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Polychlorinated Biphenyls (PCBs) in School Buildings: Sources, Environmental Levels, and Exposures

Kent Thomas, Jianping Xue, Ronald Williams, Paul Jones, Donald Whitaker

Office of Research and Development
National Exposure Research Laboratory

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Executive Summary

E.1 Background

Caulk containing polychlorinated biphenyls (PCBs) was used in some buildings, including schools, in the 1950s through the 1970s. PCBs were used as a plasticizer in caulk, added either during manufacture or mixed on site prior to installation. Other potential sources of PCBs, such as fluorescent light ballast capacitors, were also used in school buildings during that era. PCBs were used in other types of capacitors, transformers, plasticizers, coatings, inks, adhesives, and carbonless copy paper but the extent of these uses in school buildings is not well known. Materials and components containing PCBs are still present today in many of these older buildings. PCBs are semi-volatile organic chemicals and can be transported in and around buildings through vaporization into the air and through absorption into dust and materials. PCBs may be present in the air, dust, soil and on surfaces in and around school buildings leading to the potential for occupant exposure through multiple routes. In September 2009 the U.S. EPA announced new guidance for school administrators and building managers for managing PCBs in caulk and to help minimize possible exposure. However, there was limited information on PCBs in school buildings in the United States. Neither the PCB sources, nor the routes of exposure, have been well-characterized in school buildings. As such, there remained considerable uncertainty regarding the extent to which children and staff members may be exposed to PCBs in school environments. The EPA also announced in 2009 that additional research would be performed by the Office of Research and Development's (ORD) National Exposure Research Laboratory (NERL) and the National Risk Management Research Laboratory (NRMRL) to further study this issue. The research was intended to help fill information gaps and improve our understanding of PCBs in school buildings and approaches for mitigating exposures.

E.2 Objectives

Information on sources of PCBs and levels in school environments is needed to improve risk management decision-making. ORD's NERL planned research to better understand and characterize PCB sources, emissions, environmental concentrations, and exposures in school environments. Research was also planned by ORD's NRMRL to perform laboratory studies of PCB sources and transport and to evaluate selected mitigation approaches.

In order to better understand the significance of PCB-containing caulk and other building materials and components as a source of PCB exposures to children, teachers, and staff in school buildings, the ORD's NERL planned research to utilize a limited set of real-world measurements to:

1. characterize PCB-contaminated caulk and other potential primary and secondary sources of PCBs in school buildings,
2. characterize levels of PCBs in school air, dust, soil, and on surfaces and to investigate relationships between potential PCB sources and environmental levels,
3. apply an exposure model for estimating children's exposure to PCBs in schools with PCB sources,
4. evaluate which routes of exposure (e.g., inhalation, contact with surfaces or dust) are likely to be most important, and
5. provide information to assist in developing risk management practices for reducing exposure to PCBs in schools.

E.3 Approach

NERL exposure scientists and their contractor collected multiple air, dust, soil, and surface wipe samples from a school building scheduled for demolition. Scientists also collected samples from building materials like caulk, tiles, paints, mastics, and others. These environmental and material samples were analyzed for PCB Aroclor mixtures to determine total PCB concentrations. A subset of these samples was then analyzed for PCB congeners (individual PCB compounds) to provide information regarding the presence and relative amounts of individual PCBs and to evaluate relationships between different sources and environmental media.

NERL scientists also used environmental and building material PCB Aroclor measurement data from five schools that were generated by the New York City School Construction Authority under a pilot remedial investigation plan developed under an agreement with U.S. EPA Region 2.

Measurement results and information from these six school buildings provided a limited data set for characterizing real-world PCB sources and environmental levels in schools that were built from the late 1950s to the early 1970s. Environmental measurement results were used to generate distributions of estimated PCB exposures for several different child age groups using the Stochastic Human Exposure and Dose Simulation (SHEDS) model. The SHEDS model was also used to estimate the relative contribution of inhalation, dermal contact, and non-dietary ingestion of dust and soil components of the total exposure.

E.4 Results

Primary PCB Source Assessment

Primary sources of PCBs are defined here as those that were manufactured containing PCBs or had PCBs added during construction. Primary sources of PCBs that might be currently found in buildings include caulk or other sealants, window glazing, fluorescent light ballast capacitors, ceiling tile coatings, and possibly other materials such as paints or floor finishes. Numerous samples of caulk, window glazing, and joint sealants were collected at the six schools. When considering measurement results for these samples it is important to remember that multiple samples of the same type of material may have been collected from several places in a school building, and that these schools were selected because they had suspected or known PCB sources. Key results for caulk and light ballast characterization at the six schools are reported below.

Caulk

- All six schools contained some interior or exterior caulk with PCB levels greater than 10,000 ppm. 8.6 % of the 427 samples of interior caulk, window glazing, and building joint material from six schools had total PCB levels > 10,000 ppm, while 82% had levels < 50 ppm. The maximum concentration was 440,000 ppm (which is 44% PCBs by weight).
- 41% of the 73 samples of exterior caulk, window glazing, and building joint material from three schools had total PCB concentrations > 10,000 ppm, while 37% had levels < 50 ppm. The maximum concentration was 328,000 ppm. No exterior caulk measurement results were available for the other three schools.
- Aroclor 1254 was the Aroclor mixture reported for most caulk samples, although the analytical laboratory often reported an altered PCB pattern with Aroclor 1254 as the best match. Caulk with an Aroclor 1260 pattern was found at one school.
- Caulk with high PCB concentrations was generally found to be intact and still somewhat flexible. Other flexible caulks and sealants without high PCB levels were also found, while dry and brittle sealants did not have high levels of PCBs.
- Total PCB emission rates were estimated for caulks with > 50,000 ppm PCBs collected in several rooms, around the exterior of a window, and for an exterior joint. Estimated emission rates ranged from 53 to 3100 µg/hr and depended on the PCB concentration in the caulk and the total surface area of the caulk in the specific room or location. The effect of different temperatures was not evaluated.
- Screening-level estimates of the range of indoor air concentrations that might result from PCB emissions from caulk inside or outside several rooms gave results ranging from 10 to 1900 ng/m^3, and depended on the estimated emission rate, air exchange rate, and for the exterior window caulk the percentage of emitted PCBs estimated to enter the classroom. Measured indoor air concentrations were higher than the screening-level estimates in two of four rooms.

Light Ballasts

- Light ballast survey results were available for five schools. The percentage of ballasts found likely to be PCB-containing ranged from 24% to 95% across the schools.
- Estimated total PCB emission rates for intact ballasts in three rooms ranged from 1.2 to 290 µg/hr (based on laboratory emissions tests of four ballasts at 45°C, near the operating temperature of ballasts when the lights are on) and from 0.08 to 18 µg/hr (based on laboratory emissions tests of four ballasts at 23°C, near the temperature of ballasts when light are off). The estimates depended on the number of PCB-containing ballasts in the room and the lowest and highest emitting ballasts in the chamber testing, which saw a nearly 80-fold difference in emission rates.
- Screening-level estimates of the range of air concentrations that might result from PCB emissions from intact PCB-containing ballasts in three rooms gave results ranging from 1.6 to 2400 ng/m^3 (at a ballast temperature of 45°C). At the median estimated emission rate the screening-level air concentration estimates ranged from 2.3 to 44 ng/m^3 and were lower than the measured air concentrations that ranged from 690 to 1460 ng/m^3.
- There was evidence of previous ballast failure in and around some light fixtures in these schools and some ballasts had been replaced with non-PCB containing ballasts. Emissions of PCBs from light fixtures that have been previously contaminated by leaking or failed ballast capacitors have not been measured, but could be substantial if PCB oil residues are present. Emission rates have not been estimated for ballasts with capacitors that are leaking or have burst, but based on the bursting of a ballast capacitor during laboratory testing it is anticipated that emissions would be substantially higher than those measured for intact ballast capacitors and would have a large impact on indoor air PCB concentrations.

Secondary PCB Source Assessment

Secondary sources of PCBs are defined here as those materials that become contaminated due to absorption from direct contact with primary PCB sources such as caulk, or through absorption of PCBs in the indoor air that have been emitted by primary sources such as caulk and light ballasts. Materials such as paints, dust, masonry, floor and ceiling tiles, and mastics may become secondary sources after years of exposure to PCBs emitted from primary sources. These materials should be considered sinks as well as sources, due to their ability to absorb PCBs from direct contact or from the air. When considering measurement results for these samples it is important to remember that multiple samples of the same type of material may have been collected from several places in a school building. Key results for secondary source characterization at the three schools with material measurements are reported below.

- 93% of the 411 building material samples collected at three schools had measureable levels of PCBs. The overall median total PCB concentration was 16 ppm (interquartile range 6.1 - 39.6 ppm).
- Paint had the highest total PCB concentrations with a median of 39 ppm (interquartile range 26 – 72 ppm). Fiberboard had a median level of 31 ppm (interquartile range 13 – 39 ppm), while lower levels were found in some other materials that often have high surface areas in buildings such as ceiling tile with a median of 7.6 ppm (interquartile range 2.7 – 12 ppm) and floor tile with a median of 4.4 ppm (interquartile range 1.4 – 8.7 ppm).
- It is impossible to be certain that these materials did not contain some PCBs when originally installed. Measured concentrations and relative levels among different materials are consistent with these materials being “sinks” that have absorbed PCBs emitted from primary sources.
- Screening-level estimates of emission rates for multiple materials in several rooms were calculated to evaluate their relative potential as secondary sources of PCB emissions following removal of primary sources. Estimated emission rates for different materials in classrooms ranged from < 1 to 100 µg/hr and cumulative totals for 20 materials in a room ranged up to 270 µg/hr. Estimated emission rates for different materials in gymnasiums ranged from < 1 to 1100 µg/hr and cumulative totals for 16 materials ranged up to 2700 µg/hr. Estimated emission rates depended on the surface area of the material and concentration of PCBs in the material. Paints and varnishes generally had the highest relative potential emissions due to the combination of higher PCB concentrations and high surface areas. (There are considerable uncertainties in these estimates, which are based on emission parameters derived from laboratory emissions testing of caulks. Emission parameters for the many different types of other materials could be substantially different than those for caulk).
- It is difficult to estimate indoor air concentrations of PCBs that might result from secondary sources following removal of primary sources because of the large number of different types of PCB-containing material in a room, and because the source – sink dynamics for multiple different materials are difficult to characterize. However, the cumulative PCB emissions from secondary sources could potentially result in indoor air PCB levels above background in school rooms following mitigation of primary sources, depending on relative emission rates, sink rates, and ventilation rates by outdoor air.
- Surface dust and dust in ventilation systems may be another secondary source for potential exposures to PCBs.

PCB Concentrations in the School Environment

PCBs may be transported from primary and secondary sources to environmental media in and around buildings including indoor air, dusts, and soils. PCBs may also be found on surfaces inside buildings. Key results for PCB concentration measurements in environmental media at six schools are reported below.

- The median indoor air total PCB concentration based on 64 measurements across six schools was 318 ng/m^3 (interquartile range 59 - 732 ng/m^3). There was considerable variability between schools with median air levels at individual schools ranging from <50 to 807 ng/m^3. There was considerable variability within schools; for example, indoor air levels ranged from 236 to 2920 ng/m^3 in different rooms at one school.
- Surface wipe samples were collected from high-contact (desks, tables) and low-contact (walls, floors, window sills) surfaces at six schools. Median total PCB concentrations were 0.147 µg/100cm^2 (interquartile range <0.100 – 0.330 µg/100cm^2) for 72 high-contact surfaces and 0.201 µg/100cm^2 (interquartile range 0.128 – 0.419 µg/100cm^2) for 78 low-contact surfaces. Concentrations ranged from <0.100 to 2.84 µg/100cm^2 for high contact surfaces and <0.100 to 2.30 µg/100cm^2 for low-contact surfaces. Median high-contact wipe levels ranged from <0.100 to 0.380 µg/100cm^2 at individual schools. There was no consistent difference between median high-contact and low-contact concentrations across the six schools.
- There was a modest but significant correlation between indoor air total PCB concentrations and total PCB levels measured in high-contact surface wipes (Spearman r = 0.531, p-value <0.001) with a lower but still significant correlation between PCBs in air and low-contact surface wipes (Spearman r = 0.247, p-value = 0.050).
- Soil samples were collected at six schools at distances of 0.15, 0.91, and 2.44 m (0.5, 3, and 8 feet) from the building. Only 33% of the samples had PCB concentrations above the quantifiable limit. The median total PCB concentration across all 309 soil samples was less than the quantifiable limit. The 75th percentile concentration was 0.98 ppm and the maximum value was 211 ppm. There was considerable variability between schools; for example one school had only 10% of the PCB levels above the quantifiable limit while another school had 100%. The 75th percentiles of total PCB concentrations across six schools at 0.15, 0.91, and 2.44 m from the building were 2.13, 0.55, and <0.5 ppm respectively, supporting the idea that higher soil PCB levels are likely to be found in closer proximity to building sources including exterior window caulk and building joints with PCBs.

- Indoor dust samples were collected at only one school. The median total PCB concentration was 22 ppm (interquartile range 17 – 53 ppm) across samples collected in seven rooms.

PCB Congener Analysis Results

Individual PCB congeners were measured in all of the air samples and in a subset of surface wipe, indoor dust, soil, caulk, and other building material samples at one school. Examining patterns of individual congeners can provide insight regarding relationships between PCBs sources and environmental media, and can also provide information useful in exposure and risk assessment. Key results for PCB congener measurements at one school are reported below.

- Analysis of sample extracts for congeners resulted in total PCB concentrations that were approximately 20% lower than the analysis of the same sample extracts using an Aroclor method.
- Air samples collected both vapor and particle-bound PCBs, but these fractions were not analyzed separately. The pattern of congeners in indoor air was more heavily weighted towards more volatile congeners as compared to non-aged Aroclor 1254 and as compared to the PCB-containing caulk at the building. The pattern of congeners in air was not as heavily weighted towards more volatile congeners as would be predicted if they were from vapor emissions from caulk alone, suggesting that a portion of the PCBs in air may be associated with airborne particles.
- The congener pattern in the PCB-containing caulk was somewhat more heavily weighted towards less volatile congeners as compared to non-aged Aroclor 1254. It is possible that the more volatile congeners have been depleted from sources such as the exterior caulk over a period of 43 years.
- Many PCB-containing fluorescent light ballasts have been shown to contain Aroclor 1242. However, Aroclor 1254 was found to be the capacitor oil in one NYC ballast and was reportedly used in light ballast capacitors prior to 1952. The congener pattern in indoor air at the school with congener measurements did not resemble a pattern that would be expected if the predominant source of PCBs was Aroclor 1242 from light ballasts, but the capacitor oil was not analyzed to determine if it was, in fact, Aroclor 1242.
- Congener patterns in surface wipe, indoor dust, and other building materials were generally similar to Aroclor 1254 and to the PCB-containing caulk. Because only four dust samples were analyzed for congeners we did not assess air – dust congener correlations, but we anticipate that such a relationship is likely to exist.
- Soil samples had a congener pattern weighted towards less volatile congeners as compared to either Aroclor 1254 and even compared to the PCB-containing exterior caulk. The higher proportion of less volatile congeners as compared to the likely source is possibly a result of weathering and favored partitioning of less volatile congeners into soil rather than air.
- Congener-specific analysis provides information that may be useful for risk assessment. For example, between 5% (indoor air) and 14% (soil) of the total amount of PCBs were comprised of the sum of the 12 dioxin-like congeners. As additional information on PCB toxicity accumulates, having congener-specific information becomes more important.

Modeled Exposure and Dose Estimates

The PCB concentrations in the air, surface wipe, soil, and estimates for dust were used in the SHEDS model to generate distributions of estimated exposures to PCBs for children in four age groups (4-5, 6-10, 11-13, and 14-18 years old). The model incorporated environmental concentration distributions based on the range of air, surface wipe, and soil measurements across the six schools. Dust measurements were not made at most schools and dust concentrations were estimated based on air concentrations and estimated dust/air partition coefficients. The model incorporated distributions of activity levels appropriate for each age group in estimating exposures. The model then generated distributions of estimated absorbed doses of PCBs resulting from the estimated exposures in the school environment for the four age groups. The model provided information on the potential relative contribution to total absorbed dose from inhalation, dermal contact, and dust and soil ingestion. Various remedial approaches were examined by the NYC School Construction Authority at the five New York City schools, and pre-and post-remediation absorbed dose estimates were prepared using environmental measurements from these schools. Absorbed dose estimation included only those exposures to PCBs that would occur to children while at school and do not include background exposure through the diet or inhalation from indoor and outdoor air while away from the school and at home. Sensitivity testing was performed to examine the impact of uncertainty in the pulmonary PCB absorption fraction and for different PCB levels in dust and soil. Key results for estimated exposures and exposure pathways are reported for the 6 – 10 year-old age group below.

- Estimated absorbed doses for 6–10 year-olds at the pre-remediation time point were 0.022 µg/kg/day at the 50th percentile and 0.041 µg/kg/day at the 95th percentile of the distribution. Estimated absorbed doses for 4 – 5, 11 – 13, and 14 – 18 year old age groups were somewhat lower.
- After incorporating indoor air and surface wipe measurements obtained following different remedial activities in five schools, estimated absorbed doses for 6–10 year-olds were 0.007 µg/kg/day at the 50th percentile and 0.012 µg/kg/day at the 95th percentile. These levels were approximately 64 - 69% lower than those at the pre-remediation time point.

- Up to the 90th percentile of the estimated absorbed dose distribution, the predominant route of exposure for all age groups at all time points in schools with the measured environmental levels would be via inhalation. It was estimated that, on average, 74% of the absorbed dose would result from inhalation at the pre- and post-remediation time points (assuming a 70% pulmonary absorption fraction). However, above the 90th percentile of the estimated absorbed dose distribution, intake from dust was predicted to be greater than intake from inhalation.
- Sensitivity analysis showed that the estimated absorbed doses were sensitive to assumptions regarding the pulmonary absorption fraction. When the pulmonary absorption fraction was changed from the baseline of 70% to 30% in the model, the median estimated exposure for the 6 – 10 year old group decreased 49% to 0.011 µg/kg/day. When the pulmonary absorption fraction was increased to 100%, the median estimated exposure for the 6 – 10 year old group increased 35% to 0.028 µg/kg/day.
- As described in more detail in subsequent sections, there are uncertainties and limitations in modeled estimates of exposure distributions and contributions of relative exposure pathways. There are currently insufficient data to perform a full uncertainty analysis for the SHEDS PCB exposure estimation.
- Exposure estimation was not performed for adults, including teachers and staff, as part of this effort due to the lack of personal activity data at school suitable for SHEDS modeling, such as those available for children in the Consolidated Human Activity Database. It is anticipated that adults would spend more time in school buildings, which would tend to lead to higher doses, but less ingestion of dust and soil and higher relative body masses would lead to lower doses.

E.5 Conclusions

Sources of PCBs in School Buildings

- PCBs-containing caulk is a primary source of PCBs in and around school buildings. PCBs from exterior caulks around windows and mechanical ventilation system air intakes can lead to elevated concentrations in indoor spaces. PCBs in exterior caulk are likely to enter the soil near school buildings with the highest soil PCB levels found in closest proximity to the building. Caulk containing PCBs was found to be mostly intact and still somewhat flexible, but visual examination alone may not be adequate for determining if PCBs are present and testing is needed to determine if caulk or other sealants in a building contain PCBs.
- PCB-containing fluorescent light ballasts remain in use in some older school buildings and are a primary source of PCBs. Emissions from intact ballast capacitors can lead to the presence of PCBs in school environments. PCB residues from previously failed ballast capacitors may remain in fixtures even if the ballast is replaced. Leaking or bursting capacitors are likely to substantially elevate PCB levels in indoor environments when they fail. Because these ballasts have exceeded their expected operational lifetimes, failure and possible leakage will continue and is likely to increase for ballasts remaining in place.
- Several paint samples had total PCB concentrations above 100 ppm, up to 718 ppm. PCBs were used as plasticizers or flame retardants in some paints, so it is possible that these paints may have incorporated PCB when they were originally applied. Thus, it is possible that paints could be primary sources of PCBs in buildings based on our definition. Although they were not encountered in this study, window glazing and ceiling tile surface coatings containing PCBs have been reported in school buildings and would be considered primary sources.
- Other primary sources of PCBs may have been used in school buildings but are no longer present today. For example, carbonless copy paper and PCB-containing capacitors in early computer video display terminals may have been used in school buildings. The potential impact of previously removed sources on current PCB levels in building environments cannot be easily determined.
- Many of the building and furnishing materials in schools were found to contain PCB levels in the 4 to 100 ppm range. It appears likely that these materials have absorbed PCBs that have been emitted from primary sources. While primary sources remain in buildings these other materials are likely to be in quasi-dynamic equilibrium, with PCB emission and absorption roughly balancing. However, when primary sources are removed, these materials may serve as secondary sources for emissions of PCBs into the air in the building. Paints may be the most significant secondary sources given their large surface areas and relatively high PCB concentrations, but other materials may be important as well. Following mitigation of primary sources it may, in some cases, be necessary to consider mitigation actions for secondary sources.

School Environment PCB Levels and Exposures

- PCBs are present in indoor air, dust, and on surfaces in school buildings with PCB-containing source materials, and are likely to be present in the soil near buildings with exterior PCB-containing caulk. Building occupants would be exposed to PCBs through expected normal contacts with these environmental media.
- Estimated average total absorbed doses that could occur from the PCBs in school buildings with environmental levels that were found in these six schools were near the reference oral dose levels for Aroclor 1254 (0.020 µg/kg/day), and the reference dose adjusted for absorption (0.017 µg/kg/day) which is a more direct comparison with modeled dose estimates from SHEDS, which estimated absorbed dose. The reference dose level was exceeded by 75% or more of the estimated

distributions of absorbed doses for the two younger age groups. These estimates do not include the additional background exposures to PCBs that occur outside of the school environment, including exposures from dietary intake and inhalation of PCBs in outdoor and indoor air at non-school locations.

- PCB concentrations in indoor air were found to exceed EPA's 2009 public health guidance levels (ranging from 70 to 600 ng/m^3 depending on age) in many school locations. Inhalation was estimated to be responsible for over 70% of the exposure that could occur in buildings with the environmental levels of PCBs that were found in these six schools. Mitigation efforts that focus on reducing indoor air PCB concentrations are likely to have the greatest impact on reducing exposures, although cleaning to reduce dust will contribute to reducing exposures, particularly for children on the upper end of the dust exposure distribution. Based on information from the five New York City schools, it appears that mitigation efforts can be successful in substantially reducing indoor air concentrations and exposures to PCBs.

Complexity of PCBs in School Buildings
PCBs in school buildings present a complex problem from exposure assessment, risk assessment, and mitigation decision-making perspectives. Different aspects of this complexity are summarized below.

- There may be multiple primary sources of PCBs in school buildings. Numerous different kinds of caulks and sealants may be present throughout many building locations and they must be sampled to determine whether they contain PCBs. Fluorescent light ballasts containing PCBs may be present and light fixtures may be contaminated with residues from ballasts that have previously failed.
- PCBs are semi-volatile organic chemicals with a wide range of vapor pressures that will vaporize from primary sources and will be transported through indoor and into outdoor environments. They are absorbed by dust and soil which can result in additional transport and exposure.
- PCBs absorb into numerous materials in a building resulting in a reservoir that remains even after primary sources are removed. These secondary sources may result in continuing exposures following removal or remediation of primary sources.
- Over 120 different PCB congeners were measured in indoor air. These different congeners have a wide range of physical properties. In addition to adding exposure and toxicity complexity, the large numbers of congeners raises a challenge of selecting the most appropriate measurement methods for assessing PCBs in buildings. Aroclor measurements are the simplest and least expensive, but they may suffer in accuracy since the congener patterns in school environmental media do not exactly match those in the Aroclors. Homolog and congener-specific analyses allow for improved accuracy and better understanding and are recommended for use where possible.
- Ventilation of building spaces with outdoor air is an important factor in the indoor air PCB concentrations that will result from source emissions. However, ventilation in some older school buildings has been found to be poor, and ventilation in older buildings is often difficult to assess and to improve.

E.6 Limitations

There are important limitations and uncertainties in the information included in this report. Key limitations and uncertainties are summarized below.

- PCB measurement results were available from only six schools. These schools were selected because they had known or suspected PCB sources. It is not known if these results are representative of older schools nationwide, both in terms of the presence of PCB-containing materials and components and the environmental concentrations measured in and around the school buildings.
- Materials and components containing PCBs were likely to have been used in buildings other than schools. This report does not address whether and to what extent PCBs may be a potential problem in other types of buildings, and if so, whether environmental concentrations and exposures are likely to be similar.
- PCB emissions from materials and light ballasts were not directly measured at the six schools. Modeled emission estimates and the resulting predictions of indoor air and dust concentrations have considerable uncertainties. Emission parameters are likely to vary across different materials and for different temperature and ventilation conditions. Two different types of chambers were used to test caulk and light ballasts emissions, possibly impacting comparability. Emissions from light ballasts are likely to vary depending on the lighting fixture design and the condition of the ballast and capacitor. Emissions from light fixtures potentially contaminated from previously leaking or failed ballasts were not evaluated.
- Attributing the relative impact of PCB emissions from caulk and light ballasts on PCB levels in the schools was difficult because both sources were present in most buildings, and the Aroclor mixture used in all light ballasts was not identified. Several paint samples were found to have several hundred ppm of PCBs, and it is not clear whether these contained PCBs when installed and might be considered primary sources.
- There is uncertainty in modeled estimates of PCB exposures due to uncertainties in key exposure model parameters. In particular, there is limited information for pulmonary absorption fraction from the range of PCB congeners in vapor and particle-bound forms. There is also uncertainty in total PCB exposures because of the lack of robust data for background exposures from dietary and other non-school sources.

