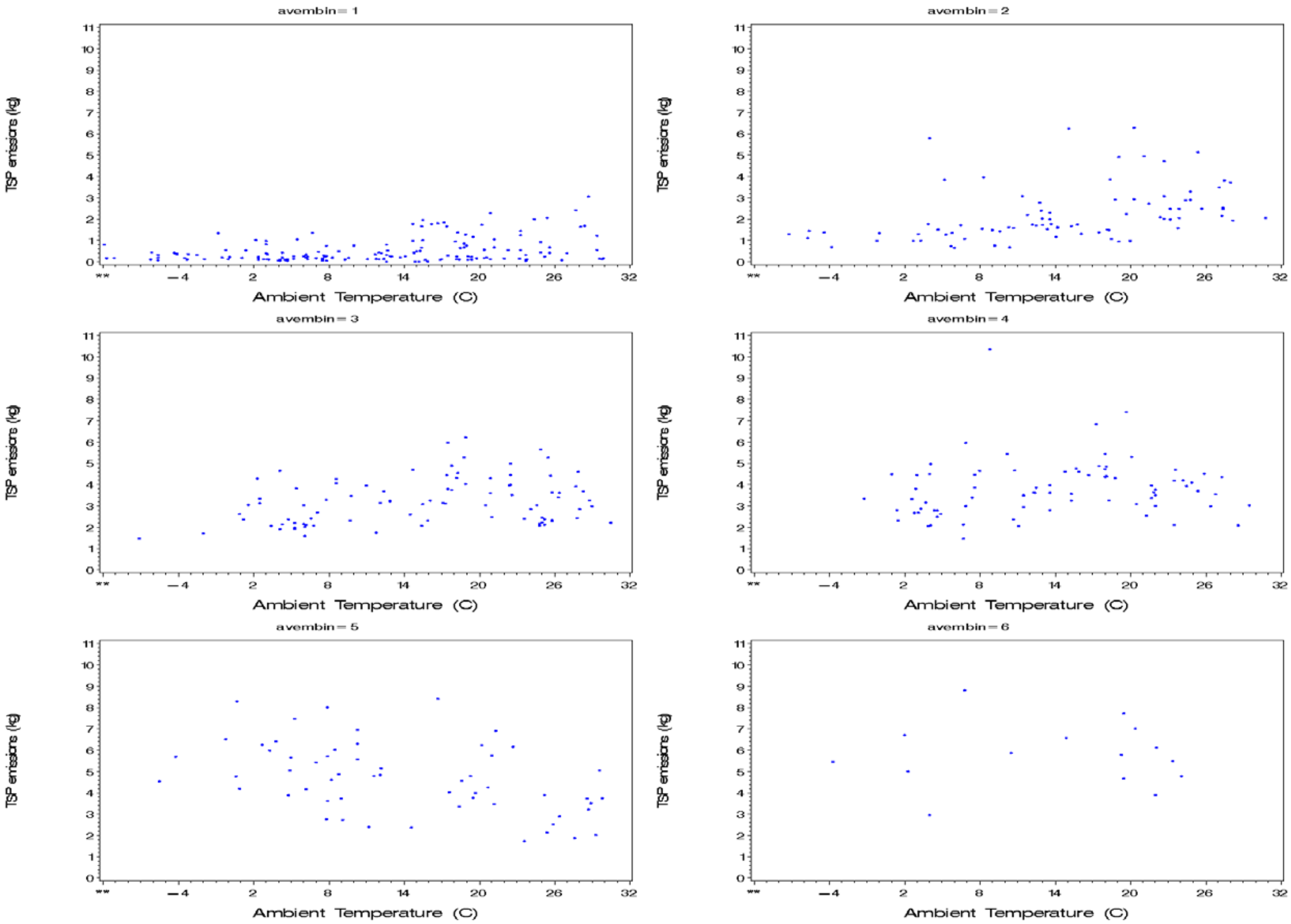

Figure 1-21. TSP Emissions Vs. Ambient Temperature, for Each Average Mass Bin

**** Internal Draft – Do Not