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Acronyms and Abbreviations

AC	Air conditioning
AER	Air exchange rate
ANSI	American National Standard Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials (now ASTM International)
BMR	Basal metabolic rate
BVA	Basal alveolar ventilation
CAFO	Consent agreement and final order
CHAD	Comprehensive Human Activity Database
CQCS	Comprehensive quantitative congener specific analysis
DCBP	Decachlorobiphenyl
GC/ECD	Gas chromatography/electron capture detector
GM	Geometric mean
EPA	United States Environmental Protection Agency
FDA	Food and Drug Administration
HID	High intensity discharge lamp ballast
H/V	Heating and ventilation
HVAC	Heating, ventilation, and air conditioning
ND	Not detected
NELAP	National Environmental Laboratory Accreditation Program
NERL	National Exposure Research Laboratory
NIOSH	National Institute for Occupational Safety and Health
NRMRL	National Risk Management Research Laboratory
NYC SCA	New York City School Construction Authority
ORD	Office of Research and Development
PCB	Polychlorinated biphenyl
PPM	Parts per million (equivalent to mg/kg)
PBPK	Physiologically-based pharmacokinetic
PK	Pharmacokinetic
PUF	Polyurethane foam
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
QL	Quantitation limit
QSAR	Quantitative structure-activity relationship
RfD	Reference dose
RPD	Relative percent difference
RSD	Relative standard deviation
SD	Standard deviation
SHEDS	Stochastic Human Exposure and Dose Simulation model
SVOC	Semi-volatile organic compound
TCDD	2,3,7,8-Tetrachlorodibenzodioxin
TCMX	Tetrachloro-m-xylene
TEQ	Toxic equivalence (as compared to TCDD)
TSCA	Toxic Substances Control Act

1.0

Introduction

1.1 Background

1.1.1 About PCBs

Polychlorinated biphenyls (PCBs) are synthetic chemicals that were manufactured in the United States between about 1930 and 1977 for use in various industrial and commercial applications because of their non-flammability, chemical stability, plasticizer, and electrical insulation properties (ATSDR, 2000). PCBs were used in numerous products and processes, including electrical, heat transfer, and hydraulic equipment; as plasticizers in various products; in paints and finishes; in pigments, dyes, and carbonless copy paper; and in other industrial and commercial applications (Erickson and Kaley, 2011; U.S. EPA, 1976). There are no known natural sources of PCBs. PCBs that were produced commercially were mixtures of individual chlorinated biphenyl compounds known as congeners (see Figure 1-1). There are a total of 209 different possible PCB congeners (Appendix A), although many congeners did not appear in commercial mixtures.

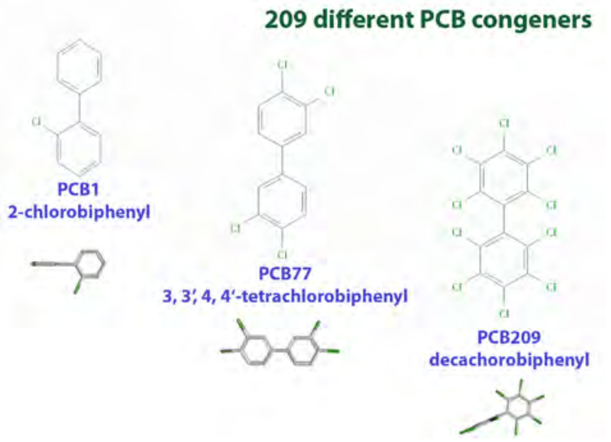


Figure 1-1. Three of the 209 different PCB congeners showing chlorine substitution patterns and schematic examples of non-planar (congeners 1 and 209) and co-planar (congener 77) orientations. Source: PubChem Compound - http://www.ncbi.nlm.nih.gov/pccompound.

Most of the PCB mixtures manufactured for commercial use in the United States are known by the trade name Aroclor. Each commercially produced Aroclor contained mixtures of some of the 209 congeners, with chlorine contents of the different Aroclors ranging from 21% to 68% (Table 1-1). Between 1957 and 1971, 12 types of Aroclors were produced (ATSDR, 2000). During this time PCBs were used in completely closed systems (such as transformers and capacitors), nominally closed systems (such as hydraulic systems and vacuum pumps), and open systems (such as plasticizers and paints) (Erickson and Kaley, 2011). In 1970, the primary U.S. manufacturer decided to discontinue use of Aroclors in open products and uses that could lead to direct transfer into the environment (Erickson, 1997). Information about commercial PCB mixtures, PCB production, and PCB nomenclature is provided by Erickson and Kaley (2011).

Table 1-1. Several commonly used Aroclor mixtures, their chlorine weight percent values, and their highest five congeners by weight percent

Common Aroclors	Chlorine Weight %	Number of Congeners Measured[a]	Congeners Five Highest by Weight %
Aroclor 1221	21%	63	1, 3, 8, 4, 15
Aroclor 1232	32%	93	1, 8, 3, 4, 18
Aroclor 1016	41%	71	18, 31, 28, 8, 33
Aroclor 1242	42%	95[b]	18, 31, 28, 8, 33
Aroclor 1248	48%	95+	70, 66, 52, 44, 31
Aroclor 1254	54%	95+[b]	118, 110, 105, 138, 70
Aroclor 1260	60%	93	180, 153, 149, 138, 187
Aroclor 1262	62%	95	180, 187, 153, 149, 174

[a] Based on Frame et al., 1996.

[b] See Appendix A for more information about Aroclor 1242 and Aroclor 1254 congeners.

1.1.2 PCB Exposure and Effects

Manufacture of PCBs was banned in the United States with final rules published by the U.S. EPA in May, 1979. Their use was phased out, except for certain limited uses, because of evidence they are persistent in the environment and can cause harmful health effects. PCBs can accumulate in people over time, and PCB exposure over a long period of time may be harmful to health. Short term exposure to large amounts of PCBs can lead to skin conditions such as acne and rashes and may be associated with decreased liver function, neurological effects, and gastrointestinal effects (ATSDR 2000). These types of acute toxic effects due to high levels of exposure are generally rare in the general population. Chronic exposure to lower levels of PCBs may also cause health effects (ATSDR 2000; ATSDR 2011). In animal studies, PCBs have been shown to cause effects on the immune, reproductive, nervous, hepatic, and endocrine systems. PCBs have also been shown to cause cancer in animals. Some studies in humans provide supportive evidence for some of these health effects. Studies also show that PCBs in pregnant women can have an impact on their children's birth weight, short-term memory, and learning. Because of potential neurotoxic and endocrine effects, there is concern regarding children's exposures to PCBs (ATSDR 2000; ATSDR 2011).

PCBs are highly persistent in the environment. As such, they are still present in soils and sediments in some locations today and may be found at low levels in ambient air and water. PCBs can be released into the environment from hazardous waste sites, illegal or improper disposal of industrial wastes and consumer products, leaks from old electrical transformers and capacitors containing PCBs, and burning of some wastes in incinerators. PCBs undergo bioaccumulation and may eventually enter foods that people consume. Foods with the highest PCB levels are typically fish, meat, and dairy products. Dietary consumption of contaminated foods is believed to be an important route of background exposure to PCBs for people in the United States (ATSDR, 2000).

1.1.3 PCB Uses in Buildings

Additional exposure to PCBs may occur for people who spend time in buildings where PCB-containing materials and equipment are present. A number of products manufactured before the late-1970s contained PCBs (Erickson and Kaley, 2011; U.S. EPA, 1976). Products and equipment that may contain PCBs include:

- dielectric fluid in transformers and capacitors,
- other electrical equipment, including voltage regulators, switches, circuit breakers, reclosers, bushings, and electromagnets,
- oil used in motors and hydraulic systems,
- microscope oil,
- old electrical devices or appliances containing capacitors with PCBs,
- fluorescent light ballast capacitors,
- cable insulation,
- thermal insulation material, including fiberglass, felt, foam, and cork,
- adhesives and tapes,
- oil-based paints,
- caulk, window glazing, and other sealants,
- plastics,
- carbonless copy paper,
- ceiling tile coatings, and
- floor finish.

Some of these materials can still be found in buildings, particularly those constructed or renovated between about 1950 and 1978.

Production of PCBs used as plasticizers in the United States ranged from approximately 1.4 million kg in 1957 to 8.6 million kg in 1969, decreasing to zero by 1971 (NIOSH, 1975). Caulk and other sealant materials that incorporated PCBs as plasticizers have been examined as a potential source of exposure to building occupants. Kohler et al. (2005) reported on concentrations of PCBs in more than 1300 samples of joint sealants collected from buildings in Switzerland built between 1950 and 1980. Nearly half (48%) contained PCBs, and levels exceeding 50 ppm were found in 42% of the samples. Concentrations exceeding 10,000 ppm were found in 21% of the samples, whereas concentrations exceeding 100,000 ppm were found in 9.6% of the samples. PCB content of 100,000 ppm in caulk means that the caulk contains 10% PCBs by weight. Chlorine content was examined in a subset of Swiss samples, and more than 90% had results consistent with mixtures of Aroclors 1248, 1254, 1260, and 1262.

PCB mixtures were used as the dielectric fluid in fluorescent light ballast capacitors used in standard fluorescent light fixtures and in high-intensity discharge (HID) ballasts manufactured in North America from the 1960s through the late 1970s (Environment Canada, 1991). Staiff et al. (1974) reported uses of PCBs in ballasts before 1952. The earliest date of use is not clear, but PCB use in ballast capacitors continued to 1978, a year of transition in which alternative capacitor dielectric fluids began to be used. By 1979, no ballasts capacitors were manufactured with PCBs. The most commonly used Aroclor mixtures were Aroclor 1242 and Aroclor 1016 (which has a similar chlorine content and congener mixture as Aroclor 1242) (Erickson and Kaley, 2011) but the use of Aroclors 1221 and 1254 in capacitors has also been reported (U.S. EPA, 1976). According to a citation in Staiff et al. (1974) Aroclor 1254 was primarily used in ballasts prior to 1952 with Aroclor 1242 thereafter. Capacitors used in ballasts for fluorescent light fixtures containing two 4-foot lamps contained approximately 10 – 24 g of PCBs, while HID ballast capacitors could contain between 90 and 390 g (Environment Canada, 1991; General Electric, 2004).

Table 1-2. PCB vapor pressure ranges: examples from three reports

Homolog Series	Delle Site, 1997[a] Pa at 25º C (Number of Congeners)	Falconer and Bidleman, 1994[b] Pa at 20º C or 25º C	Holmes et al., 1993[c] Pa at 25º C (Number of Congeners)
Monochlorobiphenyls	7.9E-2 to 2.1E-1 (3)	Not reported	3.2E-1 to 9.3E-1 (3)
Dichlorobiphenyls	7.4E-4 to 3.2E-1 (5)	1.0E-1 to 2.5E-1	5.1E-2 to 4.2E-1 (12)
Trichlorobiphenyls	4.8E-3 to 7.6E-2 (5)	6.3E-3 to 4.0E-2	8.4E-3 to 1.7E-1 (24)
Tetrachlorobiphenyls	1.8 E-5 to 2.2E-2 (5)	3.2E-3 to 1.6E-2	1.4E-3 to 6.6E-2 (42)
Pentachlorobiphenyls	4.0E-4 to 2.2E-3 (1)	5.0E-4 to 2.5E-3	2.7E-4 to 1.7E-2 (46)
Hexachlorobiphenyls	2.9E-6 to 1.6E-3 (3)	2.5E-4 to 7.9E-4	5.4E-5 to 6.4E-3 (35)
Heptachlorobiphenyls	Not reported	5.0E-5 to 2.5E-4	1.4E-4 to 1.6E-3 (24)
Octachlorobiphenyls	2.4E-6 to 3.0E-5 (1)	Not reported	3.8E-5 to 6.2E-4 (12)
Nonachlorobiphenyls	Not reported	Not reported	1.0E-4 to 1.3E-4 (3)
Decachlorobiphenyl	2.9E-9 to 1.4E-5 (1)	Not reported	2.8E-5 (1)

[a] Delle Site, 1997: Compiled vapor pressures for selected congeners from multiple references using direct, indirect, and prediction methods.

[b] Falconer and Bidleman, 1994: Liquid saturation vapor pressures; range across average vapor pressures of different levels of othro-substituted chlorines within homolog (estimated from Figure 2).

[c] Holmes et al., 1993: Originally from Buckhard et al., 1985, *ES&T,* 22:503-509. Based on liquid or sub-cooled liquid values rather than from solid phase.

Most fluorescent light ballasts are designed for about 50,000 hours of operation under standard conditions (Natural Resources Canada, 2009) although an earlier report suggested approximate lifetimes ranging from 10 to 15 years of normal service at operating temperatures of 85 - 90ºC (U.S. EPA, 1976). Ballast lifetime calculations from one manufacturer indicate that at an operating temperature of 65°C ballasts can be expected to operate for 50,000 hours with only 10% failure, but that the failure rate is likely to increase substantially after this period due to drying up of liquid electrolytic fluid in the capacitor and degradation of soldered contacts (Philips Lighting, undated). Staiff et al. (1974) gave a normal operating ballast surface temperature of 67 - 72°C and cited a 1966 lighting handbook stating that ballast life was normally estimated at around 12 years. If lights are operated in a building for 10 hours per day, 250 days per year, then 50,000 hours would cover approximately 20 years of use. PCB-containing light ballasts have been present in school buildings in many cases for over 40 years.

As previously noted, PCBs were used in many types of materials and components. It is not clear to what extent other types of PCB-containing materials remain in buildings today. Ceiling tiles with surface coatings containing PCBs have been reported (personal communication, U.S. EPA Region 1). It is possible that PCB-containing microscope oil remains in some buildings, and other electrical or hydraulic system components with PCBs could be present. PCBs were sometimes used as a plasticizer in paints and other types of coatings. While these coatings were used in marine, military, and grain silo applications it not clear whether PCB-containing paints and coatings were used extensively in buildings. There is one report of PCBs in floor finish in a residential application (Rudel et al., 2008).

1.1.4 PCBs in Building Environments

PCBs from caulk and other materials containing PCBs may move into the air and dust indoors and into the soil around older buildings, leading to the potential for exposures to building occupants (Currado and Harrad, 1998; Kohler et al., 2002, 2005; Priha et al., 2005; Hazrati and Harrad, 2006; Heinzow et al., 2007; Harrad et al., 2010; Herrick et al., 2004, 2007; Zhang et al., 2011; MacIntosh et al., 2012). The different vapor pressures of the 209 PCB congeners and the effects of weathering over 40 or more years may affect which congeners are present and available for exposure from different environmental media (Heinzow et al., 2007; Harrad et al., 2009). The extent of exposure to PCBs in indoor environments may depend on their vaporization into indoor air in combination with degradation of materials resulting in contaminated particles available for contact. Many researchers have measured or estimated PCB congeners vapor pressures, and results vary considerably depending on the method (Erickson, 1997). In general, congener vapor pressures decrease with increasing levels of chlorination (Table 1-2, Appendix A). Within chlorine-number homolog groups, vapor pressures increase with increasing levels of chlorination in ortho positions (Falconer and Bidleman, 1994). Multimedia fugacity modeling has been applied to PCBs in residential and office environments to examine emissions and fate in indoor environments (Zhang et al., 2011).

Based on vapor pressure characteristics, it might be anticipated that inhalation exposures to PCBs will be weighted to congeners with higher vapor pressures and lower chlorine numbers. However, PCBs in indoor environments may also be bound to particles that can become suspended in the indoor air (Zhang et al., 2011). PCB congeners measured in indoor air may not match congener patterns found in the Aroclor mixtures used in materials in a building because of the differences in congener vapor pressures and because congeners are absorbed onto particles differentially based on their vapor pressures and solid/air partition coefficients.

Harrad et al. (2009) noted that the combination of residential indoor air inhalation and dust ingestion could exceed dietary intake of PCBs in some scenarios. Exposures to PCBs in air and dust from contaminated nonresidential buildings could substantially increase exposures above those seen in residential environments. For example, levels of PCBs in the indoor air of some office buildings with PCB-contaminated sealants (up to 6000 ng/m^3 [Kohler et al., 2005]) exceed the levels reported in residential indoor air (maximum of 14 ng/m^3 total PCBs [Harrad et al., 2009] and 35 ng/m^3 for congeners 52, 105, and 153 in a contaminated home [Rudel et al., 2008]).

Of particular concern is the potential for school children's exposures to PCBs in older school buildings. Schools constructed or renovated between the 1950s and 1970s may contain both lighting fixtures with PCB capacitors and caulk or other sealants that incorporated PCBs as a plasticizer. Caulk containing PCBs may have been used around exterior windows and doors, exterior building joints, and in interior locations. PCBs may vaporize from the caulk and become airborne. PCBs may be absorbed onto (or into) other building surfaces, materials, or dust (Herrick et al., 2004). Caulk may degrade or suffer abrasion wear that can create PCB-containing dust that is then available for transport in indoor areas. PCBs from exterior caulk may be transported into soils near the building (Herrick et al., 2007).

1.1.5 PCBs in School Buildings

There have been few systematic efforts to characterize PCB sources and environmental levels at schools across the United States. Measurements of PCBs in caulk have been made for several college buildings and a number of primary and secondary schools. Environmental samples, including air, dust, wipe, and soil samples, also have been collected at a number of school buildings. Measurement results for PCBs in schools in the United States have not been widely published in the scientific literature, although Herrick et al. (2007) reported on PCBs in soil collected near buildings with PCB-contaminated caulk or joint material and MacIntosh et al. (2012) published on environmental levels and remediation results for a primary school building. Measurement results have been reported in presentation and report formats (e.g., Coghlan et al., 2002; Sullivan, 2008; TRC, 2006, 2008, 2009). From available extant data examined through 2009 (Appendix D), total PCBs in caulk in U.S. college and school buildings ranged from not detected to over 200,000 ppm. Concentrations in school indoor air ranged up to approximately 1000 ng/m^3. Total PCB levels in dust ranged up to approximately 80 ppm. Wipe samples ranged up to approximately 1 µg/100cm^2 total PCBs. Soil concentrations in samples collected next to buildings ranged up to approximately 80 ppm of total PCBs.

Although caulk is believed to be a primary source of PCBs in some older schools, there is still considerable uncertainty regarding the extent to which PCBs in other materials used in schools might contribute to exposures (Coghlan et al., 2002). Other primary sources (materials manufactured with PCBs, or materials to which PCBs were added during construction) or secondary sources (sources that have absorbed PCBs emitted from primary sources) may be present in some schools. For example, window glazing has been found in several locations to contain levels of PCBs greater than 50 ppm. Fluorescent light ballasts with PCB-containing capacitors remain in some older buildings. Secondary sources might include surfaces, materials, and dust that have been contaminated through transport and absorption of PCBs from caulk or other primary sources. An in-depth investigation in a high school found PCBs in numerous materials, including but not limited to laminate adhesive, mastics, paint, gasket, carpet, foam padding, and bulk dust (TRC, 2008; Sullivan, 2008; TRC, 2009). Some of these materials had concentrations exceeding 10 ppm, ranging up to more than 250 ppm. The potential for secondary PCB sources to contribute to exposures to children and other building occupants is not well understood. To make sound decisions regarding mitigation of exposures to PCBs in schools, it is important to understand the range of potential sources of PCBs in schools; their contributions to PCBs in air, dust, soil and on surfaces; and the magnitude of potential exposures to children and staff in school environments.

1.2 Need for Research

In September 2009 the U.S. EPA announced new guidance for school administrators and building managers for managing PCBs in caulk and to help minimize possible exposure. However, there was limited information on PCBs in school buildings in the United States. Neither the sources, including PCB-contaminated caulk, light ballasts, and secondary sources; nor the potential magnitude and routes of exposure have been systematically characterized in schools. There remains considerable uncertainty regarding the extent to which children and staff members may exposed to PCBs in school environments. Research was needed to help fill these information gaps to improve our understanding of exposure to PCBs in schools. Therefore, the EPA also announced in 2009 that research would be performed by the Office of Research and Development's (ORD) National Exposure Research Laboratory (NERL) and the National Risk Management Research Laboratory (NRMRL) to further study this issue. The research was intended to help fill information gaps and improve our understanding of PCBs in school buildings and approaches for mitigating exposures. Information on sources of PCBs and levels in school environments is needed to improve risk management decision-making. NERL developed a research plan to better understand and characterize PCB sources, emissions, environmental concentrations, and exposures in school environments (U.S. EPA NERL, 2010). A research plan was also developed by NRMRL to perform laboratory studies of PCB sources and transport and to evaluate selected mitigation approaches (U.S. EPA NRMRL, 2010).

1.3 Research Objectives

In order to better understand the significance of PCB-containing caulk and other building materials and components as a source of PCB exposures to children, teachers, and staff in school buildings, NERL planned research to utilize a limited set of real-world measurements to:

1) characterize PCB-contaminated caulk and other potential primary and secondary sources of PCBs in school buildings,
2) characterize levels of PCBs in school air, dust, soil, and on surfaces and to investigate relationships between potential PCB sources and environmental levels,
3) apply an exposure model for estimating children's exposure to PCBs in schools with PCB sources,
4) evaluate which routes of exposure (e.g., inhalation, contact with surfaces or dust) are likely to be most important, and,
5) provide information to assist in developing risk management practices for reducing exposure to PCBs in schools.

1.4 About this Report

A limited set of measurement data and information collected using a systematic approach at six schools was used to characterize primary sources of PCBs, to evaluate whether secondary sources were present and their relative importance, to describe PCB concentrations in school environmental media, and to prepare modeled estimates of exposure and characterize the relative importance of different routes of exposure. Section 2 describes the methods for sample collection, sample analysis, emissions modeling, and exposure modeling. Section 3 provides information regarding quality control and quality assurance. Section 4 describes the results for source characterization, environmental media PCB concentrations, and exposure modeling for several child age-groups. Conclusions are presented in Section 5.

2.0
Methods

2.1 Generation of School Measurements

NERL's objective was to recruit up to nine schools to participate in the research by allowing NERL and contractor scientists to collect air, surface wipe, dust, soil, caulk, and other building material samples in multiple indoor and outdoor locations (U.S. EPA NERL, 2010). With the assistance of EPA's Office of Science Policy and several EPA Regional Offices, contacts were made with numerous state and local educational agencies and school districts. Although there was often interest in understanding the problem of PCBs in school buildings at state and local levels, most organizations decided not to participate in the research study due to a variety of potential concerns and issues. NERL reached preliminary agreement with two school districts to participate in the study. But, due to factors outside of their control, the NERL researchers ultimately were not able to enroll schools from these districts into the study. NERL was able to implement the research plan and collect samples at one school building scheduled for demolition.

At the same time that NERL was planning research on PCBs in schools, the New York City School Construction Authority (NYC SCA) reached an agreement regarding the assessment and remediation of caulk containing PCBs in public school buildings with the United States Environmental Protection Agency Region 2, under a Consent Agreement and Final Order (CAFO, Docket Number TSCA-02-2010-9201). The goal of the CAFO was to develop a city-wide approach to assessing and managing caulk containing PCBs in schools built between 1950 and 1978. As a result of the agreement, New York City initiated a comprehensive pilot study during the summer of 2010, when students were absent, to evaluate the possible presence of PCB-containing caulk and preferred remedial actions in three schools, with evaluations for two additional schools conducted in 2011.

A remedial investigation plan was developed by the SCA and TRC Engineers Inc. describing the selection of the pilot schools, the approach for measuring PCBs in and around school buildings, and the caulk remediation approaches to be investigated (NYC SCA, 2010). The sampling and analysis approach was similar in many respects to the NERL research plan and sampling strategy but added remedial investigation steps. Pre-remediation samples of caulk, indoor and outdoor air, indoor surface wipes, and soils were collected in and around three NYC elementary schools during 2010. Different remedial approaches were then instituted at each school including caulk patch and repair, caulk removal and replacement, and caulk encapsulation. Post-remediation indoor and outdoor air and indoor surface wipe samples were collected to evaluate the remedial effect on PCB levels in the school environment. Analysis of both the pre- and post-remediation air samples showed levels of PCBs at some indoor locations were greater than Public Health Levels recommended by the U.S. EPA (http://www.epa.gov/pcbsincaulk/maxconcentrations.pdf). Several actions were subsequently taken at the three schools to investigate and reduce the elevated PCB concentrations in air. Examination of materials that could potentially serve as additional sources of PCBs was conducted. As part of this effort it was determined that PCB-containing fluorescent light ballasts were present throughout the schools. An additional set of air samples was collected at each school following removal of the PCB-containing light fixtures and a period of ventilation with outdoor air. The NYC SCA remedial investigation continued with two additional pilot schools in 2011, and additional work was also performed in the three previous schools. Investigation reports and measurement results are available at the NYC PCB Program web site maintained by the NYC SCA (http://www.nycsca.org/Community/Programs/EPA-NYC-PCB/Pages/default.aspx).