Quote or Cite ****

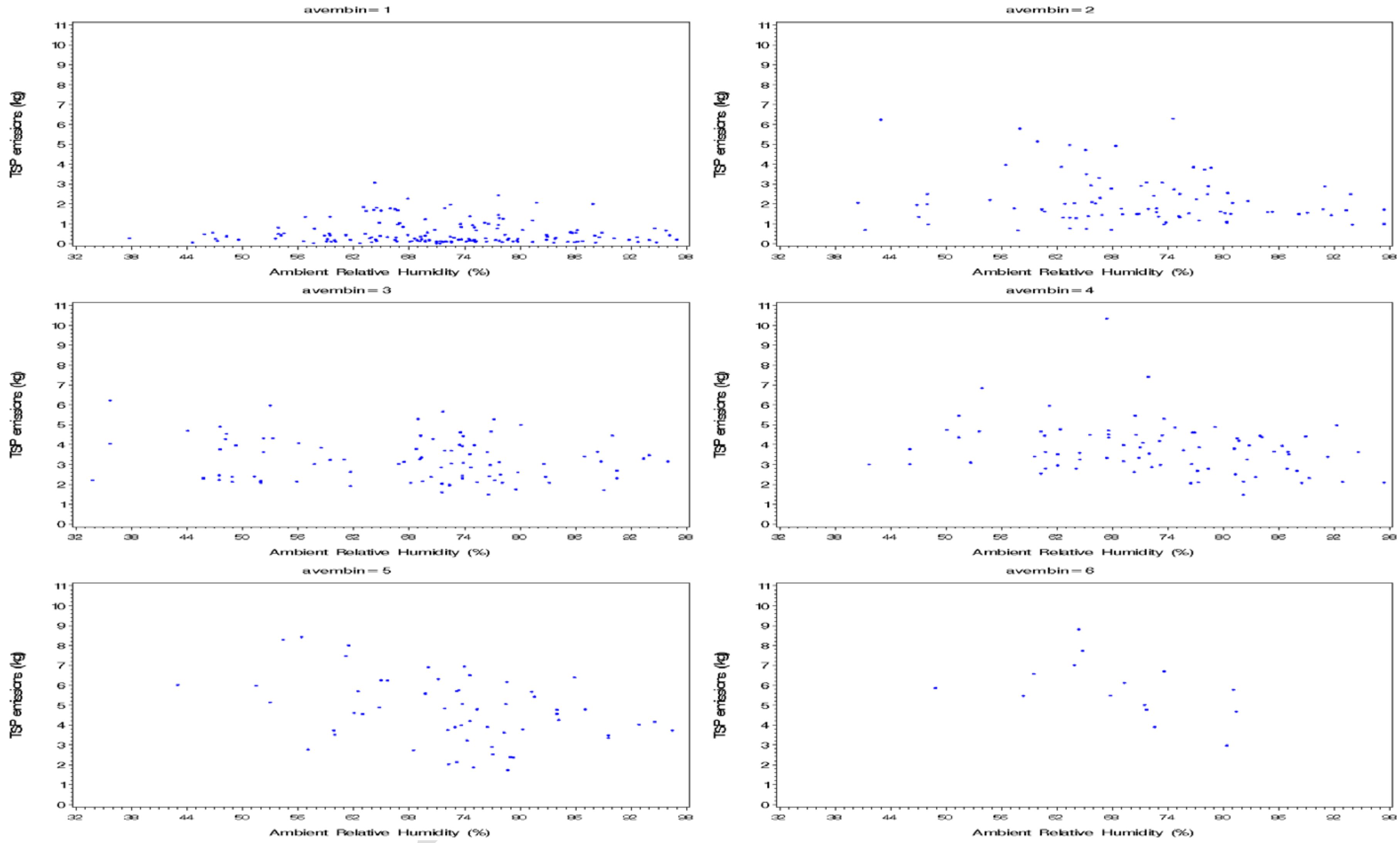

Figure 1-22. TSP Emissions Vs. Ambient Relative Humidity, for Each Average Mass Bin

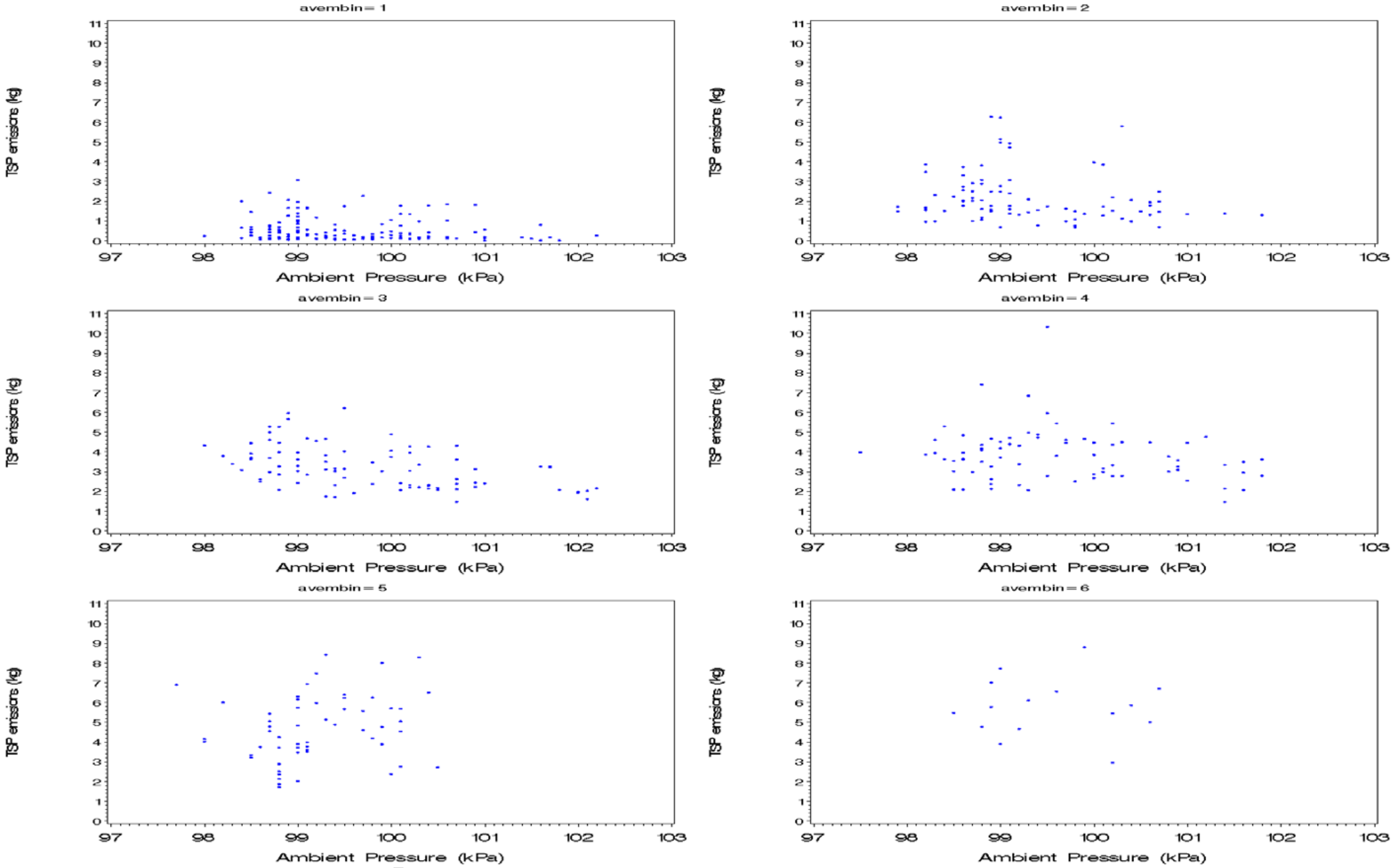

Figure 1-23. TSP Emissions Vs. Ambient Pressure, for Each Average Mass Bin

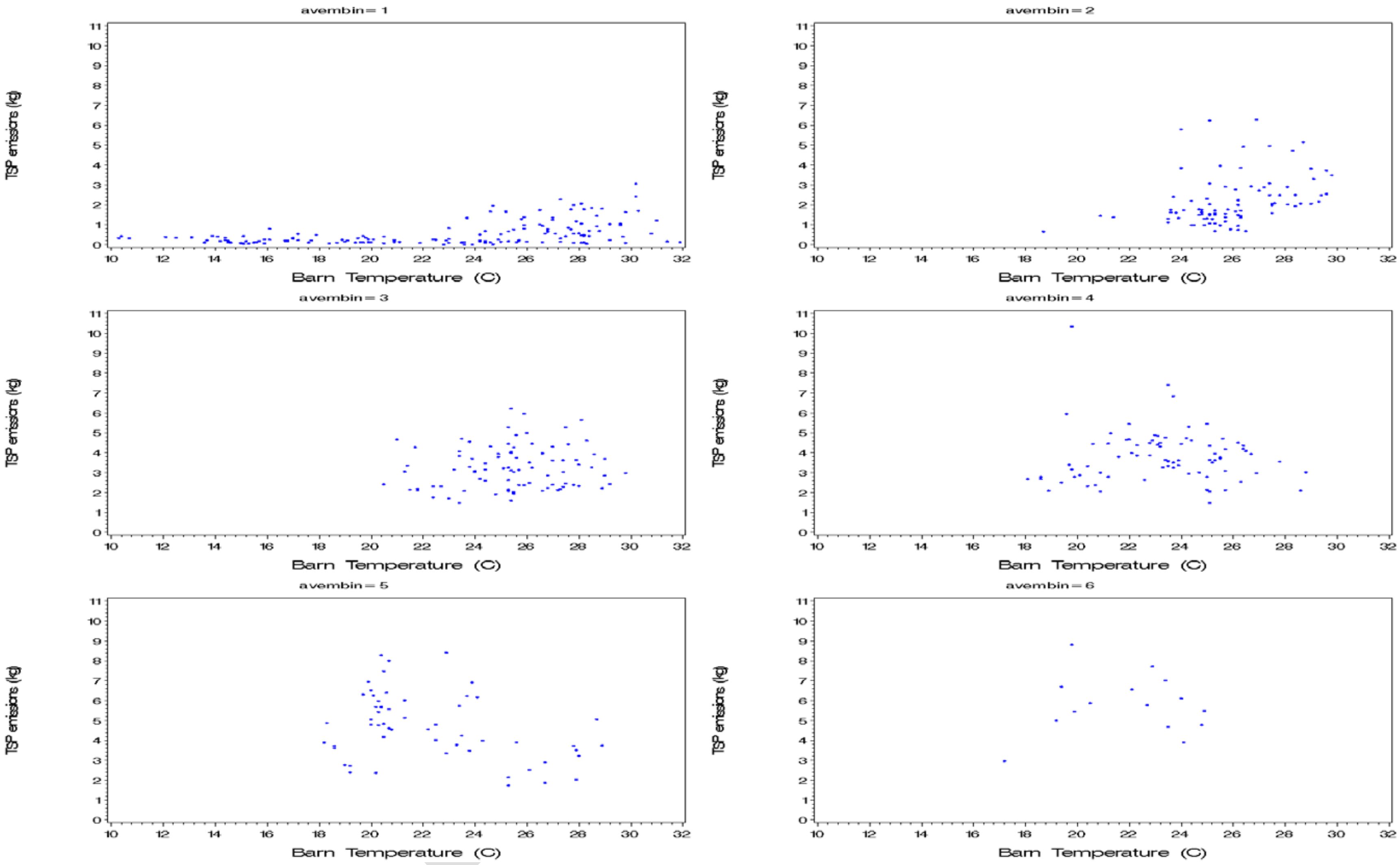

Figure 1-24. TSP Emissions Vs. House Temperature, for Each Average Mass Bin

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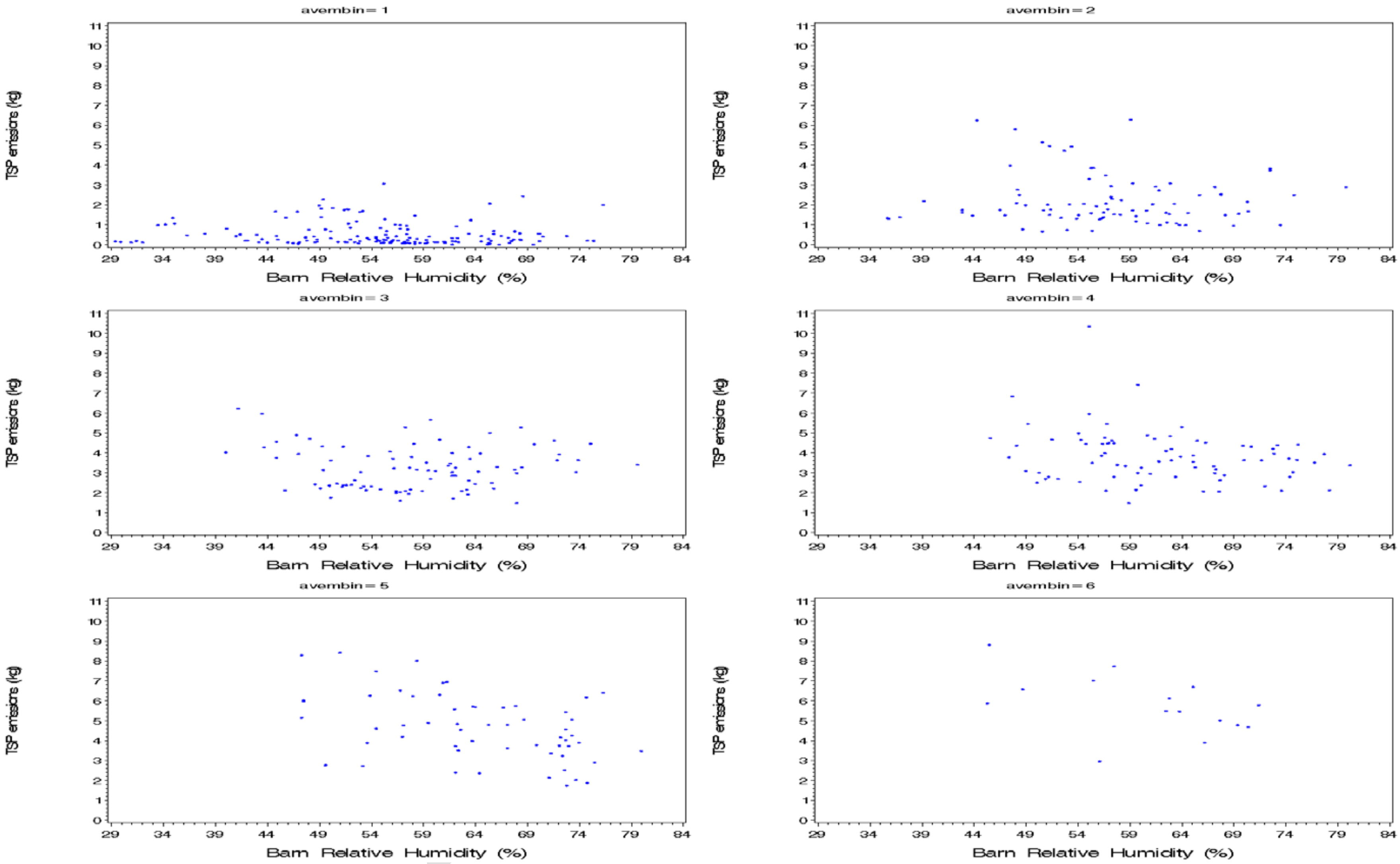

Figure 1-25. TSP Emissions Vs. House Relative Humidity, for Each Average Mass Bin

1.5 VOC Functional Form Plots

Figure 1-26 supports the use of a quadratic function of average bird mass in EEM development. Plots of all emissions values masked the emissions decrease because of large variances in emissions between the houses at that same time. Figure 1-26 contains scatter plots of VOC emission versus the average bird mass for each of the six flocks that occurred at the KY1B-2 House 3 at the top half of the figure and KY1B-1 House 5 on the bottom half of the figure.

The remaining plots in this section plot the VOC emission versus each of the predictor variables by average mass bin to assist in determining their functional forms.