U.S. EPA Region 2 requested the assistance of EPA's NERL in characterizing potential exposures associated with environmental levels of PCBs measured at the New York City Schools. Region 2 specifically requested application of NERL's Stochastic Human Exposure and Dose Simulation (SHEDS) model for estimating multi-pathway exposure distributions. Region 2 also requested assistance in understanding and characterization of primary and potential secondary sources of PCBs. Because the NYC SCA data were collected in a systematic fashion using strategies and methods similar to the NERL research plan, it was determined that the measurement results could be used to address the Region 2 interests and to meet many of the NERL objectives for source and environmental characterization and exposure modeling. Measurement results from the five NYC schools and one school sampled by NERL are used in this report.

2.2 Sample Collection

The sample collection strategy and methods used by the NYC SCA in the pilot remedial investigation efforts are described elsewhere (NYC SCA, 2010). Both the approach and the sampling methods used by the SCA were generally similar to those used by NERL.

Methods for sample collection and analysis used by NERL are summarized in Table 2-1; these methods are described in more detail in the following sections. The samples collected by NERL at one school are summarized in Table 2-2. NERL's contractor, Alion Inc., was responsible for preparing for and conducting field sampling operations. They were joined at the field site during sample collection activities by NERL scientists.

2.2.1 Indoor and Outdoor Air Sample Collection

U.S. EPA Method TO10A was used to collect total PCBs in air, using a low-volume sampling approach to minimize the size and noise of the pumps to be used in school buildings. Sample filters were pre-cleaned open-cell polyurethane foam (PUF) in 30-mm × 70-mm tubes. Total suspended particle quartz filters were used as part of the sample filter assembly; however, the filter and the PUF were extracted and analyzed together as a single sample. Separate particle- and gas-phase air concentrations were not obtained. Collection of inline backup filters to assess potential break-through were not used based on results from the NYC SCA sampling, which showed no breakthrough in almost all cases.

Sample collection tubes were situated with the inlet in a downward facing position at a height of 1 m from ground or floor level. A sampling stand was used to secure the sample filter. An active air-flow pump, capable of unattended 24-hr operation was used to provide a flow of 3.5 to 5.0 liters per minute (lpm) through the PUF. Flow measurements were performed and recorded at the initiation of sampling and then again at the completion of the nominal 24-hr sampling period. Start and stop times were recorded, so that a cumulative amount of time at an average flow rate could be calculated to yield the volume of air sampled. Total air volumes sampled through the filters ranged from 5.3 to 6.5 m^3. Indoor and outdoor air temperatures were measured periodically through the sample collection period.

2.2.2 Surface Wipe Sample Collection

Two types of indoor surface wipe samples were collected. The first type was individual samples collected from two different surfaces that might be contacted routinely by a student. These “high-contact” surface sampling locations included the tops of desks or tables. The second type was individual samples collected from building surfaces. These “low-contact” surface sampling locations included floors, walls, and window sills (where present). Several wipe samples were also collected from light fixtures including from the outside cover, diffuser, exterior of the ballast cover, and interior of the ballast cover.

Wipe samples were collected based on the wipe sample collection procedure described in ASTM Method D6661-01 [2006], “Standard Practice for Field Collection of Organic Compounds from Surfaces Using Wipe Sampling.” PCB-free gauze wipes were wetted with 5 mL of hexane to collect surface wipe samples. Each wipe sample was collected in a 100-cm^2 area as defined by a template secured to the surface. Transfer of PCBs from the surface occurred through physical wiping of the defined surface area while applying moderate pressure in a serpentine pattern. Wipes were handled using appropriate chemical-resistant gloves, followed by storage in a clean amber glass jar with a Teflon-lined cap.

2.2.3 Dust Sample Collection

There is the potential for loose (accumulated and visible) dust to be present on surfaces in school rooms. A sample size of 2 g for each sample was preferred, whereas 1 g was considered to be the minimum sample size. To obtain

Table 2-1. Summary of sample collection and analysis methods

Sample Type	Sample Collection Method	Sample Extraction Method	Aroclor Sample Analysis Method	Congener Sample Analysis Method
Air	EPA Method TO-10A (Sampling duration approx. 24-hr)	EPA Method 3540C	EPA Method10A/EPA 8082	NEA CQCS Method (Modified EPA Method 8082)
Surface wipe	ASTM D6661-01	EPA Method 3540C	EPA SW-846 8082	NEA CQCS Method (Modified EPA Method 8082)
Dust (indoor)	Research Operating Protocol[a]: Procedure for Collecting Loose Dust for PCB Analysis	EPA Method 3540C	EPA SW-846 8082	NEA CQCS Method (Modified EPA Method 8082)
Soil (outdoor)	Research Operating Protocol: Procedure for Collecting Soils for PCB Analysis	EPA Method 3540C	EPA SW-846 8082	NEA CQCS Method (Modified EPA Method 8082)

Table 2-1. Summary of sample collection and analysis methods (continued)

Sample Type	Sample Collection Method	Sample Extraction Method	Aroclor Sample Analysis Method	Congener Sample Analysis Method
Caulk and window glaze	Research Operating Protocol: Procedure for Screening Collection of Caulk and Window Glazing From Buildings for PCB Analysis	EPA Method 3540C	EPA SW-846 8082	NEA CQCS Method (Modified EPA Method 8082)
Bulk materials[b]	Research Operating Protocol: Procedure for Collecting Select Materials from Buildings, Fixtures, and Associated Items for PCB Analysis	EPA Method 3540C	EPA SW-846 8082	NEA CQCS Method (Modified EPA Method 8082)

[a] Research operating protocols were developed for the U.S. EPA/ORD research study on PCBs in schools.

[b] Bulk materials include paints, floor tiles, ceiling tiles, foam, cove molding, etc.

Table 2-2. Sample collection information (numbers of samples by type and location)[a]

Collection Location	Air	Surface Wipe	Interior Dust	Exterior Soil	Interior Caulk and Glazing	Exterior Caulk	Bulk Materials[c]
Indoor Locations							
Classroom 1	1	6	1		3[b]		
Lab Classroom 2	1	7[b]	1		3		
Classroom 3	1	7	2[b]		6[b]		20
Classroom 4	1	6[b]	2[b]		4[b]		12
Shop Classroom 5	2[b]	6	1		2		
Cafeteria	2[b]	6	1		5[b]		
Gymnasium	2[b]	5[b]	1		2		15
Outdoor Locations							
Rear side of building	1					5[b]	
Front side of building				8[b]		7[b]	
50' from front side				1			
Total Number of Samples	11	42	9	9	25	12	47

[a] Quality control field blank and field control samples are not included in this table.

[b] Includes duplicate samples.

[c] Bulk materials include samples of building materials and furnishings.

suitable sample sizes in most rooms, multiple surfaces had to be sampled including surfaces not ordinarily contacted, including cabinet tops and the tops of door molding. Where sufficient quantities of dust were available, the dust was collected using a cartridge filter assembly (pre-cleaned dust collection cassettes, Forensic Source part # 4-3109) and specialized vacuum system (3M Trace Evidence Vacuum System, Forensic Source part # 4-3005). Following collection, the dust was transferred from the filter into a clean amber vial with Teflon-lined cap. Dust samples were collected following the completion of air sample collection.

2.2.4 Outdoor Soil Sample Collection

Soil samples were collected at two locations adjacent to the building, below one joint containing caulk and below a window assembly with exterior caulk. At each of the two locations, soil samples were collected at three distances from the building: 0.15, 0.91, and 2.44 m (0.5 ft, 3 ft, and 8 ft). Each soil sample was collected to a 5-cm (2-inch) depth after carefully removing any vegetation. A total sample size of approximately 100 g was collected at each sampling location. A pre-cleaned stainless scoop was used to collect the soil. The soil was placed into a clean amber glass container with a Teflon-lined cap.

Another soil sample was collected from an area further from the school at a location that could be contacted by students. In this case, the sample came from an island in the parking area in front of the school. This sample was not intended to fully characterize a school yard but is intended to assess whether there is a potential for soil exposures in areas that would need to be considered in exposure modeling efforts. An area 3.05 m × 3.05 m (10 ft × 10 ft) was identified. Soil samples were collected from the 0 to 5-cm depth at five locations (corners and center) within the designated area. Soil samples were combined into a single container and mixed. A total sample size of approximately 100 g was collected.

2.2.5 Caulk Sample Collection

Caulk samples (including caulk, window glaze, and joint sealant) were collected from interior locations in which environmental samples were collected and from selected exterior locations including from around window frames, building joints, and an entranceway joint. Sample collection generally followed the standard operating procedure, "Sampling Porous Surfaces for Polychlorinated Biphenyls (PCBs)" (U.S. EPA, 2008). However, only one sample of each selected type of caulk was collected, rather than three to form a composite. Duplicate samples were collected at designated locations to examine variability. Also, a sample size of 2 to 4 g was collected, rather than 10 g. Caulk samples were collected by physically removing sections of caulk using clean knives, scalpels, and tweezers (or other clean implements, as needed). Pieces of caulk were removed from the site of interest and placed in a single pre-cleaned amber glass jar with a Teflon-lined cap. Caulk samples were collected as they existed in the selected rooms; no emphasis was made on collecting samples of deteriorating caulk because intact caulk potentially may contain higher levels of PCBs. Attempts were made to collect a sample of each type of caulk, window glazing, and joint sealant in each room. Additional descriptive information was recorded including its location, use, current condition, and the presence of any paints or coatings. The length, width, and depth of the sampled caulk was also measured and recorded. Caulk samples were collected after air sampling was completed.

2.2.6 Other Material Sample Collection

Selected materials other than caulk were collected from three rooms in the school building (two classrooms and the gymnasium), when they were available and accessible, as potential primary or secondary sources of PCBs in school buildings. Where possible, 10 g of material was the preferred material sample size, with a minimum sample size of 2 g. Samples were collected using pre-cleaned instruments such as a scalpel, razor, spatula, utility knife, paint scraper, putty knife, or other hand tool, as needed. Wall concrete block was collected from three distances from an interior joint caulk, with the material collected up to 0.5-inch depth using an impact drill. Materials collected for PCB analysis were stored in clean amber glass containers with Teflon-lined lids. Material samples were collected following the completion of air sample collection.

2.2.7 Light Ballast Survey

Fluorescent light ballasts were surveyed in the rooms in which samples were collected to determine if PCB-containing ballasts might be present. A visual survey of a subset of fixtures was conducted by removing the light fixture lamps, removing the ballast cover, and examining the ballast label. Information from the ballast label was recorded. Many of the ballast labels stated "No PCBs" and were considered to be PCB-free. A smaller number of ballast labels did not state "No PCBs" and these ballasts were considered likely to contain PCBs. Ballasts were not surveyed in the gymnasium.

2.2.8 Sample Transport and Storage

All samples were transported and stored for analysis under conditions appropriate for minimizing contamination by PCBs or losses of PCBs. At the field collection site all samples were stored in coolers with ice packs sufficient to maintain a temperature of approximately 4°C. Samples were transported to the laboratory with ice packs sufficient to maintain a temperature of approximately 4° C. Storage of samples and sample extracts at the analytical laboratory was at general freezer temperatures of approximately –20°C. Samples with potentially high levels of PCBs (such as caulks or other primary PCB source materials) were stored and transported in separate coolers to minimize any potential cross-contamination of samples with low levels of PCBs (such as air and wipe samples).

2.3 Sample Extraction and Analysis

All samples were analyzed by NEA, a Division of Pace Analytical Services, Inc. NEA is a National Environmental Laboratory Accreditation Program (NELAP) accredited laboratory and maintains certifications for New York (EPA: NY00906, ELAP: 11078), New Jersey (NY026), Connecticut (PH-0337), Massachusetts (M-NY906), and North Carolina (668).

2.3.1 Sample Extraction

All samples were extracted following EPA Method 3540C. Method 3540C is a Soxhlet procedure for extracting non-volatile and semi-volatile organic compounds from solid materials. The surrogate recovery compounds tetrachloro-meta-xlyene (TCMX) and decachlorobiphenyl (DBCP – a PCB congener) were added to the sample media prior to extraction. Sulfuric acid, Florisil, and mercury shake clean-up steps were used to prepare extracts for analysis. Extracts were concentrated to different final volumes depending on the sample type and detection limit goals.

2.3.2 Sample Analysis for Aroclors

All sample extracts were analyzed for Aroclor mixtures following EPA Method 8082 using dual column gas chromatography with electron capture detection. Multi-level calibrations were performed for Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. Calibration levels of 20, 100, 250, 500, and 1000 parts per billion were used for each Aroclor. Continuing calibration check standards were analyzed periodically to verify calibration stability. Sample extracts were injected on two different gas chromatography columns, Phenomenex, Zebron ZB-1, 30 m, 0.25 mm ID, 0.25 µm and Phenomenex, Zebron ZB-5, 30 m, 0.25 mm ID, 0.25 µm. Some sample extracts required dilution to bring the extract concentration into the calibration range. Aroclor quantitation was based on relative response factors for five chromatographic peaks following electron capture detection. A 40% relative percent difference acceptability limit was used for comparing the results obtained for the two chromatography columns. The highest value from the two columns was used for reporting when the acceptability criterion was met. In some cases sample results were reported as exhibiting an altered Aroclor pattern. In some cases, particularly for indoor air samples, more than one Aroclor (typically Aroclors 1248 and 1254 for air samples) was used to report an altered PCB pattern exhibited by the sample. Actual Aroclor 1248 was not present in the samples, but was reported to more accurately quantify PCB present in sample that had undergone environmental alteration. When multiple Aroclor values were reported, they were summed to generate total PCB concentrations in the samples. The laboratory used procedures to estimate relative contributions from different Aroclors for shared congeners so as not to overestimate the concentration attributed to each Aroclor mixture. In a few cases for samples with very high concentrations (exterior caulks for example) the dilution was so large that it was not possible to determine the surrogate recoveries. A final concentration was calculated using the extract concentration and applying air volume, surface area, or solid material mass and dilution factors as appropriate.

2.3.3 Sample Analysis for PCB Congeners

All of the air samples and a subset of other samples types were analyzed for PCB congeners using an NEA adaptation of EPA Method 8082 titled “Comprehensive Quantitative Congener Specific” (CQCS) analysis. The same sample extracts that had been previously analyzed for Aroclors were also analyzed using the CQCS method. The method utilizes high resolution gas chromatography with electron capture detection. Multi-level calibrations were performed using calibration mixtures containing all 209 PCB congeners. Calibration levels of 0.1, 0.5, 5.0, 25, and 50 ng/mL were used for each congener. 1,2,3,4,5,6,7,8-octachloronaphtalene was added to all calibration solutions and sample extracts as the internal standard. Continuing calibration check standards were analyzed periodically to verify calibration stability. Calibration and sample extracts were injected onto a Chrompack CP-Sil5/C18, 50 m length, 0.25 mm ID, and 0.10 micron phase thickness gas chromatography column. Of the 209 congeners, approximately 62 do not occur in Aroclor mixtures or are present at trace level (<0.05% by weight percentage). The chromatography column resolves 146 chromatographic peaks, providing complete separation for 99 congeners and co-elution of congeners for the remaining 47 chromatographic peaks. Of those 47 peaks with co-eluting congeners, 20 include a congener that is not found in Aroclor mixtures. Congener quantitation was based on relative response factors for each chromatographic peaks following electron capture detection. Peaks which are known to represent co-eluting congeners were mathematically quantitated as individual congeners using established ratios from Frame et al. (1996). A final concentration of each congener was calculated using the extract concentration and applying air volume, surface area, or solid material mass and dilution factors as appropriate. Chlorine-number homolog concentrations were calculated by summing the individual congener concentrations belonging to each homolog group.

2.4 Caulk Emissions Modeling

Caulk containing high concentrations of PCBs has been found in older buildings, including school buildings. It is of interest to understand the potential impact that PCB-containing caulk may have on indoor air levels of PCBs in school buildings. Total emission rates of PCBs from PCB-containing caulk collected at six locations at two schools were estimated using emission parameters generated from laboratory chamber emission rate test results for caulk described by Guo et al. (2011). The laboratory testing was performed using microchambers to minimize loss of PCBs to chamber surfaces. There were a limited number of locations that had both PCB-containing caulk and the information available to calculate parameters used in the estimation, including the surface area of the caulk that was present and the room volume. These six locations were used as examples to highlight a range of emissions that might be encountered.

Emission rates of chemicals from solid materials are primarily controlled by the chemical’s solid/air partition coefficient and the diffusion coefficient for the chemical in the solid material. Guo et al. (2011) described the relationship between a normalized emission factor and a chemical's vapor pressure:

$$\ln NE_i = b_1 + b_2 \ln P_i \qquad \text{(Eq. 2.1.1)}$$

where

NE_i = emission factor for congener i (µg/m^2/hr) normalized to a constant (1000 µg/g) concentration of a PCB congener in a material.

P_i = vapor pressure for congener i (torr)

b_1, b_2 = constants

Guo et al. (2011) measured the emission rates for ten PCB congeners (17, 52, 66, 77, 101, 105, 110, 118, 154, 187) from 12 samples of caulk, each tested from 4 to 7 times at 23°C, to generate information for calculating the emission constants (b_1 and b_2 in Equation 2.1.1). Both constants (b_1 and b_2) were observed to be consistent among different caulk samples, which indicated that a single correlation could be applied to all caulk samples. The average values for b_1 and b_2 were 14.02 and 0.976, respectively (Guo et al., 2011), resulting in the following relationship:

$$\ln NE_i = 14.02 + 0.976 \ln P_i \qquad \text{(Eq. 2.1.2)}$$

Equation 2.1.2 can be used to estimate the emission rate for a PCB congener from caulk when its concentration in the caulk is known and the vapor pressure is known or can be estimated.

PCB Aroclor concentrations were measured in the caulks from six locations for which the surface area of the caulk at that location could also be calculated. Aroclor 1254 was the reported Aroclor in each caulk. The concentration of each congener in the caulk was estimated by multiplying the weight fraction of each congener as reported by Frame et al. (1996) for the G4 Aroclor 1254 standard (see Appendix A) by the total measured Aroclor concentration in the material.

Several sets of vapor pressure data for PCBs congeners are available in the literature for many of the 209 PCB congeners. Two publications were used to obtain vapor pressures for as many congeners as possible and for all of the congeners reported by Frame et al. in Aroclor 1254 (Fischer et al. 1992, Methods A and B; Foreman and Bidleman 1985, Methods A and B). For some congeners, vapor pressure data have not been reported in the literature but have been estimated using physical/chemical properties approaches [U.S. EPA Estimation Programs Interface Suite™ (MPBWIN™ model as accessed via ChemSpider)]. Vapor pressures were selected for emission rate estimation in the following descending priority scheme, where all of the congener vapor pressures available from one source were used prior to moving to the next source:

1. Fischer et al. Method B,
2. Fischer et al. Method A,
3. Foreman and Bidleman Method A
4. Forman and Bidleman Method B, and
5. EPI Suite™.

Examples of PCB congener vapor pressures are described in Table 2-3 (for a more complete list see Appendix A). The congeners in Table 2-3 are those that were measured during laboratory chamber emissions measurement testing (Guo et al, 2011). There is a large range in vapor pressures among the congeners, with congener 17 having a vapor pressure approximately 200-fold higher than congener 187.

The calculation to estimate the total emission rate of PCBs from a material in a room includes multiple steps. The steps are described below along with an example calculation:

Table 2-3. Vapor pressures for selected target congeners in Aroclor 1254

PCB Congener	Number of Chlorines	P (torr)
17	3	5.82×10^{-4}
52	4	1.50×10^{-4}
66	4	4.42×10^{-5}
77	4	1.43×10^{-5}
101	5	2.99×10^{-5}
105	5	5.82×10^{-6}
110	5	1.68×10^{-5}
118	5	8.42×10^{-6}
154	6	1.36×10^{-5}
187	7	2.79×10^{-6}

Step 1: Calculate the concentration of each congener in a material [X_i in (μg/g)]:

X_1 = Weight percent of congener in Aroclor 1254 × Aroclor 1254 concentration

Congener 52 example in a gymnasium door frame caulk:

$X_i = 5.38\% \times 117{,}000\ \mu g/g = 6290\ \mu g/g$

Step 2: Obtain the vapor pressure for the congener

Congener 52 example: 1.5×10^{-4} torr
(Fisher et al. 1992, Method B)

Step 3: Calculate the normalized emission factor (NE_i) from Equation 2.1.2:

Congener 52 example:

$\ln NE_i = 14.02 + 0.976 \ln 1.5 \times 10^{-4} = 5.42$

$NE_i = 226\ (\mu g/m^2/hr)$

Step 4: Convert the normalized emission factor to the emission factor (E_i):

$E_i = (NE_i \div 1000\ \mu g/g) \times X_i$

Congener 52 example:

$E_i = (226\ \mu g/m^2/hr \div 1000\ \mu g/g) \times 6290\ \mu g/g = 1420\ \mu g/m^2/hr$

Step 5: Multiply the emission factor by the surface area of the material in the room to obtain the total estimated congener emission rate from the material in that room:

$R_i\ (\mu g/hr) = E_i\ (\mu g/m^2/hr) \times S\ (m^2)$

Congener 52 example:

$R_i = 1420\ \mu g/m^2/hr \times 0.143\ m^2 = 203\ \mu g/hr$

Step 6: Sum the estimated emission rates across all of the congeners expected to be present in Aroclor 1254 (based on Frame et al., 1996):

$$R_{A1254} = \sum_{i=1}^{n} R_i \qquad \text{(Eq. 2.1.3)}$$

Step 7: Adjust the total estimated Aroclor 1254 emission rate. Equation 2.1.3 estimates the total Aroclor 1254 emission rate assuming that the congener proportions in the caulk are equivalent to those in unaged Aroclor 1254. As shown in Section 4.5, caulk that has been in a building for over 40 years has an altered congener pattern. Based on congener measurements for caulk in School 6, Table 4-31 shows that the total emission rate was overestimated by a factor of 1.8 assuming unaged Aroclor 1254 as compared to the actual congener proportions measured in the caulk. Another factor to consider is that the caulk chamber testing might have overestimated emission rates due the presence of freshly cut surfaces. Three tests used to examine this (Guo et al., 2011) showed an average of 19% higher emissions for freshly cut surfaces in chamber testing. The two factors, when combined (0.55 x 0.81 = 0.45), yield an adjustment factor of 0.45 that can be applied to total emissions estimates:

$$R_{totadj} = R_{A1254} \times 0.45$$

This approach assumes that the emission factors generated for the emissions of PCBs from caulk in the laboratory test chamber experiments are applicable to the caulks sampled in the building. It also assumes that the temperature and air flow conditions used in chamber testing are applicable to the conditions in the rooms.

Guo et al. (2011) reported the predictive errors for the P-N calculation method for the ten congeners measured in their chamber emission rates studies. The error was calculated by using Equation 2.1.4, and the results are presented in Table 2-4. It is anticipated that the average error would be applicable across estimated total PCB emission rates using the P-N calculation method.

$$\varepsilon = \left| \frac{E_p - E_m}{E_m} \right| \times 100\% \qquad \text{(Eq. 2.1.4)}$$

where

ε = predictive error (%)
E_p = predicted emission factor ($\mu g/m^2/hr$)
E_m = measured emission factor ($\mu g/m^2/hr$)

Table 2-4. Predictive error for the P-N correlations[a]

Congener ID	P-N Correlation Error
#52	30.0%
#66	40.8%
#101	32.3%
#105	21.6%
#110	31.2%
#118	29.7%
#154	59.4%
Average	35.0%

[a] (Guo et al. 2011 Eq. 4.6)

Screening-level estimates of the concentration of PCBs in indoor air that might result from emission from caulk were generated for four school building locations. The following equation, including the adjustment factor described in Step 7 above, was used to estimate steady-state indoor air PCB concentrations resulting from emissions from caulk, if there was only one type of caulk with PCBs in the location:

$$C = \frac{\sum_{i=1}^{n} R_i}{Q} \times 0.45 \qquad \text{(Eq. 2.1.5)}$$

where:

C = total PCB concentration in room air ($\mu g/m^3$)

R_i = emission rate from caulk from congener i ($\mu g/hr$)

n = number of congeners with emission rate estimates

Q = ventilation rate for the room with outdoor air (m^3/hr) (based on room volume × ACH)

If there were multiple kinds of caulk with PCBs in a location, the following equation was used:

$$C = \frac{\sum_{i=1}^{m} \sum_{j=1}^{n} R_{ij}}{Q} \text{ x } 0.45 \qquad \text{(Eq. 2.1.6)}$$

where

R_{ij} = emission rate for congener i from source j
m = number of congeners with emission rate estimates
n = number of caulk types in the room

The estimates are based on numerous assumptions, and therefore should be considered only screening level. Assumptions include:

- well mixed air in room
- constant temperature
- temperature equivalent to chamber conditions that generated caulk emission parameters (23°C)
- constant ventilation rate
- steady-state emission
- steady state and approximately equal absoption/desorption of PCBs in other materials in the room
- no chemical reactions of PCBs
- PCBs from other school spaces are not impacting the levels in air for the room of interest
- emission parameters for caulk in the room are the same as for the caulk tested in lab chambers

2.5 Light Ballast Emissions Modeling

PCB-containing fluorescent light ballasts remain in operation in some older buildings, including school buildings. The capacitors in these ballasts are not perfectly sealed and small amounts of PCBs can be emitted from intact capacitors (Guo et al., 2011). Measured emission rates from apparently intact light ballasts are highly dependent on the ballast temperature, with very low emissions at room temperature and much greater emissions, relatively, at temperatures of 45 - 50°C, approaching normal ballast operating temperatures (Guo et al., 2011; Hosomi, 2005). There is interest in understanding the impact that light ballasts may have on PCB concentrations in indoor spaces.