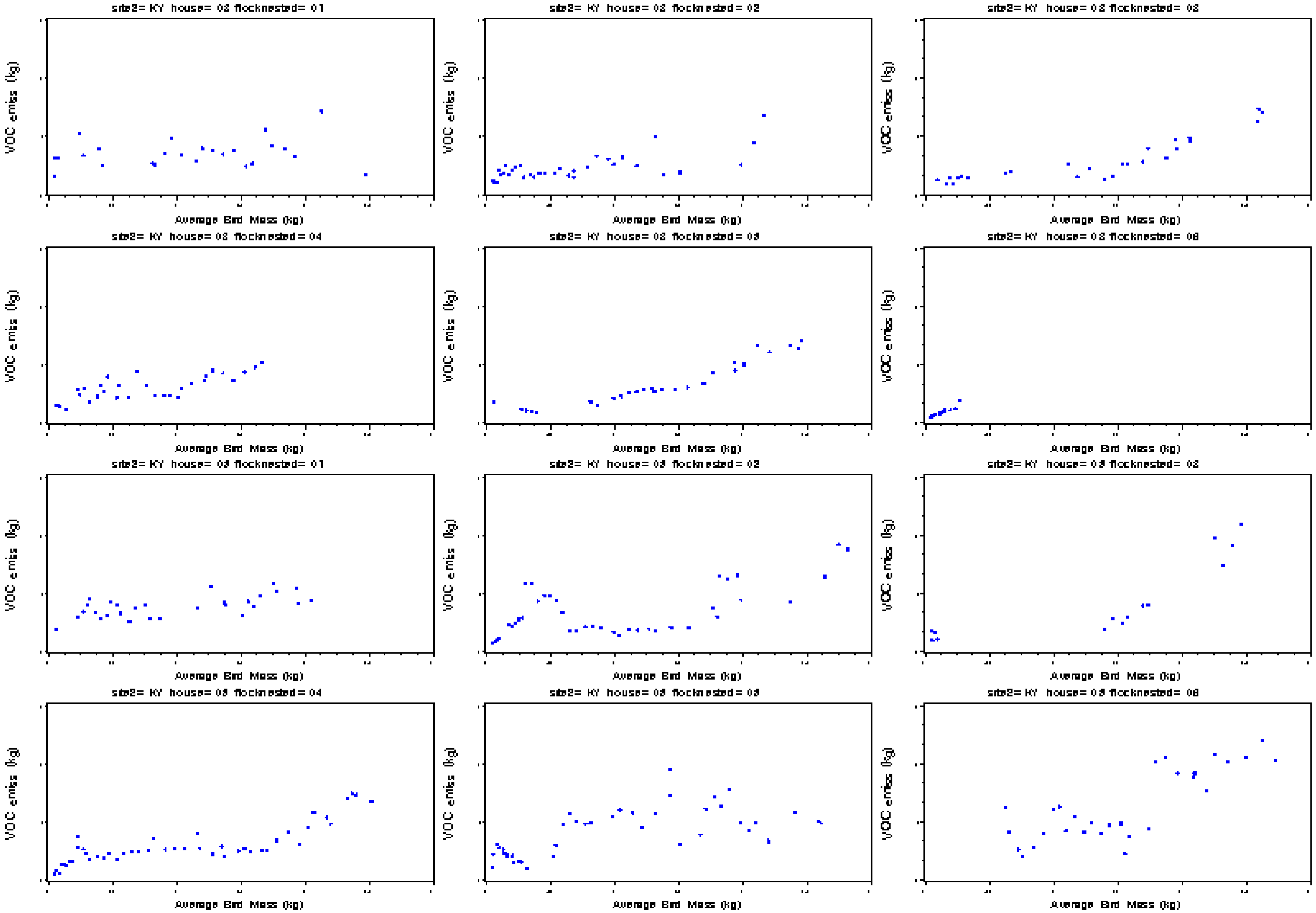

Figure 1-26. VOC Emissions Vs. Average Bird Mass, for Each Flock

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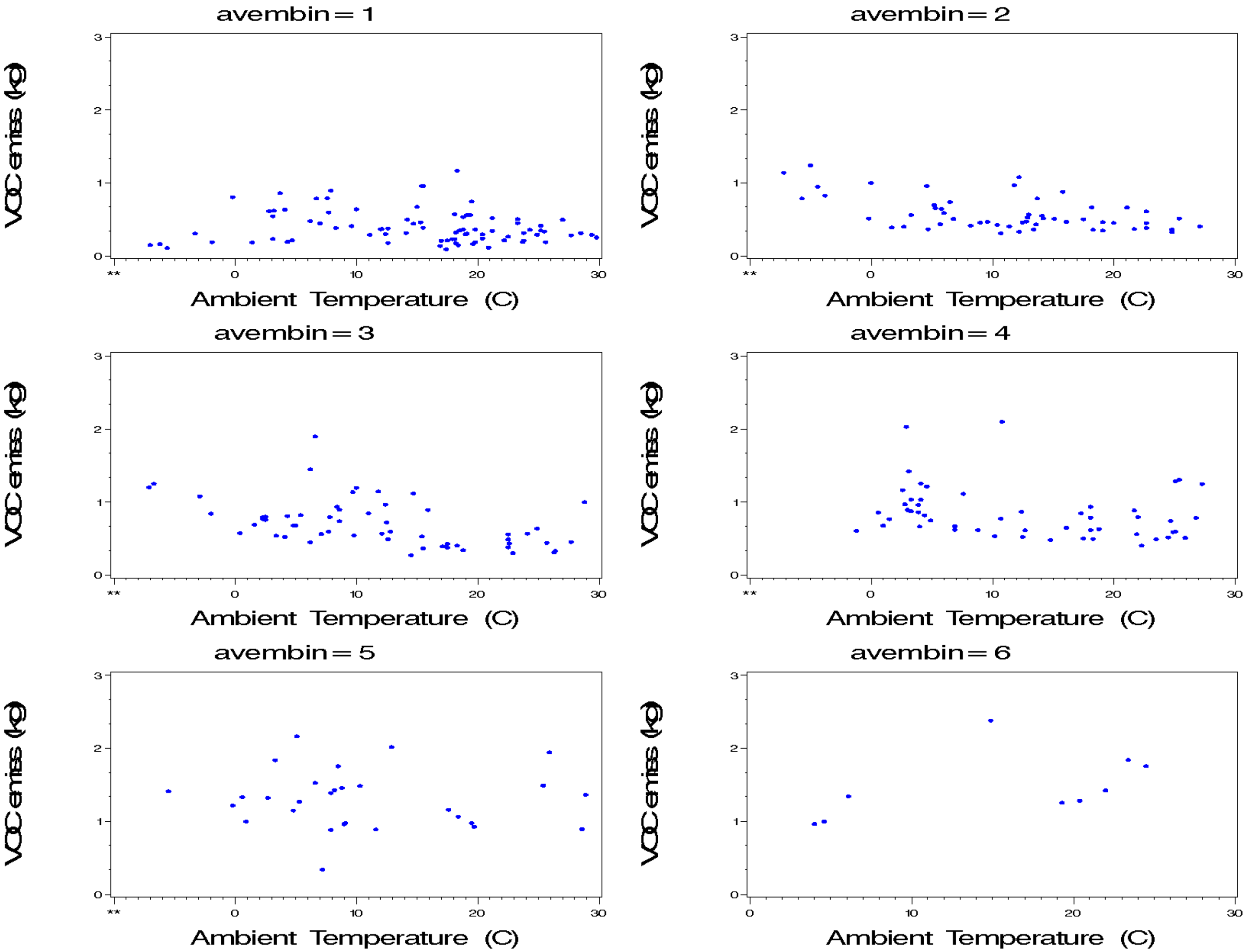