Laboratory chamber emissions tests were performed for four intact PCB-containing ballasts at temperatures from 23 to 45°C (Guo et al., 2011). These emission tests were performed using 55-L stainless steel chambers, as compared to the microchambers used for caulk emission testing. Emission measurement results were used here to perform screening-level estimates of a range of total emission rates that might be encountered in school classrooms and the resulting air concentrations.

Light ballasts capacitors tested in the chambers were found to contain Aroclor 1242 (Guo et al., 2011). Guo et al. measured congeners 13, 15, 17, 18, 22, 44, 49, 52 in chamber testing as important components of the Aroclor 1242 mixture. Measured emission rates for each congener are presented in Table 2-5 for the four ballasts tested at 45°C. In order to use the congener emission results for estimating total PCB emissions (assuming Aroclor 1242) several steps were taken.

First, the congeners were grouped by chlorine-number homolog and the emission rates were summed. Estimates for the total emission for all congeners in the homolog group were generated by multiplying summed emission rate for measured congeners at 45°C by the ratio of total weight percent in the homolog group to the weight percent represented by the measured congeners (Table 2-5). Next, the sum of the total emissions for the 2, 3, and 4-homolog groups was calculated to estimate a value approaching the total PCB emission rate for Aroclor 1242. The combined weight percent of congeners in those three homolog groups represents over 95% of the total weight percent for Aroclor 1242 (see Appendix A) based on Frame et al. (1996). Finally, the estimated total PCB emission rate for each chamber-tested ballast was multiplied by the number of PCB-containing ballasts in three building rooms as an estimate of total PCB emission rates that might be encountered in rooms where intact PCB-containing ballasts are present and are in operation (lights are on). Because there was an almost 80-fold difference in the highest and lowest estimated emission rate across the four chamber-tested ballasts, the lowest, median, and highest total emission rates were used to generate a range of results.

It is also of interest to estimate ballast emissions for the condition when the lights are off and the ballasts are at room temperature. The four ballasts were tested in the laboratory chamber at several temperatures, including 23°C which is similar to room temperature. Because the emission rates were much lower at 23°C as compared to 45°C during chamber tests, many of the congener analyses had results below the detection limit (Table 2-6). Congeners 17 and 18 had 50% and 100% measurable results at 23°C. Ratios of emission rates at 45°C vs. 23°C were calculated. The average of the ratios for congeners 17 and 18 were used to estimate the overall total PCB emission rates at 23°C by dividing the emission rates previously estimated at 45°C by the average ratio of 16.2 (Table 2-6). The estimated total PCB emission rate for each chamber-tested ballast at 23°C was multiplied by the number of PCB-containing ballasts in three building rooms as an estimate of total PCB emission rates that might be encountered in rooms where intact PCB-containing ballasts are present and are not in operation (lights are off).

Screening-level estimates of the ranges of concentrations of PCBs in indoor air that might result from emission from intact light ballasts were generated for three school building locations. These three school rooms were selected only as examples to highlight the ranges of total emissions that might be found based simply on the number of ballasts present in the room. The following equation was used to estimate steady-state indoor air PCB concentrations resulting from emissions from ballasts using the lowest, median, and highest rates across the four chamber-tested ballast emission rates:

$$C = \frac{\sum_{b=1}^{n} R_b}{Q} \qquad \text{(Eq. 2.1.7)}$$

where:

C = total PCB concentration in room air (µg/m^3)
R_b = emission rate from ballast b (µg/hr)
n = number of PCB-containing ballasts in the room
Q = ventilation rate for the room with outdoor air (m^3/hr) (based on room volume × ACH)

The estimates are based on numerous assumptions, and therefore should be considered only screening level. Assumptions include:

- well mixed air in room
- constant temperature
- temperature equivalent to chamber conditions that generated emission rates
- constant ventilation rate
- steady-state emission
- steady state and approximately equal absoption/desorption of PCBs in other materials in the room
- no chemical reactions of PCBs

Table 2-5. Estimated total PCB emission rates for four intact light ballasts in chamber testing

	Ballasts Tested in Emission Chamber at 45°C			
	Ballast 1	**Ballast 2**	**Ballast 3**	**Ballast 4**
Congener 13 (µg/hr)	ND[a]	0.0029	0.0049	0.224
Congener 15 (µg/hr)	0.0072	0.0120	0.0210	0.953
Σ Congeners (µg/hr)	0.0072	0.0149	0.0259	1.18
Weight Percent of Measured Congeners in Aroclor 1242	2.12	2.12	2.12	2.12
Total 2-Chlorine Homolog Weight Percent in Aroclor 1242	13.4	13.4	13.4	13.4
Estimated Emission Rate for 2-Chlorine Homologs (µg/hr)	0.0459	0.0941	0.164	7.45
Congener 17 (µg/hr)	0.0256	0.038	0.0313	1.72
Congener 18 (µg/hr)	0.0832	0.114	0.0856	5.42
Congener 22 (µg/hr)	0.0050	0.0113	0.0058	0.364
Σ Congeners (µg/hr)	0.114	0.162	0.123	7.51
Weight Percent of Measured Congeners in Aroclor 1242	15.5	15.5	15.5	15.5
Total 3-Chlorine Homolog Weight Percent in Aroclor 1242	48.0	48.0	48.0	48.0
Estimated Emission Rate for 3-Chlorine Homologs (µg/hr)	0.352	0.504	0.380	23.3
Congener 44 (µg/hr)	ND	0.0059	0.0024	0.161
Congener 49 (µg/hr)	ND	0.0045	ND	0.154
Congener 52 (µg/hr	0.0055	0.0091	0.0036	0.254
Σ Congeners	0.0055	0.0195	0.0060	0.569
Weight Percent of Measured Congeners in Aroclor 1242	9.7	9.7	9.7	9.7
Total 4-Chlorine Homolog Weight Percent in Aroclor 1242	32.7	32.7	32.7	32.7
Estimated Emission Rate for 4-Chlorine Homologs (µg/hr)	0.0184	0.0658	0.0203	1.92
Σ 2, 3, and 4-Chlorine Homologs (µg/hr)	0.416	0.664	0.564	32.7
Median of Total (µg/hr)	0.614			
Mean ± Standard Deviation of Total (µg/hr)	8.57 ± 16.0			

[a] ND = Not detected.

- PCBs from other school spaces are not impacting the levels in air for the room of interest
- ballasts contains congeners equivalent to Aroclor 1242
- emission rates for ballasts in the rooms are the same as for the ballasts tested in lab chambers

Because emission testing for caulk and light ballasts were performed in two different types of chambers, it is possible that surface velocity conditions were different, possibly affecting the emission rates due to different boundary layer conditions. Losses to the chamber walls were also possible for the larger chambers used for light ballast emissions, potentially resulting in underestimation of total emission rates. Thus, some caution is warranted in making direct comparisons between estimated caulk and light ballast emission rates.

2.6 Building Material Emissions Modeling

Most of the building materials collected in three school buildings had measurable levels of PCBs. There is interest in understanding whether these materials might be important as secondary sources of PCB emissions, particularly once primary sources have been removed or otherwise mitigated. Screening-level emission rates were calculated to provide a relative sense of potential emissions from different building materials and to better understand whether these materials are potentially important sources for exposures to PCBs in school buildings.

Screening-level emission estimates for materials in nine building rooms were generated using the material PCB concentration and the measured surface area of the material in the room. These rooms were selected as examples based on the availability of information regarding the air concentration, the surface areas of multiple materials in those rooms, and PCB concentration measurements for the materials. The approach described in Section 2.4 for caulk was applied to the materials. The estimated emission rates should only be considered screening-level estimates because emission parameters generated for caulk in laboratory chamber tests were applied to all of the other materials. No emission parameter data are available for PCB congeners for the many different materials that were sampled in the school rooms. It is not clear whether, and how well, the caulk emission parameters apply to the other materials. It is likely that are considerable differences in emission parameters for materials that have different physical and chemical properties, different thicknesses, and different surface areas.

The screening-level estimates generated for the building materials were not used to generate estimated room air PCB concentrations for two reasons. First, as noted above, the estimated emission rates have considerable uncertainties. Second, the relative dynamics of absorption and desorption (the materials acting both as sources and sinks) have not been well characterized for school room environments, particularly when there are multiple materials serving as sources and sinks at the same time. This makes it difficult to accurately predict the air concentration that will result from PCBs in these materials.

2.7 SHEDS Exposure Modeling

2.7.1 SHEDS Background Information

SHEDS-Residential is one of modules of the SHEDS-Multimedia human exposure/dose model (http://www.epa.gov/heasd/products/sheds_multimedia/files/

Table 2-6. Ratio of PCB emissions at different temperatures from four light ballasts tested in a laboratory chamber

PCB Congener	% Results > Detection Limit[a] 23°C	35°C	45°C	Average Ratio of Emission Rates 45/23°C	Average Ratio of Emission Rates 45/35°C
13	0	0	75	NC[b]	NC
15	0	75	100	NC	4.0
17	50	100	100	15.9	3.0
18	100	100	100	16.4	2.8
22	0	50	100	NC	2.2
44	0	25	75	NC	NC
49	0	25	50	NC	NC
52	0	25	100	NC	NC
			Average of Ratios	16.2	3.0

[a] For four intact light ballasts with no visible leaks that were tested for emissions at several different temperatures in a laboratory test chamber.

[b] NC = Not Calculated. Ratio calculations were used only when at least 50% of the measurements were greater than the detection limit.

SHEDSResidential_TechManual_2012.pdf; Zartarian et al., 2012; Glen et al., 2012). The primary function of the SHEDS-residential model is to estimate the exposure of a population to one or more specified chemicals from inhalation, ingestion (by mouthing of hands or objects), or dermal contact in a residential setting. SHEDS uses the Monte Carlo statistical method to simulate a population of individuals based on time-location-activity diaries in EPA's Consolidated Human Activity Database (CHAD; www.epa.gov/chadnet1) and weights from the U.S. Census. These individuals are not specific persons, but are stochastically created synthetic persons whose collective properties reflect the simulated population and input distributions for exposure-related variables. For each individual, SHEDS constructs a sequence of activities, media concentrations, and the resulting exposures over the selected simulation period, which may range from one day to a year or more (although simulation time steps can range from 1 minute to 1 hour within a day). These individual exposure time series may be stored or exported, or aggregated over time to give time-integrated or time-averaged exposures (Figure 2-1). They may also be input to a dose model, either internal or external to SHEDS, to follow the fate of the chemical after it enters the human body. Exposure is defined in this model as the contact between a chemical agent and a simulated human target at the external body surface, either the skin surface or the oral/nasal boundary. Dose is defined in this model as the amount of chemical that enters the target after crossing the exposure surfaces. Details regarding the pathways, distributional functions, and exposure/dose equations are provided in the SHEDS Technical Manual (Glen et al., 2012).

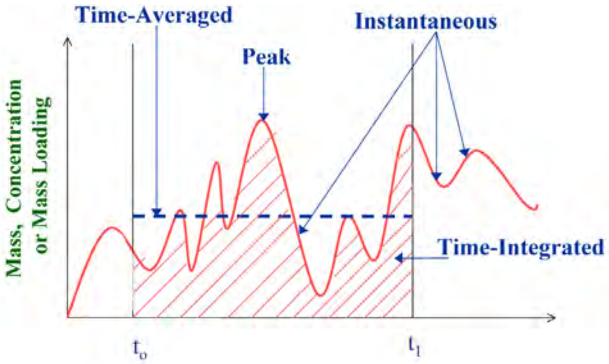


Figure 2-1. Hypothetical exposure profile for an individual

SHEDS can be used for various purposes, including estimating population distributions of exposure and dose; understanding intensity, duration, frequency, and timing of exposures; identifying critical media, exposure routes, and factors; considering how to identify and address greatest uncertainties; and comparing modeled estimates against real-world data. Figures 2-2 and 2-3 illustrate the SHEDS methodology. The model estimates the exposure and/or dose of individuals in a user-specified population cohort

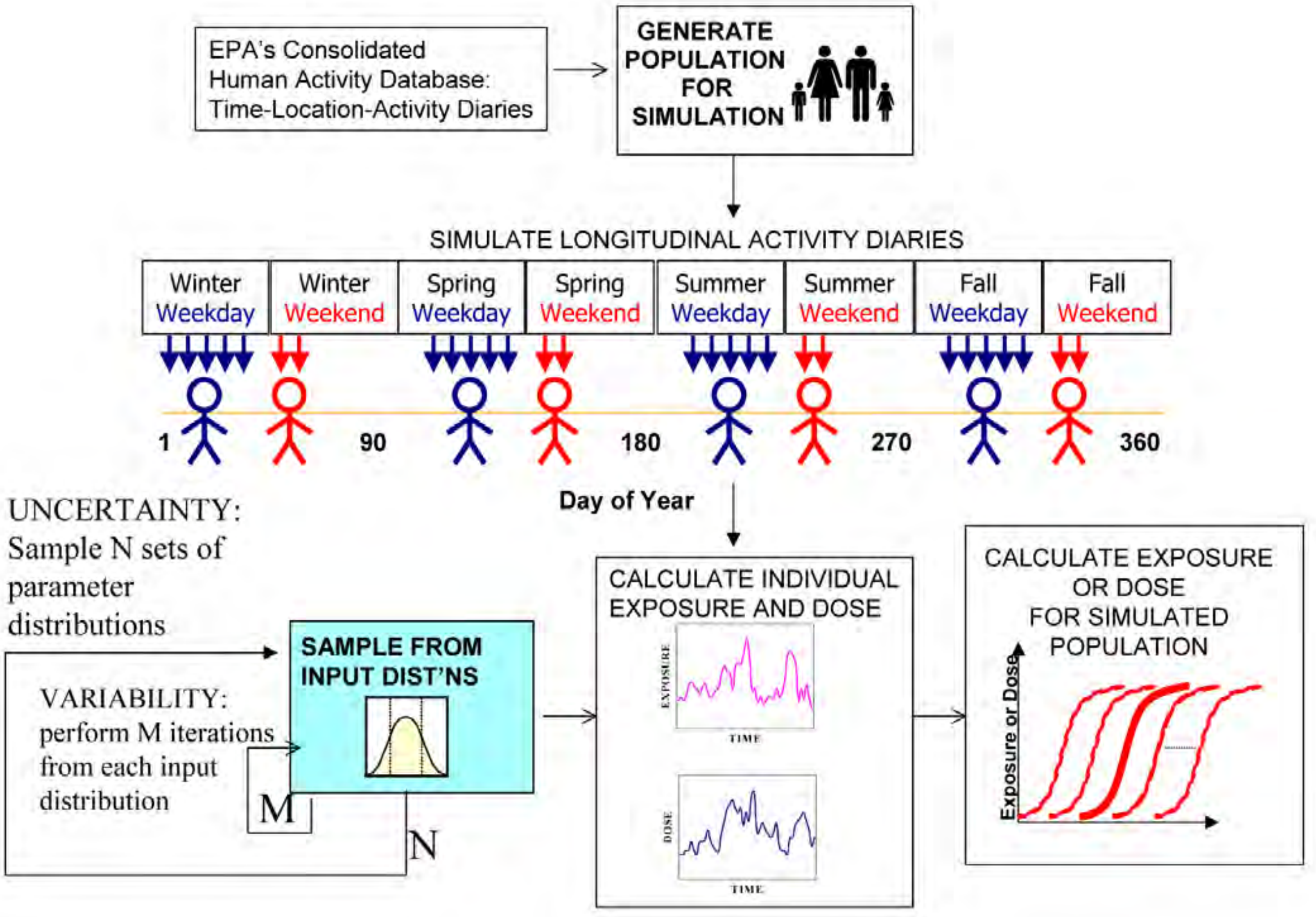


Figure 2-2. Overview of SHEDS residential methodology

to a particular chemical via three primary exposure routes: inhalation, non-dietary ingestion (i.e., via soil/dust ingestion, hand mouthing, or object mouthing pathways), and dermal contact in a residential setting. To do this, it simulates the daily activities and locations of individuals using sequential time/location/activity diaries from EPA's Consolidated Human Activity Database (CHAD) (McCurdy et al. 2000). SHEDS utilizes the Xue et al. (2004) approach for longitudinal diary assembly.

For each individual in a SHEDS-Residential run, the following general steps are applied (see the SHEDS Technical Manual for more detail: Glen et al., 2012):

1. Randomly select the age, gender, and other demographic properties of interest, given the distribution of the target population.
2. Generate a longitudinal activity diary, which indicates the sequence and duration of activities and locations for that person. For the residential module, these are based on sequential time-location-activity diaries from EPA's CHAD database.
3. Generate concentration time series for each potential contact medium (e.g., indoor air, indoor smooth surfaces, indoor textured surfaces, outdoor lawn).
4. Simulate the contacts between the individual and the affected media. These depend on the diary activity/location information and contact probabilities derived from user-specified inputs.
5. Calculate pathway-specific exposure time series for the individual, using the results of the prior two steps and user-specified distributions for exposure factors.
6. Generate an approximation for the components of the intake or absorbed dose time series and export these for use in a simple pharmacokinetic (PK) or more complex physiologically-based pharmacokinetic (PBPK) model.
7. Time-aggregate to daily totals of absorbed dose.

The SHEDS-Residential model was applied to the dose modeling estimation for school PCB environmental measurement data because the school environment is, in many ways, similar to the residential environment, particularly with regard to multiple exposure pathways. Rather than using residential activity data, school activity data from CHAD were used in this PCBs assessment. Dose estimation was not performed for adults, including teachers and staff, as part of this effort due to the lack of school activity data such as those available for children in the Consolidated Human Exposure Database.

2.7.2 Input Data for SHEDS School PCB Modeling

Key inputs for PCBs exposure simulation are concentrations of PCBs in various media. PCB environmental measurement data from the schools were pooled and fitted to lognormal distributions for indoor air, soil and wipe sample concentrations for total PCBs (Table 2-7). The hypothesis for a normal distribution of log-transformed measurement results for air was not rejected based on the Shapio-Wilk test (0.05 level). Significance levels were slightly exceeded for surface wipe and dust measurements but this was likely due to the higher number of non-detect values; the log distribution appeared to best represent the data for SHEDS modeling purposes.

Only those soil results for samples collected from the 0 – 5 cm (0 – 2") depth were used as inputs to the model. Dust measurements were not made at most schools and dust concentrations were estimated based on air concentrations measured in each room and estimated dust/air partition coefficients (see Appendix E). Also, outdoor air concentrations from other studies (Appendix D) were used for PCB exposure simulation because there were insufficient measurements to fit distributions and the quantitation limit for the school measurements was high relative to typical outdoor air levels. Outdoor air measurement results used in this analysis had a median of 0.4 ng/m^3 (mean of 18 ± 25 ng/m^3 total PCBs). Outdoor air concentrations were applied to the fraction of estimated time spent outdoors while at school.

Absorption parameters of PCBs by humans are another set of important inputs (Table 2-8, information from ATSDR, 2000). Absorption information and their application in SHEDS is described below.

<u>*Inhalation Absorption*</u>

PCBs, when administered orally, are well absorbed by experimental animals and at generally high fractions by humans (ATSDR, 2000). There is very limited information available for PCB pulmonary absorption. A recent study of inhalation of vapor phase PCB congeners by rats estimated that 33 µg of the 40 µg inhalation exposure was present across multiple tissues, suggesting at least 82% of the PCBs were absorbed (Hu et al., 2010). Another study examined pulmonary absorption of a chemical similar to PCBs, 2,3,7,8-TCDD, following instillation in rats and estimated 95% absorption of the administered dose (Dilberto et al., 1996). A portion of the PCBs in air are likely absorbed to dust and/or soil particles. A study examined the relative absorption of 2,3,7,8-TCDD on soil as compared to a different substrate following pulmonary instillation and found 100% relative absorption (Nessel et al, 1992). These studies suggest a relatively high pulmonary absorption rate, but this is still uncertain for humans across a range of congeners and different vapor/particle phase fractions. Volckens and Leith examined the deposition of inhaled SVOCs and found for up to 7-chlorine PCB congeners that deposition to the lung as vapor dominated (2002). A value of 70% pulmonary absorption was used for this PCBs exposure simulation, and sensitivity analyses were conducted ranging from 35% to 100% to examine the impact on modeled dose estimates.

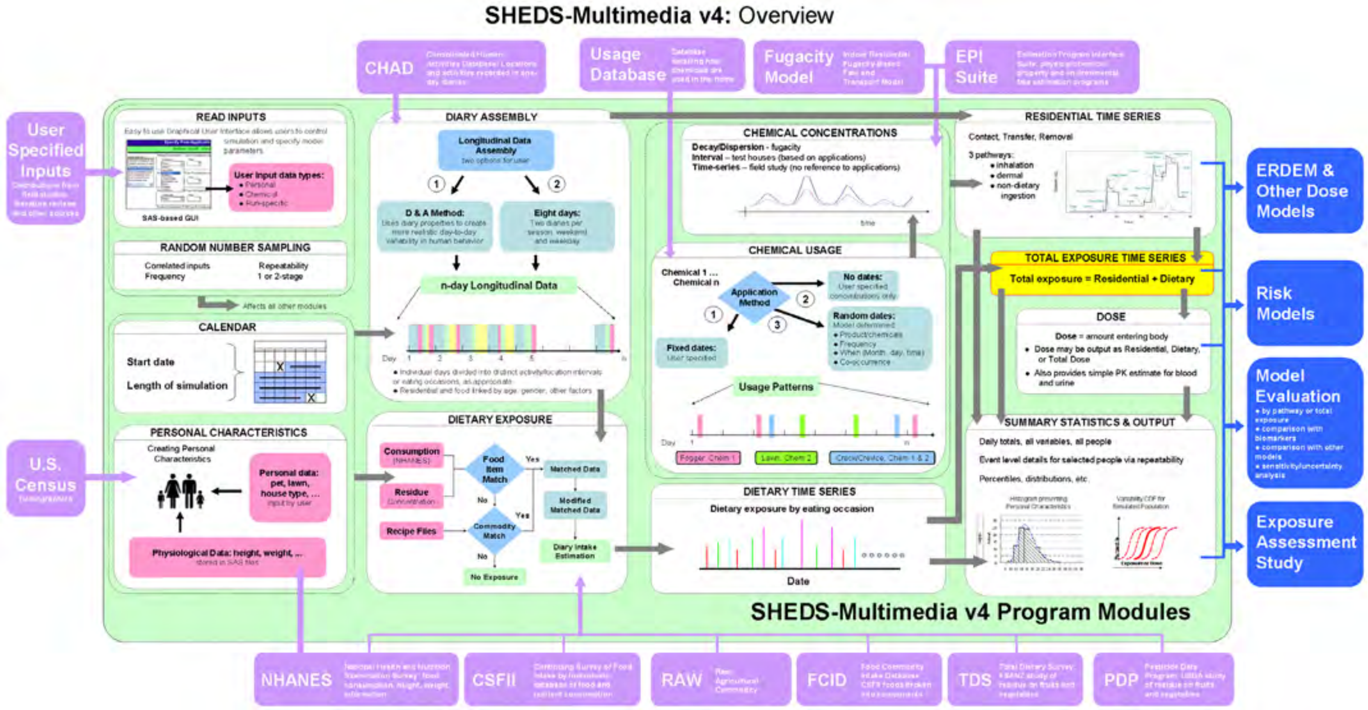


Figure 2-3. General overview of SHEDS multimedia exposure model

Gastrointestinal Absorption

As with fats and other fat-soluble chemicals, PCBs are most likely absorbed from the gut via lymphatic circulation and consequently avoid first-pass metabolism in the liver (Hansen 1999). Price et al. (1972) found that 88% of the ingested PCBs were not excreted, and were therefore assumed to be retained in the body (7–9 year old girls). This estimate of PCB absorption in young girls is supported by the more comprehensive, congener specific mass balance study of Schlummer et al. (1998). Retention was estimated to be >90% and 85.4% of the administered dose in monkeys (Allen et al. 1974b) and ferrets (Bleavins et al. 1984), respectively. An absorption value of 85% was used for the simulation.