Figure 1-27. VOC Emissions Vs. Ambient Temperature, for Each Average Mass Bin

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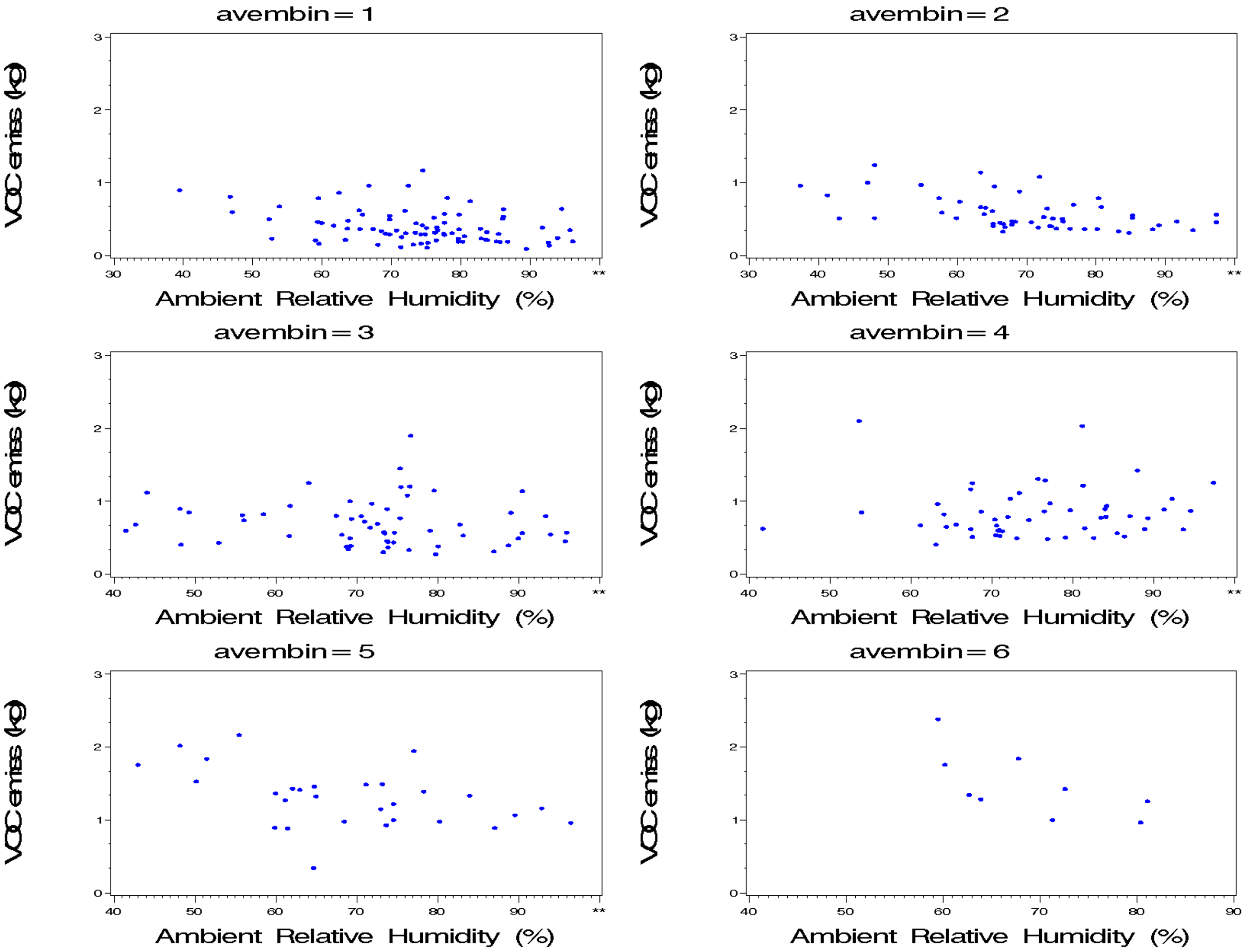

Figure 1-28. VOC Emissions Vs. Ambient Relative Humidity, for Each Average Mass Bin