Dermal Absorption

Experimental data on the percutaneous absorption of PCBs in humans is limited to in-vitro studies that used human cadaver skin (Wester et al. 1990, 1993) with ^{14}C-labeled Aroclor 1242 and 1254. Over a 24-hour period, 2.6, 10, and 43% of the dose was retained in human skin when the Aroclor 1242 was formulated in soil, mineral oil, or water, respectively. Similar results were observed with Aroclor 1254, with 1.6, 6.4, and 44.3% of the dose retained in human skin, following PCB exposure in a soil, mineral oil, or water vehicle, respectively. The in-vitro data indicate that PCBs readily enter human skin and are available for systemic absorption, and that the dosing vehicle has a major role in regulating the relative retention of PCBs in human skin.

In a related study, Wester et al. (1990, 1993) assessed the in-vivo percutaneous absorption of PCBs in adult female Rhesus monkeys. Topical administration of Aroclor 1242 resulted in 14, 20, 18, and 21% absorption of the administered dose when formulated in soil, mineral oil, trichlorobenzene, or acetone, respectively. In contrast to the above in-vitro results with human skin, the vehicle had little effect on the systemic absorption of the PCBs applied to the skin of monkeys. This may be due to the uncertain viability of the human skin used in the in-vitro studies and the fact that the in-vitro study primarily assessed retention of PCBs in human skin and could not estimate systemic absorption. Absorption efficiency ranged from 0.15 to 34% of the applied radioactivity in the monkeys and averaged 33% (42% chlorine) and 56% (54% chlorine) of the applied radioactivity in the guinea pigs.

For this simulation, 2% was used for dermal absorption rate per day for dust or soil using a uniform distribution, with 10% and 40% for the daily dermal absorption rate for the residues.

Other default inputs are listed in Table 2-9 (from Appendix G - default values for non-chemical specific variables from the SHEDS-Multimedia version 4 Technical Manual; Glen, 2012). The U.S. EPA Child-specific Exposure Factors Handbook was consulted in selecting input values, but relevant data for fitting distributions for soil and dust contact and ingestion were available from Kissel et al. (1996), Holmes et al. (1999), and Ozkaynak et al. (2011) and were used in this analysis. The object mouthing rates shown in Table 2-9 were used in conjunction with the residue data from the dermal wipe samples.

Inhalation rate

Short-term inhalation rates are generated for SHEDS based on several factors (Glen et al., 2012). The basal metabolic rate (bmr) is calculated from a regression equation using body weight as the independent variable. The units for bmr are megajoules per day. The slope, intercept, and standard

Table 2-7. Input variables for the SHEDS-multimedia model

PCBs Environmental Concentration Inputs	Units	Distribution	Geo. Mean	Geo. SD
Distributions Used for Modeling All 6 Schools (pre-remediation)				
Indoor air PCBs	$\mu g/m^3$	lognormal	2.29E-01	4.26
Outdoor air PCBs	$\mu g/m^3$	lognormal	2.08E-03	12.94
Wipe PCBs in high contact area	$\mu g/cm^2$	lognormal	1.51E-03	2.85
Soil PCBs	µg/kg	lognormal	524.6	3.71
Estimated dust PCBs	µg/kg	lognormal	7032	4.26
Distributions Used for Modeling 5 Schools (pre- and post-remediation)				
Indoor air PCBs for 5 schools (pre-remediation)	$\mu g/m^3$	lognormal	2.03E-01	4.44
Outdoor air PCBs (pre- and post-remediation)	$\mu g/m^3$	lognormal	2.08E-03	12.94
Wipe PCBs in high contact area (pre-remediation)	$\mu g/cm^2$	lognormal	1.18E-03	2.45
Soil PCBs for 5 schools (pre- and post-remediation)	µg/kg	lognormal	535.6	3.65
Estimated dust PCBs (pre-remediation)	µg/kg	lognormal	6236	4.44
Indoor air PCBs (post-remediation)	$\mu g/m^3$	lognormal	7.45E-02	2.87
Wipe PCBs in high contact area (post-remediation)	$\mu g/cm^2$	lognormal	1.08E-03	2.47
Estimated dust PCBs (post-remediation)	µg/kg	lognormal	2294	2.87
Distributions Used for Modeling 3 Schools (Year 1 pre- and post-remediation and Year 2 pre-remediaiton)				
Year 1 Indoor air PCBs (pre-remediation)	$\mu g/m^3$	lognormal	3.19E-01	3.86
Year 1 Wipe PCBs in high contact area (pre-remediation)	$\mu g/cm^2$	lognormal	1.29E-03	2.31
Soil PCBs	µg/kg	lognormal	524.6	3.71
Year 1 Estimated dust PCBs (pre-remediation)	µg/kg	lognormal	9820	3.86
Year 1 Air PCBs (post-remediation)	$\mu g/m^3$	lognormal	7.63E-02	2.87
Year 1 Wipe PCBs in high contact area (post-remediation)	$\mu g/cm^2$	lognormal	1.03E-03	2.38
Soil PCBs	µg/kg	lognormal	524.6	3.71
Year 1 Estimated dust PCBs (post-remediation)	µg/kg	lognormal	2347	2.87
Year 2 Indoor air PCBs (pre-remediation)	$\mu g/m^3$	lognormal	9.96E-02	3.07
Year 2 Wipe PCBs in high contact area (pre-remediation)	$\mu g/cm^2$	lognormal	8.46E-04	2.43
Soil PCBs	µg/kg	lognormal	524.6	3.71
Year 2 dust PCBs (pre-remediation)	µg/kg	lognormal	3065	3.07

deviation of the residual are taken from the body weight and surface area files by age and gender. A minimum value of 0.1 megajoules per day is permitted. The basal inhalation rate is the rate in effect for activities with a METS of one and has units of cubic meters of air per hour. The basal alveolar ventilation rate, bva, is related to the basal metabolic rate:

$$\text{bva} = \text{bmr} \times 0.166 \times 0.01963 \times (0.20 + 0.01 \times \text{u}) \times 60$$

The factor 0.166 converts from megajoules per day to kilocalories per minute. The factor 0.01963 converts from liters of oxygen consumed to cubic meters of air inhaled. The variable "u" is uniformly distributed between zero and one, and then term (0.20 + 0.01 × u) represents the metabolic efficiency (liters of oxygen consumed per kilocalorie expended). The final factor of 60 converts the per minute rate to the per hour rate. Multiplication of metabolic ratio of energy expenditure for an activity to the resting rate (METS) and bva leads to the inhalation rate for SHEDS. In this way, we link age, body weight and activity levels with inhalation rate. SHEDS is using macro activity, therefore, we only use short-term inhalation rates. Table 2-10 displays summary statistics of average inhalation rates by age groups.

Table 2-8. Key input variables for the SHEDS-multimedia model

Concentration or Process Inputs	Units	Distribution Form	Distribution Parameters[a] v1	v2
Absorption fraction for lungs	[-]	point	0.7	
Dermal absorption rate per day for dust or soil	1/day	point	0.02	
Dermal absorption rate per day for surface residues	1/day	uniform	0.1	0.43
GI tract absorption rate per day for dust or soil	1/day	point	0.85	
GI tract absorption rate per day for surface residues	1/day	point	0.85	
Bioavailability fraction for dust/soil	[-]	point	1	
Bioavailability fraction for surface residues	[-]	point	1	
Residue-skin transfer efficiency	[-]	normal	0.051	0.022
Soil-skin adherence factor	mg/cm2	lognormal	0.11	2
Body-surface fractional contact rate	1/20min	beta	42	166
Hand-surface fractional contact rate	1/20min	Weibull	10	2.5
Fraction of body unclothed	[-]	beta	3	6.7
Surface-skin transfer coefficient for body (unclothed)	cm2/hr	lognormal	3070	1.68
Surface-skin transfer coefficient for hand	cm2/hr	lognormal	3070	1.68
Dust ingestion rate (indoor, direct only, 4=age =5)	mg/hr	lognormal	0.706	4.009
Dust ingestion rate (indoor, direct only, 6<=age <=10)	mg/hr	lognormal	0.446	8.011
Dust ingestion rate (indoor, direct only, age >=11)	mg/hr	point	0	
Soil ingestion rate (outdoor, direct only, 4=age=5)	mg/hr	lognormal	0.722	6.293
Soil ingestion rate (outdoor, direct only, 6<=age <=10)	mg/hr	lognormal	0.276	9.774
Soil ingestion rate (outdoor, direct only, age >=11)	mg/hr	point	0	

[a] Distributional parameters (v1, v2): lognormal (geometric mean, geometric standard deviation); normal (mean, standard deviation); uniform (minimum, maximum); Weibull (shape, scale); beta (α, β).

Time and activity in school

The simulated population of 6-18 year-old children was generated using ~35,000 person-days from the new CHAD database; time-location-activity diaries were selected according to age and school attendance information. Longitudinal activity diaries of the simulated schoolchildren were generated using a published method to optimize inter- and intra- individual variability (that uses 8 CHAD person-days by season and weekday/weekend for each age/gender cohort; Xue et al., 2004). Applying this method generated an average 6.34 hours indoor and 0.2 hours outdoor during school time. Higher ventilation rates were applied for the outdoor time due to an expected higher level of physical activity. The longitudinal activity patterns for each individual were then combined with available PCB concentration data and exposure factors and inserted into exposure pathway equations as described in the SHEDS-Multimedia technical manual.

Only PCB exposures incurred during school hours (in/around the school) were modeled; neither dietary intake nor intake away from school was considered. Routes considered were inhalation, dermal contact, and soil ingestion. For dermal contact, wipe data were used; these likely include

Table 2-9. Key input variables for the SHEDS-multimedia model

Concentration or Process Inputs	Units	Distribution Form	Distribution Parameters[a]	
			v_1	v_2
Hand mouthing events per hr (indoor, 4=age=5)	events/hr	Weibull	0.75	12.59
Hand mouthing events per hr (outdoor, 4=age=5)	events/hr	Weibull	0.55	5.53
Hand mouthing events per hr (indoor, 6<=age <=10)	events/hr	Weibull	1.36	7.34
Hand mouthing events per hr (outdoor, 6<=age <=10)	events/hr	Weibull	0.49	1.47
Hand mouthing events per hr (age >=10)	events/hr	point	0	
Fraction of surface of one hand that enters mouth	[-]	beta	3.7	25
Object mouthing events per hr (indoor, 4=age=5)	events/hr	Weibull	0.58	6.9
Object mouthing events per hr (outdoor, 4=age =5)	events/hr	Weibull	0.55	5.38
Object mouthing events per hr (indoor, 6<=age <=10)	events/hr	Weibull	0.84	1.2
Object mouthing events per hr (outdoor, 6<=age <=10)	events/hr	Weibull	0.55	1.1
Object mouthing events per hr (age >=11)	events/hr	point	0	
Object-surface concentration ratio	[-]	uniform	0	0.2
Object-mouth contact area	cm2	exponential	1	10
Object-mouth transfer efficiency	[-]	beta	2	8
Transfer coefficient for object mouthing (age >=4)	cm2/hr	point	0	
Removal efficiency during bath/shower	[-]	uniform	0.9	1
Removal efficiency during events without water	1/hr	point	0	
Removal efficiency during mouthing	[-]	beta	2	8
Removal efficiency during hand washing	[-]	uniform	0.3	0.9
Mean # hand washes/day per person	1/day	lognormal	3.74	2.63
Maximum dermal loading for body	µg/cm^2	triangle	0.1	0.6
Maximum dermal loading for hands	µg/cm^2	triangle	0.1	1

[a] Distributional parameters (v_1, v_2): lognormal (geometric mean, geometric standard deviation); normal (mean, standard deviation); uniform (minimum, maximum) ; triangle (minimum, mode, maximum); Weibull (shape, scale); beta (α, β).

Table 2-10. Average inhalation rate (m^3/day)

Age group (yr)	Mean	SD	Percentiles					
			p5	p25	p50	p75	p95	p99
06-10	8.20	1.85	5.82	6.96	7.91	9.01	11.95	14.46
11-13	10.98	2.50	7.56	9.16	10.68	12.34	15.72	18.21
14-18	12.86	3.01	8.60	10.78	12.50	14.60	18.24	21.06

both PCB residues and PCBs bound to dust. We assumed children 11 years and older had no soil/dust ingestion due to lack of data, however, this is likely to result in only a very small underestimation in the total exposure for children 11-18 years old. Direct dermal contact with and ingestion of caulk was also not included due to an absence of information on relevant contact rates and how much PCBs would be available for dermal transfer from caulk-bound PCBs.

Handling of Values Below the Quantifiable Limit

Quantifiable limits (QLs) for air were usually about 50 ng/m^3. The QL for soil was 0.5 mg/kg for most samples and 0.1 µg/100 cm^2 for all wipe samples. A value of one-half of the QL was substituted for samples with values <QL. The models were re-run using a substitution of zero for values <QL; overall model results were similar with those using one-half QL substitution. Only the model results using substitution of one-half of the QL are reported here.

3.0

Quality Assurance and Quality Control

Quality assurance (QA) and quality control (QC) procedures were implemented for the NERL PCBs in schools measurement study by following the guidelines and procedures detailed in the project's Quality Assurance Project Plan (QAPP), "*PCBs in Schools - Field and Laboratory Data Collections*." Quality control samples were used where appropriate and available for assessing potential contamination of field sampling materials, and spiked samples were used to assess recovery of PCB from sampling materials. Duplicate samples were collected where appropriate to assess precision. Laboratory quality control and quality assurance procedures and analyses were used by NEA-Pace Analytical to ensure data of known quality were produced. Data quality reviews were conducted by EPA's research contractor (Alion Inc.) and by EPA staff. The QA and QC results described below apply to the measurements made at one school by NERL and NERL contractors.

Quality assurance and quality control procedures and results for the New York City School Construction Authority remedial investigation pilot study for the five New York City schools are documented in the remedial investigation plan that was developed by the SCA and TRC Engineers Inc. (NYC SCA, 2010) and in the remedial investigation reports (NYC SCA, 2011; NYC SCA 2012). Overall, the NYC SCA reported that a very high percentage of measurements (>99%) were found to be acceptable for use, and in almost all cases < 2% of the measurement data were reported to be qualified across multiple QA/QC criteria. The NYC SCA quality assurance and quality control results are not included in this report, the reader is referred to the original primary documentation (NYC SCA, 2011; NYC SCA 2012).

3.1 Quality Control Results for Aroclor Analysis

Field and laboratory quality control samples were prepared and analyzed to assess recovery of target chemicals and the recovery of surrogate compounds added to all samples prior to analysis, to evaluate the potential for contamination of sampling and analysis materials by target analytes, and to examine precision in sampling and analysis. The completeness of scheduled sample collection and analysis was also examined. This section describes results for analysis of PCB Aroclors.

All of the air, surface wipe, dust, soil, and caulk samples scheduled for collection were successfully collected and analyzed for Aroclors (see Table 2-2). Three of the other building material samples scheduled for collection were not collected. These included samples of blackboard, whiteboard, and spray insulation. Over 98% of the scheduled samples were successfully collected and analyzed.

Field controls were prepared for air and surface wipe samples by adding known amounts of Aroclor 1254 to sampling filters and wipes. Field controls were transported to the sampling site and then were transported and stored with the samples until extraction and analysis. Recovery of Aroclor 1254 from field controls is reported in Table 3-1. Average recoveries were 85.3 ± 11.0% for air filter media and 86.0 ± 8.9% for wipe media. Laboratory controls were prepared for air and surface wipes by adding known amounts of Aroclor 1254 to sampling filters and wipes. Laboratory controls were prepared at the same time as the field controls, but then were stored at the analytical laboratory until extraction and analysis along with the samples and field controls. Recovery of Aroclor 1254 from laboratory controls is reported in Table

Table 3-1. Aroclor analysis: recovery of Aroclor 1254 from field and laboratory controls

		Spiking Level	Field Controls[a] % Recovery		Laboratory Controls[b] % Recovery	
Media	N	ng/sample	Mean	SD	Mean	SD
Air	3	1000	85.3	11.0	92.7	3.9
Surface Wipe	3	1000	86.0	8.9	112	0.6

[a] Sample media were spiked, transported to and from the field site, and stored with samples until analysis.

[b] Sample media were spiked at the same time as field controls and stored in the laboratory until analysis.

Table 3-2. Aroclor analysis: recovery of Aroclor 1254 from laboratory matrix spikes[a]

Media	N	Spiking Level	Spiking Units	% Recovery Mean	% Recovery SD
Air	4	1000	ng/sample	98.5	3.5
Surface Wipe	5	12.5	µg/sample	106	13.0
Dust	2	0.245 - 1.25	µg/g	97.2	1.8
Soil	2	1.21 – 1.24	µg/g	96.4	6.3
Caulk	4	1.20 – 1.25	µg/g	108	5.6
Other Materials	4	1.24 – 1.25	µg/g	99.8	5.6

[a] Sample media were spiked in the laboratory immediately prior to extraction.

Table 3-3. Aroclor analysis: recovery of surrogate analytes from samples and duplicate samples[a]

		Spiking Level µg/sample		TCMX % Recovery		DCBP % Recovery	
Media	N	TCMX[b]	DCBP[c]	Mean	SD	Mean	SD
Air	11	0.025	0.25	82.1	6.8	87.6	5.8
Surface Wipe	44	0.25	2.5	94.2	6.5	99.3	13.0
Dust[d]	8	0.05	0.5	79.4	22.8	89.4	15.1
Soil	9	0.25	2.5	96.2	6.0	106	6.2
Caulk[d]	26	0.25	2.5	100	6.3	102	16.2
Other Materials	47	0.25	2.5	98.3	12.5	101	15.5

[a] Two surrogate analytes were spiked on every sample and duplicate sample prior to extraction.

[b] TCMX = Tetrachloro-meta-xylene.

[c] DCBP = Decachlorobiphenyl (PCB Congener #209).

[d] One dust sample and 12 caulk samples were diluted significantly for analysis; surrogate recoveries not available for these samples and are not included in the recovery statistics.

3-1. Average recoveries were 92.7 ± 3.9% for air filter media and 112 ± 0.6% for wipe media. Laboratory matrix spikes were used to assess recovery of Aroclor 1254 from all media at the laboratory. Unused sampling media or surrogates of each type of sample matrix (PUF filter, wipe material, dust, soil, and caulk) was fortified with known amounts of Aroclor 1254 and the matrix spike samples were extracted and analyzed along with the samples. Recovery of Aroclor 1254 are reported in Table 3-2 and ranged from 98.5 ± 3.5% for air filter media to 108 ± 5.6% for caulk media. All recovery results met the 80 – 120% QAPP data quality objective.

The two surrogate standard compounds tetrachloro-meta-xylene (TCMX) and decachlorobiphenyl (PCB Congener #209; DCBP) were added to every sample prior to analysis to assess recovery through the laboratory extraction and analysis process. Surrogate analyte recovery results are reported in Table 3-3. Average recoveries ranged from 82.1 ± 6.8% for TCMX in air samples to 106 ± 6.2% for DCBP in soil samples. Surrogate samples in one dust sample and in 12 caulk samples were diluted significantly and the surrogate standard recoveries could not be measured. One wipe sample, one caulk sample, and two materials samples had recoveries below the 60% acceptance level for DBCP, and one dust sample had a TCMX recovery lower than the acceptance level. In those samples, the analytical result for the other surrogate analyte met the acceptance level and the sample analysis results were accepted.

Field blanks were used to assess potential contamination by PCBs. Air filters and wipe sampling media were used along with PCB-free caulk and soil materials. The media were placed in the same type of containers used for samples. Field blanks were transported to the sampling site and then were transported and stored with samples until extraction and analysis. Field blank results are shown in Table 3-4. Mean total PCB concentrations on all types of field blanks were lower than the quantifiable limits (QLs). Laboratory blanks were prepared for air filters and surface wipes by storing unused media at the laboratory until extraction and analysis along with samples. Laboratory blank results are shown in Table 3-4. Mean total PCB concentrations were lower than the QL. Laboratory method blanks were prepared to assess potential PCB contamination in the extraction materials and methods through the instrumental analysis procedure. Unfortified extraction solvent was carried through the extraction and analysis procedures along with the samples. Laboratory method blank results are shown for all media in Table 3-5. Except for caulk, all laboratory blank results were lower than the QLs. For caulk the average measured total PCB values on the method blanks was 0.063 ± 0.092 µg/g which was slightly higher than the 0.05 µg/g QL. Overall, the background contamination levels as measured in field blanks, laboratory blanks, and laboratory method blanks were judged to have no impact on the use and interpretation of measurement results. Although the laboratory method blank result for caulk was slightly greater than the QL value, almost all caulk samples had concentrations well above the QL, and values of the samples of most interest had levels hundreds of times higher than that measured in the method blanks. Sample measurement results were not adjusted for background concentrations.

Table 3-4. Aroclor analysis: total PCBs measured on field and laboratory blanks

				Field Blanks[a]		Laboratory Blanks[b]	
Media	**N**	**QL[c]**	**Units**	**Mean**	**SD**	**Mean**	**SD**
Air[d]	3	50	ng/m^3	3.1	0.58	10.5	12.1
Surface Wipe	3	0.1	µg/100 cm^2	ND[e]	ND	0.001	0.002
Dust	3	0.047	ppm	0.024	0.022	NP[f]	NP
Soil	2	0.050	ppm	0.012	0.002	NP	NP

[a] Unfortified sample media, transported to and from the field site, and stored with samples until analysis.

[b] Unfortified sample media, prepared at the same time as field blanks and stored in the laboratory until analysis.

[c] QL = quantitation limit.

[d] Based on an assumed nominal air volume of 5.5 m^3.

[e] ND = not detected.

[f] NP = none prepared.

Table 3-5. Aroclor analysis: total PCBs measured in laboratory method blanks

				Lab Method Blanks[a]	
Media	**N**	**QL[b]**	**Units**	**Mean**	**SD**
Air[c]	2	50	ng/m^3	10.3	10.0
Surface Wipe	5	0.1	µg/100 cm^2	0.027	0.028
Dust	2	0.047	µg/g	0.010	0.011
Soil	2	0.050	µg/g	0.003	0.004
Caulk	4	0.050	µg/g	0.063	0.092
Other Materials	4	0.050	µg/g	0.008	0.008

[a] Unfortified solvent taken through extraction and analysis.

[b] QL = quantitation limit.

[c] Based on an assumed nominal air volume of 5.5 m^3.

Precision was examined using duplicate sample collection and analysis as well as the precision in measurements for various quality control samples and analyses. Precision results for duplicate sample collection and analysis are reported in Table 3-6. Results are reported as the relative percent difference (RPD). Duplicate air samples collected in close proximity provide a good measure of sampling and analysis precision because pollutants in indoor air collected side-by-side within a room are typically homogeneous. The mean RPD for duplicate air samples was 13.6 ± 6.0% which met the precision QAPP objective of ± 20%. Duplicate sample collection for surface wipe, dust, soil, and caulk materials includes a sample non-homogeneity component in addition to sampling and analysis method precision. One of the purposes of this work was to provide information regarding variability of PCBs in these media in school buildings. The mean RPD ranged from 26.0 ± 12.0% for surface wipes to 70.8 ± 31.1% for dust. The dust collected for duplicate samples was collected in the same room, but obtaining sufficient sample sizes required vacuuming multiple surfaces in the room. The results suggest the potential for considerable variability in dust PCB concentrations for different locations within the same school room.

Table 3-6. Aroclor analysis: precision results for duplicate sample measurements[a]

		Relative % Difference[b]	
Media	**N**	**Mean**	**SD**
Air	3	13.6	6.0
Surface Wipe	3	26.0	12.0
Dust	2	70.8	31.1
Soil	2	43.0	38.5
Caulk	9	29.8	18.8
Other Materials[c]	0	---	---

[a] Duplicate sample results serve as an indicator of measurement precision for relatively uniform media such as air; for other media the duplicate sample results include elements of both measurement precision and non-homogeneity of analytes in the environment.

[b] Relative % difference calculated as $2 \times (|X_1 - X_2|)/(X_1 + X_2) \times 100$.

[c] No duplicate samples collected.

3.2 Quality Control Results for Congener Analysis

All of the indoor air samples, the outdoor air sample, and a subset of the remaining sample extracts previously analyzed for Aroclors were scheduled for congener-specific analysis and were successfully analyzed.

Recovery of the sum of the congeners in Aroclor 1254 in the air filter media field controls is reported in Table 3-7. Average recoveries were 85.9 ± 12.3%. Laboratory matrix spike recovery results are reported in Table 3-8. Recovery of the sum of the congener concentrations in Aroclor 1254 congeners ranged from 91.1% for caulk to 112% for dust. Recoveries of the surrogate compounds TCMX and DCBP are shown in Table 3-9 and ranged from 72.6 ± 28.6% for caulk TCMX to 153 ± 13.2% for DCBP in dust samples. The remaining average recovery results ranged from 81 to 117%.

Air media field blank results are reported in Table 3-10. No congeners were measured in the air field blanks at detectable levels (the congener QL was 0.5 ng/sample). Laboratory method blank results are shown in Table 3-11. Results were below detectable levels for all congeners for the air, surface wipe, dust, soil, and other materials blanks. The method blank value for the sum of measured congeners in the single caulk method blank was 0.03 µg/g which was far below the total PCB concentrations measured in most caulk samples.