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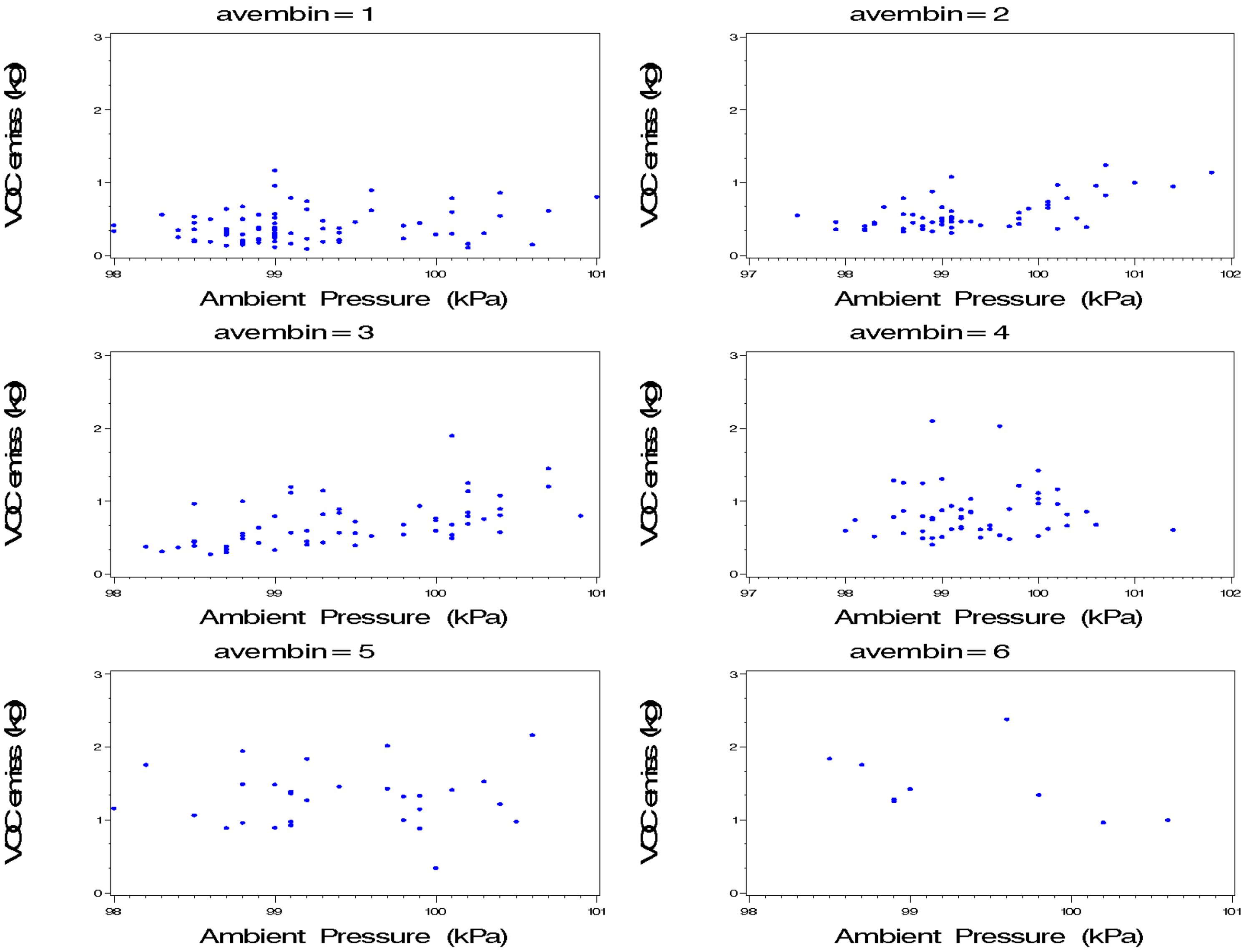