Precision was examined using duplicate samples collected for air and caulk. Precision results for duplicate sample collection and analysis are reported in Table 3-12. The average RPD for three air sample duplicates was 17.9 ± 4.5% while the RPD for the single caulk duplicate sample analyzed for congeners was 41.7%.

Table 3-7. Congener analysis: total recovery of congeners in Aroclor 1254 from field controls

		Spiking Level	Field Controls[a] % Recovery	
Media	**N**	**ng/ sample**	**Mean**	**SD**
Air	3	1000	85.9	12.3

[a] Sample media were spiked, transported to and from the field site, and stored with samples until analysis.

Table 3-8. Congener analysis: total recovery of congeners in Aroclor 1254 from laboratory matrix spikes[a]

		Spiking	Spiking	% Recovery	
Media	**N**	**Level**	**Units**	**Mean**	**SD**
Air	4	1000	ng/sample	96.1	2.6
Surface Wipe	2	12.5	µg/sample	94.2	24.1
Dust	1	0.245	µg/g	112	---
Soil	2	1.21	µg/g	95.0	7.0
Caulk	1	1.23	µg/g	91.1	---
Other Materials	1	1.25	µg/g	95.2	---

[a] Sample media were spiked in the laboratory immediately prior to extraction.

Table 3-9. Congener analysis: recovery of surrogate analytes from samples and duplicate samples[a]

		Spiking Level µg/sample		TCMX % Recovery		DCBP % Recovery	
Media	**N**	**TCMX[b]**	**DCBP[c]**	**Mean**	**SD**	**Mean**	**SD**
Air	11	0.025	0.25	93.1	6.9	104	10.3
Surface Wipe	10	0.25	2.5	81.0	5.1	85.0	4.2
Dust	4	0.05	0.5	103	3.2	153	13.2
Soil	3	0.25	2.5	94.9	1.0	109	12.7
Caulk[d]	5	0.25	2.5	72.6	28.6	88.2	27.5
Other Materials	18	0.25	2.5	93.3	8.7	117	20.1

[a] Two surrogate analytes were spiked on every sample and duplicate sample prior to extraction.

[b] TCMX = Tetrachloro-meta-xylene.

[c] DCBP = Decachlorobiphenyl (PCB Congener #209).

[d] Four caulk samples were diluted significantly for analysis; surrogate recoveries not available for these samples and are not included in the recovery statistics.

Table 3-10. Congener analysis: total PCBs measured on field blanks

				Field Blanks[a]	
Media	**N**	**QL[b]**	**Units**	**Mean**	**SD**
Air	3	0.5	ng/m^3	ND[c]	---

[a] Unfortified sample media, transported to and from the field site, and stored with samples until analysis.

[b] QL = quantitation limit.

[c] ND = not detected.

Table 3-11. Congener analysis: total PCBs measured in laboratory method blanks

				Lab Method Blanks[a]	
Media	**N**	**QL[b]**	**Units**	**Mean**	**SD**
Air	2	0.5	ng/m^3	ND[c]	---
Surface Wipe	2	0.0025	µg/100 cm^2	ND	---
Dust	1	0.00025	ppm	ND	---
Soil	2	0.00125	ppm	ND	---
Caulk	1	0.00125	ppm	0.030	---
Other Materials	4	0.00125	ppm	ND	---

[a] Unfortified solvent taken through extraction and analysis.

[b] QL = quantitation limit.

[c] ND = not detected.

Table 3-12. Congener analysis: precision results for duplicate sample total PCB measurements[a]

		Relative % Difference[b]	
Media	**N**	**Mean**	**SD**
Air	3	17.9	4.5
Caulk	1	41.7	---

[a] Duplicate sample results serve as an indicator of measurement precision for relatively uniform media such as air; for other media the duplicate sample results include elements of both measurement precision and non-homogeneity of analytes in the environment.

[b] Relative % difference calculated as $2 \times (|X_1 - X_2|)/(X_1 + X_2) \times 100$

3.3 Quality Assurance Assessments

Quality assurance assessments of field and laboratory data collection and analyses were performed at multiple levels. A summary of reviews and outcomes is provided below.

- On-site QA assessment of field sampling procedures and adherence to protocols was performed. Air sampling flow rate measurements were verified using audit flow devices. Corrective action was taken when it was determined that air sampling pumps were not being started at targeted flow rates.
- All field sampling data were QA reviewed to ensure accuracy and completeness. Corrective action was taken for three air samples that did not have the correct total sampled air volume calculated correctly. The correct air volume data were applied to Aroclor and congener analysis results.
- The analytical laboratory performed ongoing review of calibration, continuing calibration checks, QC recovery and background assessments, and instrumental performance parameters. Two groups of sample extracts were reanalyzed based on data quality review.
- Analytical laboratory results were first QA reviewed by NERL's contractor, and then again by NERL scientists to ensure that the results were complete and accurate. Quality control results were summarized and examined to ensure overall data quality objectives were met.
- NRMRL experts reviewed the caulk/materials emission model and model calculations.
- A NERL QA review was performed to ensure that the measurement data were accurately transcribed into data analysis files and that calculations were correctly performed. Transcription accuracy into the report tables was also assessed.

4.0
Results

4.1 School Information

Basic information regarding the six schools with PCB measurement results used in this report is shown in Table 4-1. Five of the schools were primary schools and two of those contained pre-kindergarten classes. The sixth school was a secondary school. The school buildings were constructed between 1959 and 1972 and all but one had 3 floors. The secondary school had multiple wings with 2 to 3 floors per wing. Only one school (School 1) had heating, ventilation, and air conditioning (HVAC) forced air units serving the entire building. For the other five schools, different types of heating and ventilation systems were present in the schools including exhaust ventilation ducts only, single room unit ventilators, and zoned heating/ventilation systems for specific spaces such as gymnasiums. These schools did not have building-wide air conditioning systems and in many cases relied on natural ventilation, including opening windows, in warmer months. Several schools had window air conditioners in some rooms.

Table 4-1. School building information

School	Grade Levels	Year Constructed	Floors	Ventilation System(s)
1	K-5/PK-12[a]	1972	3	- 6 HVAC units serving different building zones - Window glazing previously replaced
2	K-5	1962	3	- Classroom/bathroom exhaust systems with 19 roof exhaust fans - Separate H/V systems for gymnasium and auditorium - Window-mounted AC units in most classrooms - Windows/frames previously replaced
3	PK-5/K-1	1963	3	- Classroom/bathroom exhaust systems with 15 roof exhaust fans - Basement fans provide H/V for gymnasium and auditorium - Window-mounted AC units in most classrooms - Windows/frames previously replaced
4	PK-5	1959 Additions 1968,2005	1	- Exhaust systems vented to roof in older building areas - Office window-mounted AC units - 3 HVAC units in new construction
5	PK-8	1961	3	- Four HVAC systems - not operable - 11 roof exhaust fans - 10 window and 10 portable AC units
6	9-12	1968	2 to 3	- Unit ventilators in classrooms and cafeteria - H/V systems in auditorium and gymnasium - Several window AC units

[a] K = kindergarten; PK = pre-kindergarten

Five schools were part of the NYC remedial pilot investigation while the sixth school was scheduled for demolition and had no measurements associated with remedial activities. Information regarding the sampling time points and different remedial and sampling activities is summarized in Table 4-2. Much more detailed information regarding remedial activities and outcomes at the five NYC schools is provided in the NYC SCA remedial investigation reports (NYC SCA 2011; NYC SCA 2012). The remedial investigation is ongoing and further information will be available in the future (http://www.nycsca.org/Community/Programs/EPA-NYC-PCB/Pages/default.aspx). The measurement time points that were used in SHEDS exposure/dose modeling are shown in Table 4-2. It is important to recognize that different types of remedial actions were taken at the different school buildings, and that caulk remediation completed during the first year at Schools 1, 2, and 3 only occurred in the rooms or transitory areas to be sampled.

The conditions at each of the schools at the measurement time points used in the SHEDS exposure/dose modeling are shown in Table 4-3. All of the measurements at these time points occurred between late spring and early fall, with outdoor temperatures ranging from 69 to 94°F and indoor temperatures ranging from 70 to 84°F. The status of the operation of ventilation systems and whether doors and windows were open or closed in the measurement rooms is also reported in Table 4-3. At School 1, it was learned following the post-remedial sampling time points that the HVAC system controllers were not operating correctly on all units and that exterior air had not been incorporated at the designed ventilation rates. This may have been a factor in indoor air PCB concentrations at that school. The gymnasium heating/ventilation system at School 6 was not operating during the indoor air sample collection period and the lack of forced ventilation with outdoor air may have impacted indoor air concentrations in the gym.

Table 4-2. School building remediation activity and environmental sampling summary

School	Activity	Additional Information	Date	Samples[a]	SHEDS[b] Modeling
1	Pre-remediation		July 2010	A, W, S	Yes
	Caulk patch and repair	Sampled spaces only	July 2010	A, W	
	Ventilation with outdoor air	24-hr high vol., filtered	Aug 2010	A	
	Soil cover and access restriction	>1 ppm PCB	Aug 2010		
	Cleaning & light fixture removal	Pre-K, K only	Aug 2010	A	Yes
	Supplemental cleaning		Aug 2010	A	
	HVAC evaluation and repair		Sept 2010	A	
	Pre-remediation		June 2011	A,W,S	Yes
	Encapsulate exterior caulk		July 2011		
	Soil removal/replacement	>1 ppm PCB	Aug 2011		
	Caulk patch and repair	Whole building	Aug 2011	A,W	
2	Pre-remediation		July 2010	A,W,S	Yes
	Caulk removal	Sampled spaces only	Aug 2010	A,W	
	Ventilation with outdoor air	24-hr high vol., filtered	Aug 2010	A	
	Soil cover and access restriction	>1 ppm PCB	Aug 2010		
	Heating/ventilation cleaning	Whole building	Aug 2010		
	Cleaning & light fixture removal	Whole building	Aug 2010	A	Yes
	Caulk encapsulation	Whole building	Sept 2010	A	
	Exterior caulk removal		Apr 2011		
	Pre-remediation		June 2011	A,W	Yes
	Soil removal/replacement	>1 ppm PCB	Aug 2011		
	Caulk removal	Whole building	Aug 2011	A,W	
3	Pre-remediation		July 2010	A,W,S	Yes
	Caulk encapsulation	Sampled spaces only	Aug 2010	A,W	
	Ventilation with outdoor air	24-hr high vol., filtered	Aug 2010	A	
	Soil cover and access restriction	>1 ppm PCB	Aug 2010		
	Heating/ventilation cleaning	Whole building	Aug 2010		
	Cleaning & light fixture removal	Whole building	Aug 2010	A	Yes
	Pre-remediation		June 2011	A,W	Yes
	Soil removal/replacement	>1 ppm PCB	July 2011		
	Caulk encapsulation	Whole building	Aug 2011	A,W	
	Re-Cleaning	Selected rooms	Aug 2011	A	
4	Pre-remediation		May 2011	A,W,S	Yes
	Soil cover and access restriction	>1 ppm PCB	2011		
	Light fixture removal	Whole building	Aug 2011	A,W	
	Caulk encapsulation	One stairwell	Sept 2011	A	Yes
5	Pre-remediation		June 2011	A,W,S	Yes
	Soil cover and access restriction	>1 ppm PCB	2011		
	Remove/replace windows	Selected areas w old windows	Aug 2011	A, W	
	Re-cleaning	Sampled spaces	Sept 2011	A,W	Yes
6	Pre-demolition		July 2011	A,W,S,D	Yes

[a] A = air samples, W = surface wipe samples, S = soil samples, D = dust samples.

[b] SHEDS exposure modeling using data at this time point.

Table 4-3. School building information at sampling time points used in exposure modeling

School	Sample Time Point	Sample Date	Average Indoor Temp. °F	Outdoor High Temp. °F[a]	Conditions
1	Pre-Remediation	July 2010	74	87	- HVAC systems operational - Windows and doors closed
	Post-Remediation (Caulk patch/repair & light removal)	Aug 2010	70	69	- HVAC systems operational - Outdoor air dampers found closed in some units - Windows and doors closed
	Pre-Remediation	June 2011	74	72	- HVAC systems operational - Doors closed
2	Pre-Remediation	July 2010	83	94	- Exhaust systems operational; window ACs off - Windows and doors closed
	Post-Remediation (Caulk removal & light removal)	Aug 2010	76	79	- Exhaust systems operational; window ACs off - Windows opened; doors closed
	Pre-Remediation	June 2011	77	83	- Exhaust systems operational - Doors closed, windows opened slightly
3	Pre-Remediation	July 2010	77	83	- Exhaust systems operational; window ACs off - Windows and doors closed
	Post-Remediation (Caulk encapsulation & light removal)	Aug 2010	74	82	- Exhaust systems operational; window ACs off - Windows opened; doors closed
	Pre-Remediation	June 2011	78	80	- Exhaust systems operational - Doors closed, windows opened slightly
4	Pre-Remediation (Light removal)	May 2011	83	84	- Exhaust systems operational; window AC units on - Windows opened slightly where no AC units - Doors closed
	Post-Remediation	Aug/Sept 2011	72	80/78	- Exhaust systems operational; window AC units on - Windows opened slightly where no AC units - Doors closed
5	Pre-Remediation	May 2011	84	79	- Exhaust systems operational - Doors closed, windows opened slightly
	Post-Remediation (Window replacement)	Aug/Sept 2011	79	84/83	- Exhaust systems operational; window AC units on - Windows opened slightly where no AC units - Doors closed
6	Pre-Demolition	July 2011	81	86/91	- Room unit ventilators operating - Gymnasium H/V not operating - Doors and windows closed; lights on

[a] Outdoor air high temperature on sampling day(s) from a nearby National Weather Service reporting station.

4.2 PCB Source Characterization

4.2.1 Caulk

Between the 1950s and early 1970s PCBs were sometimes added to caulk and other sealants as a plasticizer. In some cases PCBs were added to caulk at the construction site to improve its application properties. PCB-containing sealants have been shown to be present in buildings, and buildings with PCB-containing sealants have higher indoor air PCB concentrations than other buildings. A total of 427 samples of interior caulk and other sealants such as window glazing and building joint material were collected at five of the six schools. A total of 73 samples of exterior caulks and sealants were collected at three of the schools. A summary of total PCB measurement results is reported in Table 4-4. Measurement results reported in Table 4-4 were divided into samples with values greater than or less than 100 ppm because only a few samples had measurement results between 100 and 1000 ppm, and very few had values between 100 and 200 ppm. The analysis laboratory reported that Aroclor 1254 was the PCB mixture best matched in most of the caulk samples, with Aroclor 1260 reported for some caulk samples at School 1. The median concentration for interior caulks with values <100 ppm was 6.9 ppm, while the median level for caulks with >100 ppm was 102,000 ppm (or about 10% PCBs by weight). The highest measured concentration in indoor caulk was 440,000 ppm (44% PCBs by weight) from caulk around a school display case. In exterior caulks the median for <100 ppm caulks was 5.9 ppm and for >100 ppm caulks the median was 130,000 ppm. The highest concentration measured in exterior caulk was 328,000 ppm.

Caulk total PCB measurement results are shown separately by school for interior and exterior caulks in Table 4-5. When considering caulk measurement results from these schools it is important to note that multiple samples of the same kind of caulk may have been collected from different locations in and around the building. Schools 1 and 6 had lower levels of PCBs in interior caulks than the other three schools. The median interior caulk value for School 1 was 309 ppm for samples with >100 ppm, while School 6 did not have any interior caulks with >100 ppm. At the other three schools the median interior caulk values for caulks with >100 ppm ranged from 127,000 to 232,000 ppm. The maximum value measured at School 1 was 90,700, which was at least 60% lower than the maximum levels at Schools 2, 3, and 4. For three schools with exterior caulks, median total PCB concentrations for caulks with <100 ppm ranged from 3.5 to 19 ppm. Median values ranged from 77,500 to 193,000 for caulks with >100 ppm.

Another way to show the range of caulk PCB concentrations is by concentration category (Table 4-6). Over 82% of the 427 interior caulk samples had concentrations <50 ppm while 6% had concentrations greater than 100,000 ppm. Only 37% of the exterior caulk samples had concentrations <50 ppm while 41% had concentrations

Table 4-4. Caulk total PCB measurement results for schools with available data

				Total PCB Levels in Caulk[a,b]		
	N Schools	N Samples	% > QL[c]	Median ppm	Inter-Quartile Range ppm	Overall Range ppm
Interior Caulks						
< 100 ppm	5[d]	375	86	6.91	2.90 - 17.4	<QL - 88.9
> 100 ppm	5	52	100	102,000	2,110 - 233,000	103 - 440,000
Exterior Caulks						
< 100 ppm	3[e]	27	96	5.88	2.16 - 9.94	<QL - 45.0
> 100 ppm	3	46	100	130,000	3,870 - 248,000	126 - 328,000

[a] Reported as total PCBs from Aroclor measurements.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] QL = quantitation limit; sample size dependent, typically ≤ 1 ppm (range 0.3 – 79 ppm).

[d] Schools 1,2,3,5,6.

[e] Schools 4,5,6.

Table 4-5. Caulk total PCB measurement results by school

			Total PCB Levels in Caulk[a,b]		
	N	**% > QL[c]**	**Median ppm**	**Inter-Quartile Range ppm**	**Overall Range ppm**
Interior Caulks <100 ppm					
School 1	97	62	1.78	<QL - 6.20	<QL - 64.6
School 2	101	95	10.9	5.33 - 34.6	<QL - 88.9
School 3	106	93	9.33	5.34 - 15.7	<QL - 43.6
School 5	51	92	5.84	2.55 - 16.8	<QL - 83.1
School 6	20	100	11.5	4.95 - 23.5	1.99 - 67.7
Interior Caulks >100 ppm					
School 1	14	100	309	204 - 19,300	114 - 90,700
School 2	12	100	127,000	83,000 - 151,000	103 - 243,000
School 3	14	100	217,000	82,600 - 284,000	1,430 - 440,000
School 5	12	100	232,000	138,000 - 264,000	1,600 - 306,000
School 6	0	--	--	--	--
Exterior Caulks <100 ppm					
School 4	8	100	3.50	2.07 - 5.51	1.68 - 29.6
School 5	18	94	6.62	2.34 - 10.7	<QL - 45.0
School 6	1	100	19.1	--	--
Exterior Caulks >100 ppm					
School 4	7	100	77,500	5,690 - 91,100	126 - 226,000
School 5	31	100	193,000	2,560 - 288,000	319 - 328,000
School 6	8	100	138,000	118,000 - 144,000	84,400 - 152,000

[a] Reported as total PCBs from Aroclor measurements.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] QL = quantitation limit; sample size dependent, typically ≤ 1 ppm (range 0.3 – 79 ppm).

>100,000 ppm. Caulk concentrations by category are shown for individual schools in Appendix B. Insufficient information was available for most of the schools to determine how many discrete types of caulk were present at each school. Approximately six different kinds of interior caulk, window glazing, and joint material were found at School 6 across the seven rooms that were sampled, with most of those appearing in multiple rooms. Two types of exterior caulk were found at School 6 where 8 samples collected from around windows and in building joints contained >80,000 ppm of PCBs and were likely the same material while a ninth exterior sample from an entranceway brick/masonry seam contained 19 ppm.

None of the interior caulks at School 6 (which included caulk, window glazing, and joint material) contained high levels of PCBs. However, no sealants were found in the hallways and stairwells. In the seven rooms that were sampled, at least one sample of every type of sealant present in the room was collected, and it appeared that the materials that were collected were common in rooms throughout the building. Given the number of sealants present inside large school buildings it is possible that a interior sealant with high PCB levels was not collected, but it is unlikely that the sampling failed to identify one that was widely used in accessible areas throughout the building.

All of the caulk samples with high PCB levels collected in NERL studies were still at least somewhat flexible and largely intact. All of the brittle or dry caulk and other sealant materials had levels of PCBs <50 ppm. However, intact and flexible caulks and other sealants were found that also had <50 ppm PCBs. It is difficult to determine whether a caulk or other sealant is likely to contain high levels of PCBs,

Table 4-6. Interior and exterior caulk and window glaze total PCB measurement results by concentration category

Concentration Category	Interior Caulk and Window Glaze Five Schools[a]	Exterior Caulk and Window Glaze Three Schools[b]
	Number of Samples	
All samples	427	73
< 50 ppm	351	27
50 – 999 ppm	33	5
1,000 – 9,999 ppm	6	11
10,000 – 99,000 ppm	11	5
100,000 – 199,999 ppm	10	9
200,000 – 299,999 ppm	14	11
300,000 – 399,999 ppm	1	5
400,000 – 499,999 ppm	1	0
	Percentage of Samples	
< 50 ppm	82.2	37.0
50 – 999 ppm	7.7	6.8
1,000 – 9,999 ppm	1.4	15.1
10,000 – 99,000 ppm	2.6	6.8
100,000 – 199,999 ppm	2.3	12.3
200,000 – 299,999 ppm	3.3	15.1
300,000 – 399,999 ppm	0.2	6.8
400,000 – 499,999 ppm	0.2	0

[a] Schools 1,2,3,5,6.

[b] Schools 4,5,6.

particularly when that material is still somewhat flexible. Sampling and analysis in a laboratory is the only sure way to know at this time. Development of field-portable screening methods would allow more rapid characterization of sealants in buildings. For example, hand-held x-ray fluorescence (XRF) devices could be evaluated for their ability to detect PCBs in materials such as caulk in-situ, but issues regarding caulk dimensions and interferences or materials that would give false positives would need to be examined.

A total PCB emission modeling approach was used to estimate PCB emissions from caulk collected at several locations at two schools. The total concentration of PCBs in caulk was measured as Aroclors and information was available for the caulks at these locations for calculation of their total surface area. The method used to estimate the total PCB emission rate was described in Section 2, and assumes that the PCB content in the caulk is equivalent to the congener mixture in Aroclor 1254, which was the Aroclor reported by the analysis laboratory.

Emission rate estimates shown in Table 4-7 are based on the emission parameters derived from chamber tests of different caulk samples at 23°C. Estimates of total PCB emission rates from several caulks collected in the gymnasium and cafeteria ranged from 140 to 600 µg/hr. Estimates from three types of caulk collected in a third floor corridor at School 2 ranged from 53 to 3100 µg/hr. Estimates of emissions from caulk at exterior window locations at two classrooms at School 6 ranged from 830 to 940 µg/hr. These window locations included caulk around the window frame, around the concrete/brick seams below the window, and from around the unit ventilator air intake grill. Finally, a total PCB emission rate of 320 µg/hr was estimated for caulk collected from a single 2-story building joint at School 6. Graphical representations of the relative emissions for several of the sets of caulk are shown in Figure 4-1. There are uncertainties in these estimates because it is not known if the emission parameters for the measured caulks match those tested in the chamber (although emission parameters for the 12 caulks that were tested were consistent). Also, the actual emission

Table 4-7. Estimates of total PCB emission rates for several examples of PCB-containing caulk

School	Room	Material	Linear Length of Caulk m (ft)	Surface Area m^2	Total PCB ppm	Estimated Emission Rate[a] µg/hr
2	Gymnasium	Interior Door Frame Caulk	33.5 (110)	0.1431	117,000	460
2	Gymnasium	Interior Bay Door Caulk	5.2 (17)	0.0442	137,000	160
2	Cafeteria	Door Frame Caulk	25.6 (84)	0.219	57,100	340
2	Cafeteria	Metal Door Frame Caulk	23.2 (76)	0.198	112,000	600
2	Cafeteria	Bay Door Frame Caulk	4.3 (14)	0.036	146,000	140
2	Corridor	Interior Door Caulk	110 (360)	0.468	243,000	3,100
2	Corridor	Interior Wall Panel Caulk	3.7 (12)	0.0468	217,000	280
2	Corridor	Interior Metal Panel Caulk	2.7 (9)	0.0117	165,000	53
6	Classroom 3	Exterior Window Caulk[b]	28.3 (93)	0.271	112,000	830
6	Classroom 4	Exterior Window Caulk[b]	29.9 (98)	0.286	120,000	940
6	N/A	Exterior Joint Caulk[c]	6.4 (21)	0.0813	142,000	320

[a] Based on PCB emission parameters derived from chamber measurements of other caulks at 23°C.

[b] Calculated using entire length of caulk around both window frame units, the single unit ventilator inlet, and concrete-brick seams below both windows.

[c] Calculated for one joint that was 2 stories high. There were multiple joints around the building exterior.

rate is likely to depend on the temperature. Guo et al. (2011) found in chamber testing that emission rates increased by approximately 6-fold with a 10°C increase in temperature. The temperature of caulk on the exterior of a building may also become higher than ambient temperature due to radiant heating from the sun and/or, in the winter because of heat from the building.

The emission rates estimated for caulks at four of the building locations (Table 4-7) were used to generate screening level estimates of the indoor air PCB concentrations that could potentially result under different assumed conditions of ventilation with outdoor air. The approach for calculating screening-level PCB indoor air concentration estimates was described in Section 2, using Equation 2.1.6. Numerous assumptions apply to this estimation approach, and results reported in Table 4-8 are considered to be only screening-level estimates. One important factor is the room air exchange rate.