Figure 1-29. VOC Emissions Vs. Ambient Pressure, for Each Average Mass Bin

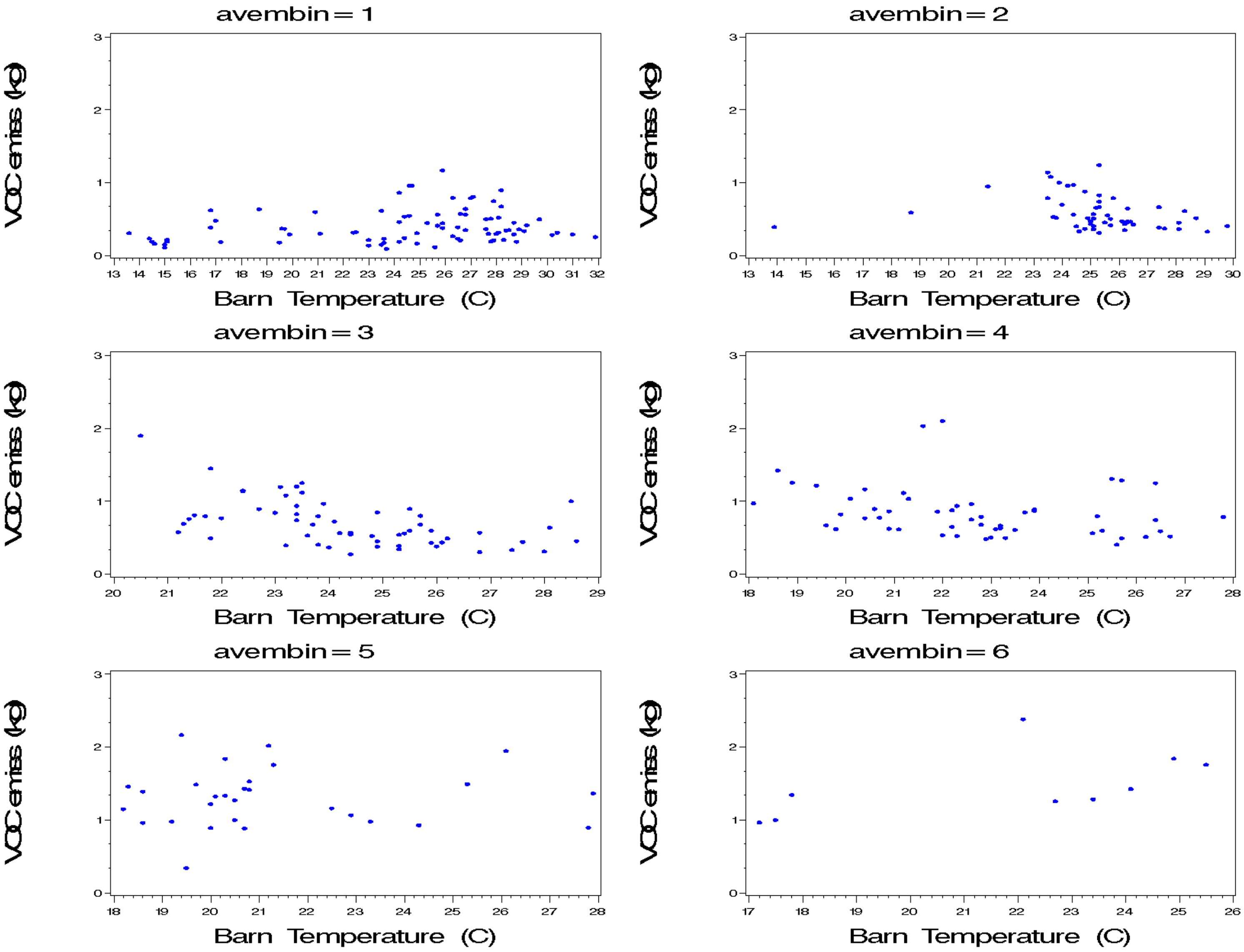

Figure 1-30. VOC Emissions Vs. House Temperature, for Each Average Mass Bin

**** Internal Draft – Do Not Quote or Cite ****

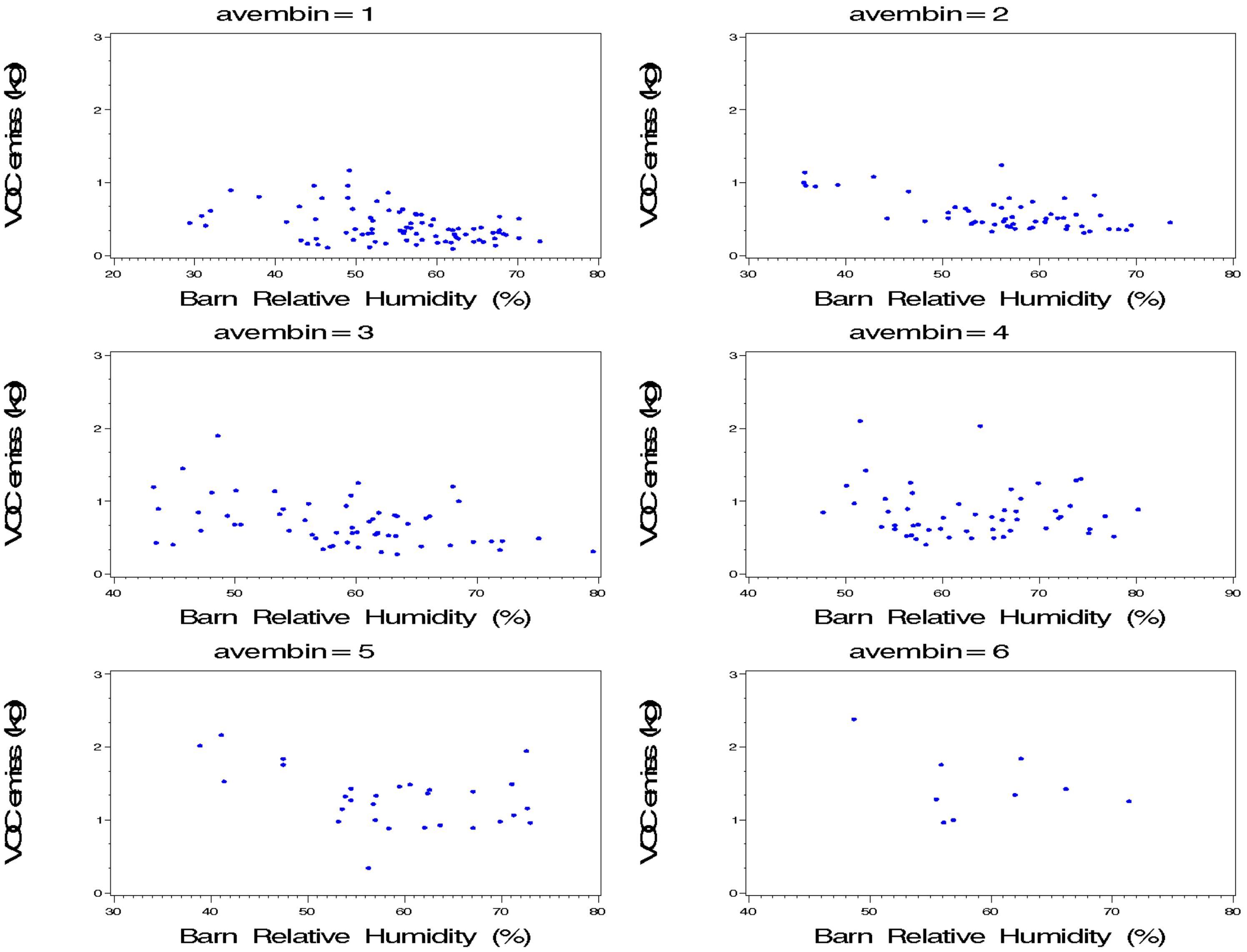

Figure 1-31. VOC Emissions Vs. House Relative Humidity, for Each Average Mass Bin