While recognized as important for indoor pollutant modeling, accurate measurement of ventilation conditions including both indoor/outdoor air exchange and inter-zonal flows in large old buildings – and for specific rooms within those buildings - is difficult. Information on this approach and the conditions that must be met to do this have been described (Persily, 1997) and an ASTM method has been developed, Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation, ASTM D6245-07. A central tenet of the procedure for producing accurate ventilation rate information, whether using decay or equilibrium procedures, is that the space to be evaluated is a single zone wherein the tracer concentration is uniform and that only exchanges air with the outdoors. By definition, the tracer concentration must not differ by more than 10% from the average across all locations in the building or building zone. For spaces that do not meet the 10% criterion, it must be demonstrated that there is no significant airflow from other building spaces, such as hallways or other rooms, into the test space. It is important that the indoor pollutant of interest be measured at the same time that AER is being measured since ventilation rates in a room can change rapidly under different ventilation system and door/window use conditions.

Other researchers have measured air exchange rates (AERs) in school building rooms and a wide range of AERs have been reported, ranging from less than 0.5 to 12 hr^{-1} (MacIntosh et al., 2012; Nazaroff et al., 2010; Godwin and Batterman, 2007; Bartlett et al., 2004; Scheff et al., 2000). AER measurements have been based on measurements of ventilator airflow rates, equilibrium or decaying CO_2, or SF_6 decay. These methods allow an assessment of the

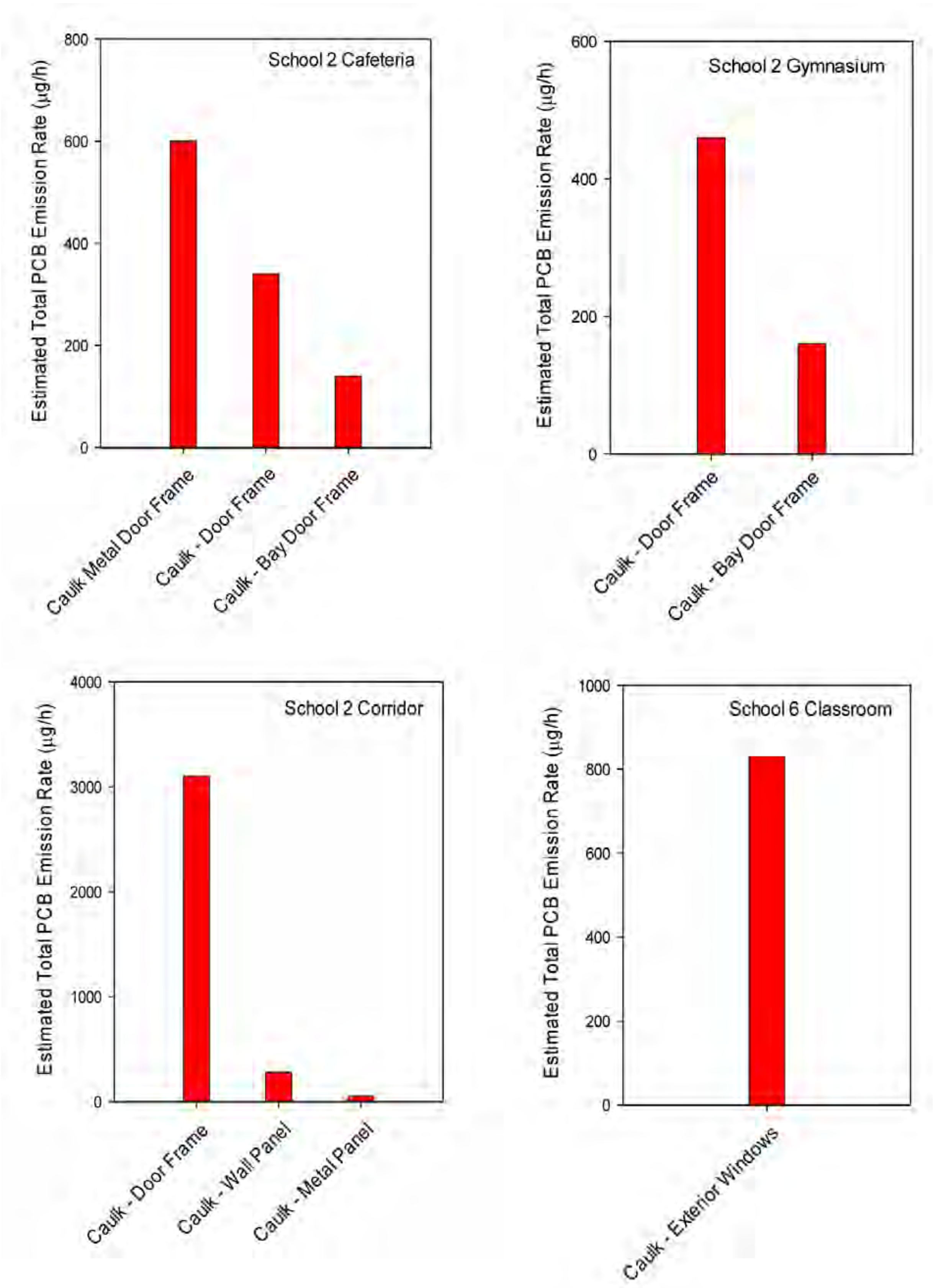


Figure 4-1. Estimated total PCB emission rates from caulk in several building locations

Table 4-8. Screening-level comparison of predicted air concentrations resulting from PCB emissions from caulk to measured concentrations

Room[a]	Room Volume m³	Estimated Emission Rate[b] µg/hr	% Emissions Entering Room[c]	Predicted Total PCB Air Concentration in Rooms at Different Air Exchange Rates[d] ng/m³ AER = 0.5	AER = 1.0	AER = 2.0	AER = 4.0	Measured Total PCBs In Room Air[e] ng/m³
Gymnasium	2666	620	100	460	230	120	58	1360
Cafeteria	1134	1080	100	1900	950	480	240	600
Classroom 3	201	830	1	83	41	21	10	950
			5	410	210	100	52	
			10	830	410	210	100	
Classroom 4	182	940	1	100	52	26	13	690
			5	520	260	130	65	
			10	1000	520	260	130	

[a] Gymnasium and cafeteria at School 2; Classroom 3 and Classrom 4 at School 6.

[b] Estimated total PCB emission rates from caulk based on PCB emission parameters derived from chamber measurements of other caulks at 23°C.

[c] Percent of the total PCB emissions entering the room air. For the two classrooms, the PCB-containing caulk was around the two exterior windows, one exterior unit ventilator intake grill, and exterior concrete/brick joints below the windows. Values of 1%, 5%, and 10% of the PCB emissions entering the classrooms from the exterior caulk were used. For the gymnasium and cafeteria, all caulk was located inside the rooms and a value of 100% was used.

[d] Predicted air concentrations at several possible air exchange rates for the room. Calculations based on the estimated PCB emission rate and ventilation rate (see Eq. 2.1.6). Assumes 23°C, steady state emission and ventilation conditions, steady-state absorption/desorption from other room materials, complete room air mixing, the concentration of PCBs in the ventilation air is zero, caulk is the only source of PCBs, and that the PCB mixture in the caulk is equivalent to Aroclor 1254.

[e] Air samples were collected under different temperature conditions; gym and cafeteria @ 28°C; classrooms 3 and 4 @ 27°C. The exterior temperature for classrooms 1 and 2 ranged from an overnight low of 19°C and a daytime high of 33°C. The estimated emission rates and predicted room air concentrations may be underestimates relative to actual conditions because they are based on emission parameters generated at 23°C.

overall ventilation rate for a room, but do not always provide accurate information regarding how much of the total ventilation air flow is occurring between the room being assessed and other building spaces. This is important for indoor pollutants such as PCBs, which can be generated in other building spaces and transported between building spaces – it can't be assumed that the ventilation air coming into a room from other interior building spaces is PCB-free. It is also important to recognize that AERs for a room can change rapidly depending on changes in operation of mechanical ventilation systems and opening and closing of doors and windows.

Actual ventilation rates were not measured in the schools included in this report at the time of sample collection, and ventilation rates may change substantially under different conditions of mechanical ventilation system operation, window and door opening, human activity, and temperature. Screening-level estimates were prepared using air exchange rates (AER) of 0.5, 1.0, 2.0, and 4.0 air changes per hour (assuming that all of the ventilation air was from outdoors with low/no PCBs). For comparison, current ANSI/ASHRAE standards call for 7.4 L/s (15 cubic feet per minute) per person for outdoor air ventilation rates in classrooms with 5 – 8 year old children; giving an overall AER with outdoor air of 3.3 ach for 25 people in a 200 m^3 classroom. Forty- to fifty-year-old school buildings may not meet current ANSI/ASHRAE standards. The gymnasium described in Table 4-8 had a ventilation system design AER of 4.33 and had measured AERs of 1.75 and 1.52 using ventilator airflow measurement and tracer decay measurement, respectively (NYC SCA, 2012). Measurement-based values are not available for the other three rooms used in this screening-level example, but it is anticipated that the range of 0.5 – 4.0 AER will cover the range of likely ventilation rates under most use conditions. Thus, screening level estimates were generated for a range of possible AER.

Exterior caulk with high PCB levels was present at two windows for each of two of the classrooms in Table 4-8. These classrooms had no interior caulk with high PCB levels. It is not known what fraction of the PCBs emitted from outdoor installations will enter indoor spaces. The amount is likely quite variable depending on the location and extent of the PCB-containing caulk, the temperature, wind speed, whether windows are open or closed, whether caulk is present at ventilation system intake openings, and the operation of the ventilation system. In this screening-level estimation exercise, indoor air concentrations were estimated using a range of penetration rates including 1, 5, and 10% of total PCB emissions.

Screening-level estimates of indoor air total PCB concentrations under different AER conditions are shown in Table 4-8 for four rooms. A wide range of possible indoor air PCB concentrations resulting from emissions from PCB-containing caulk were found under the range of assumed AER and penetration conditions. Indoor air concentrations measured at one time point are shown for comparison. In general, measured concentrations were consistent with indoor air levels that might be present from caulk emissions at the Cafeteria and Classroom 4. Measured concentrations were higher than the largest estimated concentrations for the Gymnasium and Classroom 3. There are many assumptions in these estimates and the results can be considered only screening-level. Reasons for the differences could include higher room temperatures as compared to chamber testing temperatures, higher penetration rates from exterior caulk emissions, the presence of other sources (such as emissions from light ballasts or fixtures), or ventilation from more highly contaminated spaces within the building.

4.2.2 Light Ballasts

Fluorescent light fixtures installed in buildings prior to the late 1970s often used ballasts with PCB-containing capacitors. Some of those fixtures and ballasts may remain in school buildings today. PCB emissions from intact ballasts have been demonstrated in laboratory chamber studies and have been shown to be highly temperature dependent (Guo et al., 2011; Hosomi et al., 2005). PCB-containing ballasts are likely to have exceeded their expected operational lifetime, and capacitors in ballasts can fail with PCBs rapidly released into the building environment. One ballast capacitor burst during laboratory chamber emissions testing, resulting in very high levels of PCBs in the air and on chamber surfaces (Guo et al., 2011). Fluorescent light ballasts may be important sources of PCBs in building environments.

Light ballast capacitors for schools of this age are most likely to contain Aroclor 1242 or Aroclor 1016, which means that emissions of more volatile, lower chlorine-number congeners would be expected to be released into the school environment. However, use of Aroclors 1221 and 1254 in capacitors was also reported (U.S. EPA, 1976). Capacitor oil was analyzed in three ballasts tested by Guo et al. (2011) and all were identified as Aroclor 1242. NYC SCA analysis of school light ballast capacitor oil was analyzed showed that Aroclor 1242 was present in the single ballasts tested from Schools 1, 3 and 4, while Aroclor 1254 was present in a ballast from School 2. Ballast capacitor oil measurements were not available for Schools 5 and 6.

Survey results are available for fluorescent light fixtures at five schools (Table 4-9). Between 24 and 95% of the surveyed ballasts were likely to be PCB-containing. The total number of ballasts that were likely to be PCB-containing ranged as high as 879 at one school. A breakdown of the ballast survey result by room at School 6 is shown in Table 4-10. Temperatures at the surfaces of several operating ballasts (with lights on) were measured at School 6 and ranged from 48°C to 54°C.

No emission estimates have been made for two conditions that might be present in buildings. First, some ballast capacitors may have previously failed and leaked contents into light fixtures. Residues may serve as a source of PCB emissions. Second, some ballasts may be leaking and have emission rates higher than those measured in chamber testing. At this time there are no data suitable for estimating emission rates for these two conditions. It is not clear

Table 4-9. PCB-containing fluorescent light ballast survey results from five schools

School	Ballasts Not Containing PCBs	Ballasts Likely Containing PCBs	Total Ballasts in School	% Ballasts Likely Containing PCBs
1	310	417	727	57%
2	114	373	487	77%
3	344	275	619	44%
4	48	879	927	95%
6[a]	25	8	33	24%

[a] Only a subset of ballasts in School 6 were surveyed.

Table 4-10. PCB-containing fluorescent light ballast survey results at School 6

Location	Number of Ballasts Visually Examined[a]	Number of Ballasts Not Containing PCBs[b]	Number of Ballasts Likely Containing PCBs[c]
Classroom 1	1	1	0
Lab Classroom 2	5	4	1
Classroom 3	5	5	0
Classroom 4	16	13	3
Shop Classroom 5	2	0	2
Cafeteria	4	2	2
Gymnasium	0	--	--
Total across locations	33	25	8

[a] In-place visual examination of ballasts to examine ballast label.

[b] Ballast labels explicitly state “No PCBs”. Ballasts included Sylvania Quicktronic QT 2X32/120 IS; Advance REL-2P32-SC; Advance R-2S40-1-TP; Advance RQM-2S40-3-TP; Phillips Advance ICN-2P32-N; Universal 446-L-SLH-TC-P.

[c] Ballast labels did not state “No PCBs”. All ballasts were General Electric 7G1020B.

whether the one ballast tested in laboratory chambers by Guo et al. (2011) that had a much higher emission rate than the other three ballasts that were tested represents a leaking ballast condition.

Total PCB emission rates were estimated from four intact ballasts that were tested at 23°C and 45°C in a laboratory chamber (Section 2). Those emission rates were used to generate a range of estimated total emission rates for likely PCB-containing ballasts in three classrooms, with an assumption that the emission rates from the ballasts in the classroom would fall within the range of tested ballasts. Total estimated emission rates at 45°C ranged from 1.2 µg/hr from three ballasts at the lowest emission rate, up to 290 µg/hr from nine ballasts at the highest emission rate. The range of potential emission rates is shown in Figure 4-2. Total estimated emission rates at 23°C ranged from 0.08 µg/hr from three ballasts at the lowest emission rate, and up to 18 µg/hr from nine ballasts at the highest emission rate.

The estimated emission rates for intact light ballasts in the three classrooms were used to generate screening level estimates of the resulting indoor air PCB concentrations that might occur under different assumed conditions of ventilation with outdoor air. The approach for calculating screening-level PCB indoor air concentration estimates was described in Section 2, using Equation 2.1.7. Numerous assumptions apply to this estimation approach, and results reported in Table 4-11 are considered to be only screening-level because information is not available to understand whether all of the assumptions are correct for the light ballasts and conditions in the school rooms. Screening-level estimates of total PCB indoor air concentrations ranged from 1.6 to 2400 ng/m^3 for ballasts at 45°C, with median values ranging from 2.3 to 44 ng/m^3. Screening-level estimates of total PCB indoor air concentrations ranged from 0.1 to 150 ng/m^3 for ballasts at 23°C, with median values ranging from 0.14 to 2.8 ng/m^3. The lowest and median screening-level estimates of total PCB indoor air concentration are substantially lower than concentrations measured at one point in time, which ranged from 690 to 1460 ng/m^3. If all of the ballasts in a room had emission rates similar to the highest-emitting ballast in the chamber tests, it is possible that emissions could result in indoor air concentrations approaching those that were measured.

4.2.3 Secondary Source Characterization

Secondary sources of PCBs are defined here as materials that have become contaminated due to absorption of PCBs, either from direct contact with primary sources such as caulk, or through absorption of PCBs in the indoor air that have been emitted by caulk, light ballasts, or other primary sources. There are numerous materials and furnishings in buildings that have the potential to absorb semi-volatile organic chemical like PCBs. These materials can include paints, dust, foam, masonry, floor and ceiling tiles, mastics, wood, cork and pin board, and many others. After years of exposure to PCBs from primary sources, enough PCBs may have become absorbed to be become emission sources once the primary sources have been removed or otherwise remediated. These materials are also likely to continue to serve sinks as well as sources, due to their continued ability to absorb PCBs from the air and their often large surface areas. The materials' net effect as secondary sources depends on source-sink dynamics, which is affected by a number of factors including PCB concentration in materials and indoor air, diffusion and partition coefficient parameters, ventilation and room air flow rates, and temperature.

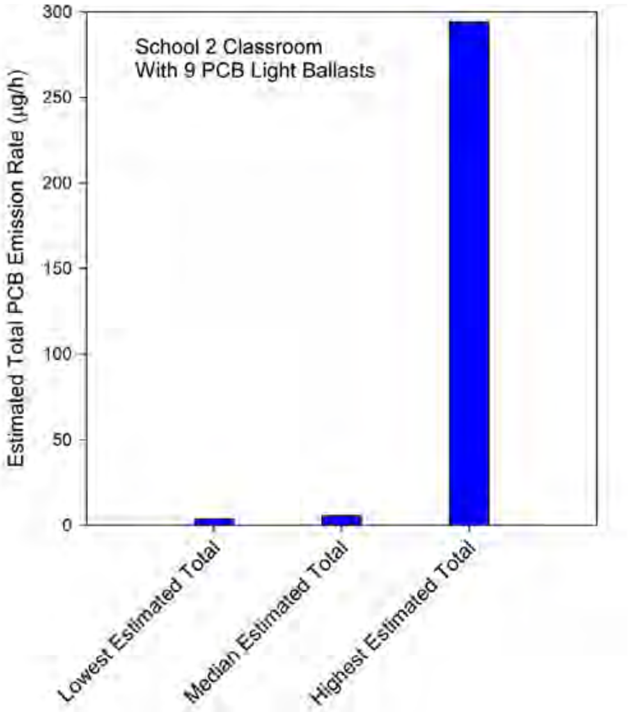


Figure 4-2. Example of the estimated range of total PCB emission rates from fluorescent light ballasts in a school classroom using the lowest, median, and highest rates from chamber tests of four ballasts

A wide range of building material samples was collected at Schools 2, 3, and 6. Materials were analyzed for total PCBs as Aroclors; Aroclor 1254 was reported for most materials, sometimes with an altered Aroclor pattern. Total PCB measurement results for 411 materials are shown in Table 4-12. When considering measurement results for these samples it is important to remember that multiple samples of the same type of material might have been collected from several places in a school building. Across all 411 materials, 93% had PCB levels higher than the quantitation limit, with a median concentration of 16.1 ppm (interquartile range 6.1 – 39.6 ppm) and a maximum value of 718 ppm. Paint had the highest total PCB concentrations with a median of 39 ppm (interquartile range 25.9 – 71.7 ppm). Fiberboard had a median level of 30.9 ppm (interquartile range 13.0 – 38.7 ppm), while lower levels were found in some other materials that often have high surface areas in buildings such as ceiling tile with a median 7.6 ppm (interquartile range 2.7 – 11.8 ppm) and floor tile with a median of 4.4 ppm (interquartile range of 1.4 – 8.7 ppm). Results for several material types

Table 4-11. Screening-level comparison of predicted air concentrations resulting from PCB emissions from fluorescent light ballasts to measured concentrations

Room and Balllast Condition[a]	Room Volume m^3	Number of PCB Containing Ballasts	Estimated Emission Rate[b] µg/hr	Predicted Total PCB Air Concentration in Rooms at Different Air Exchange Rates[c] ng/m^3				Measured Total PCBs In Room Air[d] ng/m^3
				AER = 0.5	AER = 1.0	AER = 2.0	AER = 4.0	
Using Emission Estimates at 45°C (near the temperature of light ballasts when lights are on)								
Classroom 1	231	5						1460
Lowest			0.416	18	9.0	4.5	2.2	
Median			0.614	27	13	6.6	3.3	
Highest			32.7	1400	710	350	180	
Classroom 2	249	9						859
Lowest			0.416	30	15	7.5	3.8	
Median			0.614	44	22	11	5.6	
Highest			32.7	2400	1200	590	300	
Classroom 4	182	3						690
Lowest			0.416	12	6.2	3.1	1.6	
Median			0.614	18	9.2	4.6	2.3	
Highest			32.7	980	490	240	120	
Using Emission Estimates at 23°C (near the temperature of light ballasts when lights are off)								
Classroom 1	231	5						1460
Lowest			0.026	1.1	0.56	0.28	0.14	
Median			0.038	1.7	0.83	0.42	0.21	
Highest			2.04	88	44	22	11	
Classroom 2	249	9						859
Lowest			0.026	1.9	0.94	0.47	0.23	
Median			0.038	2.8	1.4	0.69	0.35	
Highest			2.04	150	74	37	18	
Classroom 4	182	3						690
Lowest			0.026	0.78	0.39	0.19	0.10	
Median			0.038	1.1	0.57	0.29	0.14	
Highest			2.04	61	31	15	7.6	

[a] Classrooms 1 and 2 at School 2; Classroom 4 at School 6. Several estimates are made using the lowest, highest, and median emission rates from four ballasts tested in a chamber. Many light fixtures in schools show evidence of leaking or ballasts that had previously failed. There is insufficient information to estimate emissions when these conditions are present.

[b] Estimated total PCB emission rates from light ballasts based on PCB emission rates measured for several congeners from chamber measurements of four intact ballasts at several temperatures.

[c] Predicted air concentrations at several possible air exchange rates for the room. Calculations based on the estimated PCB emission rate and ventilation rate (see Eq 2.1.7). Assumes steady state emission and ventilation conditions, steady-state absorption/desorption from other room materials, complete room air mixing, the concentration of PCBs in the ventilation air is zero, the only source of PCBs is the ballasts, and that the PCB mixture in the caulk is equivalent to Aroclor 1242. No caulk with high PCB levels was found inside these classrooms. Caulk with PCBs was in hallways outside Classrooms 1 and 2 and on the exterior window and unit ventilator intake grill for Classroom 4.

[d] Air samples were collected under different temperature conditions; Classrooms 1 and 2 @ 28°C; classroom 4 @ 27°C.

Table 4-12. Total PCB measurement results for materials at three schools with available data

			Total PCB Levels in Other Materials[a]		
Material Category	**N**	**% > QL[b]**	**Median ppm**	**Inter-Quartile Range ppm**	**Overall Range ppm**
All Material Samples	411	93	16.1	6.10 - 39.6	<QL - 718
Paint	143	100	39.1	25.9 - 71.7	3.31 - 718
Fiberboard	28	100	30.9	13.0 - 38.7	2.85 - 54.8
Chair Rail/Radiator Cover	6	100	30.5	23.9 - 47.6	20.0 - 68.5
Baseboard Cove Molding	5	100	28.0	9.88 - 40.9	2.44 - 42.3
Foams/Pinboard/Corkboard	8	100	15.5	10.0 - 37.4	6.68 - 48.6
Particle Board	19	100	13.5	11.4 - 17.4	6.88 - 28.8
Varnish	30	97	11.4	7.01 - 17.8	<QL - 61.5
Mastics (Tile and Molding)	65	92	7.83	2.30 - 13.9	<QL - 230
Ceiling Tile	8	100	7.59	2.67 - 11.8	2.06 - 14.0
Wood	6	100	7.46	3.70 - 13.5	0.13 - 32.2
Laminate	29	76	5.35	1.47 - 56.9	<QL - 199
Floor Tile	56	82	4.43	1.41 - 8.68	<QL - 57.1
Ventilator Insulation	2	100	1.75	--	1.28 - 2.23
Oils and Cleaner (liquids)	3	0	<QL	<QL	<QL
Wall Concrete Block	3	0	<QL	<QL	<QL

[a] Reported as total PCBs from Aroclor measurements for materials at Schools 2,3, and 6.

[b] QL = quantitation limit; sample size dependent, typically ≤ 1 ppm.

are shown separately for each school in Appendix B. It is impossible to be certain that these materials did not contain some PCBs when originally installed. However, measured concentrations and relative levels among different materials are consistent with these materials being "sinks" that have absorbed PCBs emitted from primary sources (Guo et al., 2011).

A majority of the interior caulk samples had total PCB concentrations < 100 ppm (Table 4-4). The median concentration for caulks with < 100 ppm was 6.9 ppm. This appears to be consistent with many of the other materials in the building. While it can't be ruled out that some of these caulks contained PCBs when originally installed, the results suggest that these caulks may have absorbed PCBs from the air that were emitted by primary sources.

Because of their relatively high concentration and high surface areas, paints may be among the most important secondary sources to consider. A large number of paint samples were collected and analyzed, allowing an assessment of different types of paints (Table 4-13). Wall and ceiling paints had median total PCB levels of 29.1 and 30.5 ppm, with a maximum value of 227 ppm for a ceiling paint sample. These paints are very often flat latex paints. Paints used on metals, floors, and door and trim paints had higher median values, ranging from 36.3 to 55.0 ppm with a maximum value of 718 ppm. Several handrail paints were collected at one school, with a median total PCB concentration of 121 ppm. These types of paints are more often oil-based and glossy paint, and in some cases have thicker film thicknesses than flat latex paint. It is important to recognize that many, if not most surfaces, had multiple coats of paint. It was not possible to determine whether there were gradients in PCB levels across different coats. Other materials with relatively high surface areas in many schools, including ceiling tile and floor tile had relatively low median PCB levels of 7.6 and 4.4 ppm, respectively. Maximum PCB concentrations were much lower in these materials than they were in paints.

PCBs were historically formulated as plasticizers or flame retardants in some paints. Although most of the concentrations measured in paint samples were below 100 ppm, several were above 200 ppm, raning up to 718 ppm. It is possible that these paints, or portions of the underlying coats for some of these paints may have contained PCBs.

Polyurethane foam (PUF) has been shown to be an important reservoir and potential secondary source of PBDEs and PCBs in some buildings (Zhang et al., 2011). However, the

Table 4-13. Total PCB measurement results for subsets of paint uses

			Total PCB Levels in Paints[a]		
Material Category	N	% > QL[b]	Median ppm	Inter-Quartile Range ppm	Overall Range ppm
All Paints	143	100	39.1	25.9 - 71.7	3.31 - 718
Wall Paint	36	100	29.1	21.8 - 41.8	3.31 - 129
Ceiling Paint	28	100	30.5	14.5 - 46.6	3.43 - 227
Metal Paint (radiator, locker, etc)	31	100	36.3	27.6 - 78.0	7.00 - 382
Floor Paint	4	100	54.9	34.6 - 83.3	32.6 - 110
Door and Door Trim Paint	33	100	55.0	37.5 - 87.0	5.54 - 718
Basketball Backboard Paint	2	100	63.3	--	50.8 - 75.8
Handrail Paint	9	100	121	57.2 - 132	49.1 - 172

[a] Reported as total PCBs from Aroclor measurements for materials at Schools 2,3, and 6.

[b] QL = quantitation limit; sample size dependent, typically ≤ 1 ppm.

amount of PUF in most older school buildings is relatively small, particularly when compared to residential settings. Interestingly, the the concentration of PCBs in PUF for the few samples that were collected were generally lower than the concentrations in paints in the same buildings.

Understanding the relative potential of different secondary sources to emit PCBs is of interest for informing remedial action, should it be needed. Information about materials in nine interior spaces across three school buildings was organized to better understand both the relative potential source impact as well as the cumulative potential impact from PCB emissions from secondary sources. Screening-level estimates of emission rates for multiple materials in these rooms were calculated following the approach described for caulk in Section 2. Material descriptions, surface areas, total measured PCB concentrations, and screening-level estimates of emission rates are shown in Tables 4-14, 4-15, and 4-16. Figures 4-3, 4-4, and 4-5 show the relative screening-level emission rates for materials in three of the rooms. It is important to note that the emission rates estimated for secondary sources are applicable only after primary sources have been removed or otherwise mitigated. There are considerable uncertainties in these estimates, in part because they assume that the emission parameters derived for caulk in chamber testing apply to the wide range of different materials. In practice, the emission parameters for PCBs may be considerably different for many materials. Therefore, these are only screening level estimates for the purposes of relative comparisons.

Screening-level estimated emission rates for different materials in classrooms ranged from < 1 up to 100 µg/hr and cumulative totals for 20 materials in a room ranged up to 270 µg/hr. Estimated emission rates for different materials in gymnasiums ranged from < 1 up to 1100 µg/hr and cumulative totals for 16 materials ranged up to 2700 µg/hr. Estimated emission rates depended on the surface area of the material and concentration of PCBs in the material. Paints and varnishes generally had the highest relative potential emissions due to the combination of higher PCB concentrations and high surface areas. There are considerable uncertainties in these estimates, which are based on emission parameters derived from laboratory emissions testing of caulk. Emission parameters for the many different types of other materials could be substantially different than those for caulk. It is difficult to estimate indoor air concentrations of PCBs that might result from secondary sources following removal of primary sources because of the large number of different types of PCB-containing material in a room, and because the cumulative source – sink dynamics for multiple different materials is difficult to characterize. However, the cumulative emission rates from secondary sources could potentially result in indoor air PCB levels above ambient air background levels in school rooms following mitigation of primary sources, depending on relative emission rates, sink rates, and rates of ventilation from indoor and outdoor air.

4.2.4 Source Assessment Uncertainties and Limitations

Characterizing the source(s) of PCBs in and around school buildings is important because it will inform remediation approaches for cases where exposure reduction decisions need to be made. PCB source assessment for buildings can be difficult because there may be multiple primary sources, and transport of the semi-volatile congeners through air can contaminate dust and soil and create secondary sources of other materials in a building. Information from six school buildings examined in this work was used to try to characterize and to understand the relative potential of various PCB sources. There remain important uncertainties and limitations in this information and the emission rate estimates as discussed below.

Attribution of primary sources - The school buildings examined in this work had both caulk with high PCB concentrations and PCB-containing light ballasts. It would be helpful to understand whether one of the primary sources

Table 4-14. Screening-level estimates of total PCB emission rates for selected interior materials in three locations at School 2 for relative comparisons[a,b,c]

School	Room	Material	Surface Area m²	Total PCB ppm	Estimated Emission Rate µg/hr
2	Classroom	Wall Paint - Blue	102	36.7	100
2	Classroom	Door Paint - Blue	3.90	444	47
2	Classroom	Wall Paint - Cream	19.5	51.5	27
2	Classroom	Floor Tile - Grey	59.5	16.5	27
2	Classroom	Radiator Paint - Blue	9.66	52.0	14
2	Classroom	Door Varnish	7.80	48.2	10
2	Classroom	Door Frame Paint - Blue	3.34	102	9.3
2	Classroom	Closet Door Varnish	8.36	39.5	9.0
2	Classroom	Fiberboard	12.4	26.5	9.0
2	Classroom	Ceiling Tile	52.0	4.48	6.4
2	Classroom	Ceiling Paint - White	4.65	32.0	4.1
2	Classroom	Cove Molding	3.21	42.3	3.7
2	Classroom	Ceiling Paint - Blue	2.79	29.6	2.3
2	Classroom	Sink Door Varnish	1.86	13.4	0.68
2	Classroom	Door Frame Varnish	0.743	28.9	0.59
2	Classroom	Particle Board	0.929	10.3	0.26
2	Classroom	Wormhole Ceiling Tile	1.21	2.11	0.070
2	Classroom	Transom Glaze	0.0064	51.0	0.009
2	Classroom	Electrical Penetration Caulk	0.0052	5.30	0.001
2	Classroom	Toilet Caulk	0.0006	9.50	0.0002
2	Gymnasium	Wall Paint - Cream	358	51.5	500
2	Gymnasium	Wood Floor Varnish	401	32.2	350
2	Gymnasium	Fiber Ceiling Tile	402	10.7	120
2	Gymnasium	Ceiling Beam Paint - Cream	191	20.4	110
2	Gymnasium	Backboard Paint - White	25.6	50.8	36
2	Gymnasium	Radiator Paint - Blue	20.0	52.0	28
2	Gymnasium	Baseboard Paint - Black	5.88	115	18
2	Gymnasium	Duct Paint - Cream	46.5	12.1	15
2	Gymnasium	Bench - Varnish	10.0	34.8	9.5
2	Gymnasium	Bay Door Paint - Gray	4.37	59.1	7.0
2	Gymnasium	Vent Paint - Blue	3.90	52.0	5.5
2	Gymnasium	Door Paint - Blue	5.20	37.5	5.3
2	Gymnasium	Door Frame Paint - Blue	1.89	102	5.3
2	Gymnasium	Door Varnish	9.29	12.9	3.3
2	Gymnasium	Bay Door Soffit Paint - Gray	0.929	59.1	1.5
2	Gymnasium	Door Window Glaze	0.0520	15.0	0.021
2	Gymnasium	Electrical Penetration Caulk	0.0020	68.0	0.004
2	Gymnasium	Sink Caulk	0.0117	7.40	0.002
2	Corridor	Door Paint - Blue	23.8	116	75
2	Corridor	Radiator Paint - Blue	20.1	92.0	50
2	Corridor	Floor Tile - White	121	12.1	40

Table 4-14. Screening-level estimates of total PCB emission rates for selected interior materials in three locations at School 2 for relative comparisons[a,b,c] (continued)

School	Room	Material	Surface Area m²	Total PCB ppm	Estimated Emission Rate µg/hr
2	Corridor	Ceiling Tile	133	4.48	16
2	Corridor	Door Frame Paint - Blue	5.79	102	16
2	Corridor	Door Varnish	18.6	16.5	8.4
2	Corridor	Door Louver Paint - Blue	0.465	444	5.6
2	Corridor	Fiberboard -Gray	7.43	20.7	4.2
2	Corridor	Fiberboard - Brown	5.57	26.5	4.0
2	Corridor	Floor Tile - Cream 1	9.29	4.60	1.2
2	Corridor	Interior Door Window Glaze	0.0988	88.0	0.24
2	Corridor	Floor Tile - Cream 2	0.929	6.79	0.17

[a] Not all materials in each room were sampled. Materials such as mastics are not included here since they are not directly exposed to room air.

[b] Based on chamber-derived emission parameters for caulk – these may not apply well to all materials.

[c] These materials also act as sinks, absorbing PCBs from the room air. The estimated emission rates shown here cannot be simply used to estimate total indoor air concentrations.

is much more important than the other with regard to increasing environmental levels and potential exposures to PCBs. There appears to be evidence that both caulk with high PCB levels and PCB-containing light ballasts are likely to be important sources of PCBs in older school buildings. However, given the limitations of this study, it is difficult to determine whether one source is likely to be more important than another in school buildings.

One approach might be to examine congener patterns to try to determine if a source signature can be elucidated. A limitation was that most of the samples were analyzed for Aroclors and not specific congeners. Some of the caulk samples collected at the six buildings contained high concentrations of PCBs (in the range of 1% to 44% by weight). Aroclor analysis of these high-PCB caulks showed that most contained a pattern consistent with Aroclor 1254, or in the case of one school, a pattern resembling Aroclor 1260. The capacitor fluids in several light ballasts were analyzed; three of these contained Aroclor 1242 and one contained Aroclor 1254. Because these schools were constructed after 1952, when capacitor fluids reportedly transitioned from Aroclor 1254 to Aroclor 1242, one might expect that most ballasts contained Aroclor 1242. But with hundreds of unmeasured light ballasts in each school and the finding of a ballast with Aroclor 1254, it is not clear to what extent different Aroclor capacitor fluids may have been present in each building. Most of the air samples were reported to contain an altered Aroclor pattern with characteristics of Aroclors 1248 and 1254. Given that Aroclor 1242 is primarily composed of 2-, 3-, and 4-chlorine homologs, and Aroclor 1254 is primarily composed of 4-, 5-, and 6- chlorine homologs, it would be surprising – based on the air PCB composition - if sources with Aroclor 1242 (i.e. light ballasts) were contributing a much higher amount of PCBs into the indoor air than sources with Aroclor 1254 or 1260 (caulk and possibly some light ballasts). This is particularly true because the 2-, and 3- chlorine congeners have much greater vapor pressures that the 5-chlorine congeners, and Aroclor 1242 sources would contribute an even higher fraction of their PCBs to air than Aroclor 1254 sources. Congener-specific measurements were obtained for one school (see Section 4.4) and provide information for more directly examining source and environmental relationships.

Estimates of total PCB emission rates for several examples of school building caulk were made. As discussed later, there are limitations and uncertainties in the estimates. But, if those estimates are reasonable, then emission rates of hundreds to thousands of micrograms of PCBs per hour at specific school locations would appear to be possible. For interior caulks, these levels of emissions would contribute to increased indoor air PCB concentrations, and could serve as a source for partitioning into dust and other materials. Even assuming low penetration rates for emissions from exterior caulks around windows and ventilation intakes, exterior caulk could also contribute to increased PCB levels in indoor air, but this may be highly dependent on ambient temperature and wind conditions, as well as specific locations and uses of windows for ventilation. Given the estimates of emission rates from caulk, a question arises as to whether all of the available PCBs might have been depleted over the course of 40 – 50 years in a building, and whether these rates have been overestimated. Guo et al. (2011) used a modeling approach to show that over 50% of congener 52 would remain after 50 years in a building, and even higher proportions of less volatile congeners would remain. It is possible that some of the more volatile congeners, such as 8 and 18 might have been largely depleted in that time frame, but these two comprise < 1% of all congeners, by weight, in

Table 4-15. Screening-level estimates of total PCB emission rates for selected interior materials in three rooms at School 3 for relative comparisons[a,b,c]

School	Room	Material	Surface Area m²	Total PCB ppm	Estimated Emission Rate µg/hr
3	Classroom 1	Wall Paint - Cream	53.9	29.4	43
3	Classroom 1	Ceiling Paint - Gray	85.5	10.7	25
3	Classroom 1	Door Paint - Orange	5.57	108	16
3	Classroom 1	Cove Base - Black	6.04	40.9	6.7
3	Classroom 1	Floor Tile - Green	89.2	1.73	4.2
3	Classroom 1	Fiber Board	11.1	13.0	3.9
3	Classroom 1	Radiator Paint - Light Orange	4.83	27.5	3.6
3	Classroom 1	Fiber Board - Green	3.34	21	1.9
3	Classroom 2	Floor Tile - Gray	82.9	9.69	22
3	Classroom 2	Wall Paint - Yellow	59.5	13.5	22
3	Classroom 2	Ceiling Paint - White	62.3	10.5	18
3	Classroom 2	Cove Base Paint - Black	6.69	40.9	7.5
3	Classroom 2	Radiator Paint - Yellow	14.4	9.71	3.8
3	Classroom 2	Fiber Board - Brown	9.29	13.0	3.3
3	Classroom 2	Door Paint - Yellow	1.86	29.6	1.5
3	Classroom 3	Wall Paint - Yellow/Green	51.1	27.1	38
3	Classroom 3	Ceiling Paint - White	60.4	9.47	16
3	Classroom 3	Cove Base Paint - Light Gray	3.53	35.9	3.5
3	Classroom 3	Fiber Board - Brown	10.2	10.5	2.9
3	Classroom 3	Door Paint - Light Gray	1.86	29.7	1.5
3	Classroom 3	Particle Board - Brown	0.93	12.9	0.33
3	Classroom 3	Floor Tile - Beige	7.43	<QL[d]	--

[a] Not all materials in each room were sampled. Materials such as mastics are not included here since they are not directly exposed to room air.

[b] Based on chamber-derived emission parameters for caulk – these may not apply well to all materials.

[c] These materials also act as sinks, absorbing PCBs from the room air. The estimated emission rates shown here cannot be simply used to estimate total indoor air concentrations.

[d] QL = quantifiable limit.

Table 4-16. Screening-level estimates of total PCB emission rates for selected interior materials in three rooms at School 6 for relative comparisons[a,b,c]

School	Room	Material	Surface Area m²	Total PCB ppm	Estimated Emission Rate µg/hr
6	Classroom 3	Locker Paint - Tan	17.9	79.7	39
6	Classroom 3	Wall Paint - Beige	29.2	38.3	31
6	Classroom 3	Wall Paint - White	11.8	64.9	21
6	Classroom 3	Ventilator Paint - Beige	5.71	71.9	11
6	Classroom 3	Pin Board	7.32	48.6	9.7
6	Classroom 3	Door Paint - Brown	4.08	71.4	7.9
6	Classroom 3	Ceiling Tile	68.5	2.06	3.8
6	Classroom 3	Floor Tile - Grey	58.1	2.07	3.3
6	Classroom 3	Floor Tile - Beige	19.4	5.73	3.0
6	Classroom 3	Chair PUF Foam	0.534	42.9	0.62
6	Classroom 3	Cove Molding	2.36	2.44	0.16
6	Classroom 3	Interior Window Glaze 1	0.109	9.22	0.027
6	Classroom 3	Ventilator Gasket Foam	0.0277	35.6	0.027
6	Classroom 3	Interior Window Glaze 2	0.0176	40.4	0.019
6	Classroom 3	Interior Joint Caulk	0.197	2.40	0.013
6	Classroom 3	Ventilator Insulation	0.0987	2.23	0.006
6	Classroom 3	Door Window Glaze	0.0064	11.7	0.002
6	Classroom 3	Wall Concrete Block	41.0	<QL[d]	--
6	Classroom 4	Wall Paint - White	40.1	41.4	45
6	Classroom 4	Locker Paint - Tan	18.9	35.2	18
6	Classroom 4	Door Paint - Brown	6.19	72.6	12
6	Classroom 4	Ventilator Paint - Brown	5.68	52.7	8.2
6	Classroom 4	Ceiling Tile	62.2	2.85	4.8
6	Classroom 4	Floor Tile - Grey	70.1	0.959	1.8
6	Classroom 4	Pin Board (2 boards)	4.94	10.4	1.4
6	Classroom 4	Cove Molding	2.38	9.88	0.64
6	Classroom 4	Cork Board	1.11	11.4	0.35
6	Classroom 4	Interior Window Glaze 2	0.0697	23.01	0.044
6	Classroom 4	Interior Window Glaze 1	0.0998	11.79	0.032
6	Classroom 4	Interior Joint Caulk	0.0955	4.15	0.011
6	Classroom 4	Ventilator Insulation	0.0987	1.28	0.003
6	Gymnasium	Wood Floor Varnish	668	61.5	1100
6	Gymnasium	Wall Paint 1	524	39.1	560
6	Gymnasium	Wall Paint 2	189	92.2	480
6	Gymnasium	Floor Underlayment	668	19.7	360
6	Gymnasium	Gym Floor Wood	668	5.39	98
6	Gymnasium	Backboard Paint	18.9	75.8	39
6	Gymnasium	Door Paint - Black	25.6	35.1	24
6	Gymnasium	Bleacher Seat Wood	194	3.13	17
6	Gymnasium	Cove Molding	10.3	28.0	7.9
6	Gymnasium	Exercise Mat PUF Foam	32.4	6.68	5.9

Table 4-16. Screening-level estimates of total PCB emission rates for selected interior materials in three rooms at School 6 for relative comparisons[a,b,c] (continued)

School	Room	Material	Surface Area m²	Total PCB ppm	Estimated Emission Rate µg/hr
6	Gymnasium	Backboard Wood	18.9	9.53	4.9
6	Gymnasium	Bleacher End Wood	8.43	14.8	3.4
6	Gymnasium	Plywood Subfloor	668	0.125	2.3
6	Gymnasium	Interior Joint Caulk	0.627	21.7	0.37
6	Gymnasium	Pin Board	1.11	8.79	0.27
6	Gymnasium	Interior Caulk - Fountain	0.0108	5.21	0.002

[a] Not all materials in each room were sampled. Materials such as mastics are not included here since they are not directly exposed to room air. The gym sub-floor and underlayment are included because it is not clear whether and to what extent their emissions might impact room air.

[b] Based on chamber-derived emission parameters for caulk – these may not apply well to all materials.

[c] These materials also act as sinks, absorbing PCBs from the room air. The estimated emission rates shown here cannot be simply used to estimate total indoor air concentrations.

[d] QL = quantifiable limit.

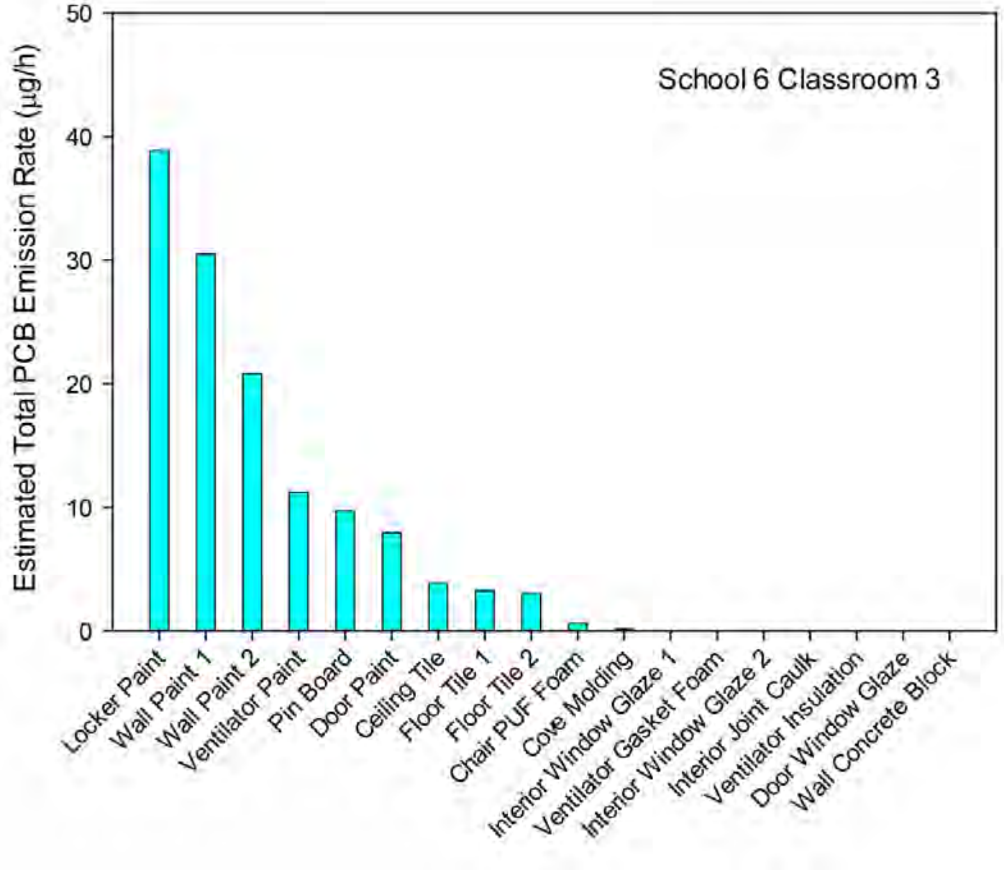


Figure 4-3. Screening-level estimates of total PCB emission rates from materials in the gymnasium in School 2

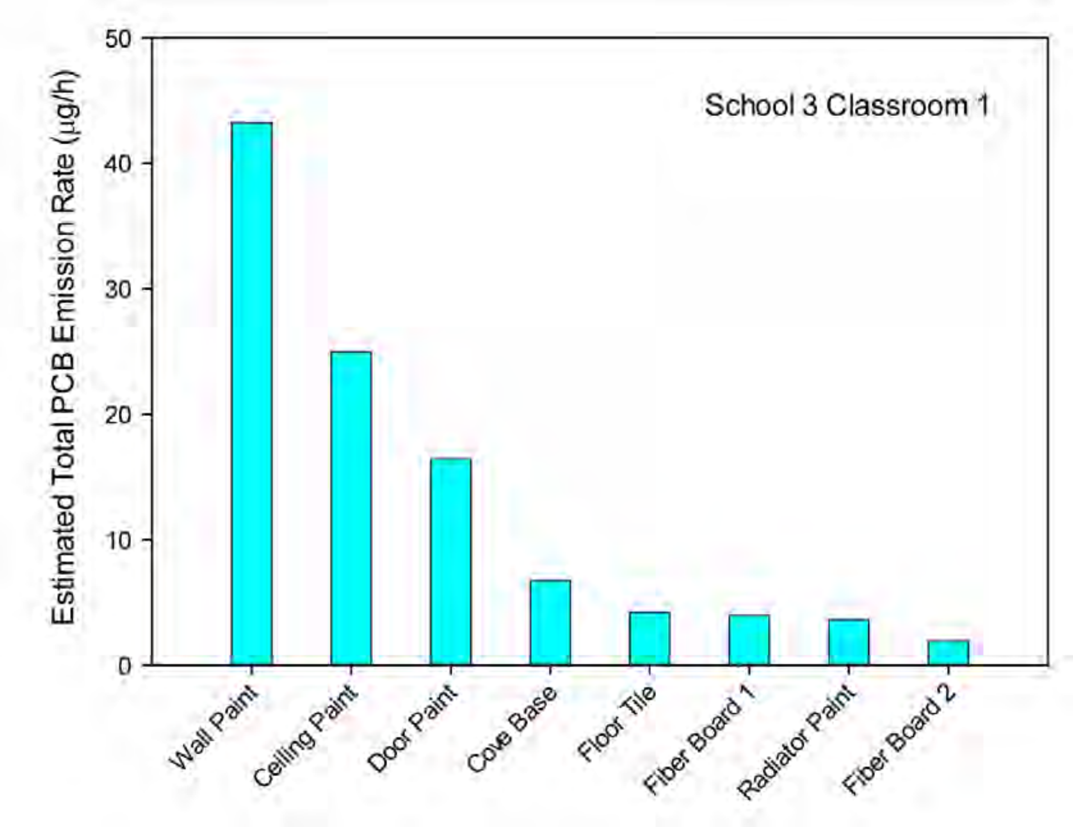


Figure 4-4. Screening-level estimates of total PCB emission rates from materials in a classroom in School 3

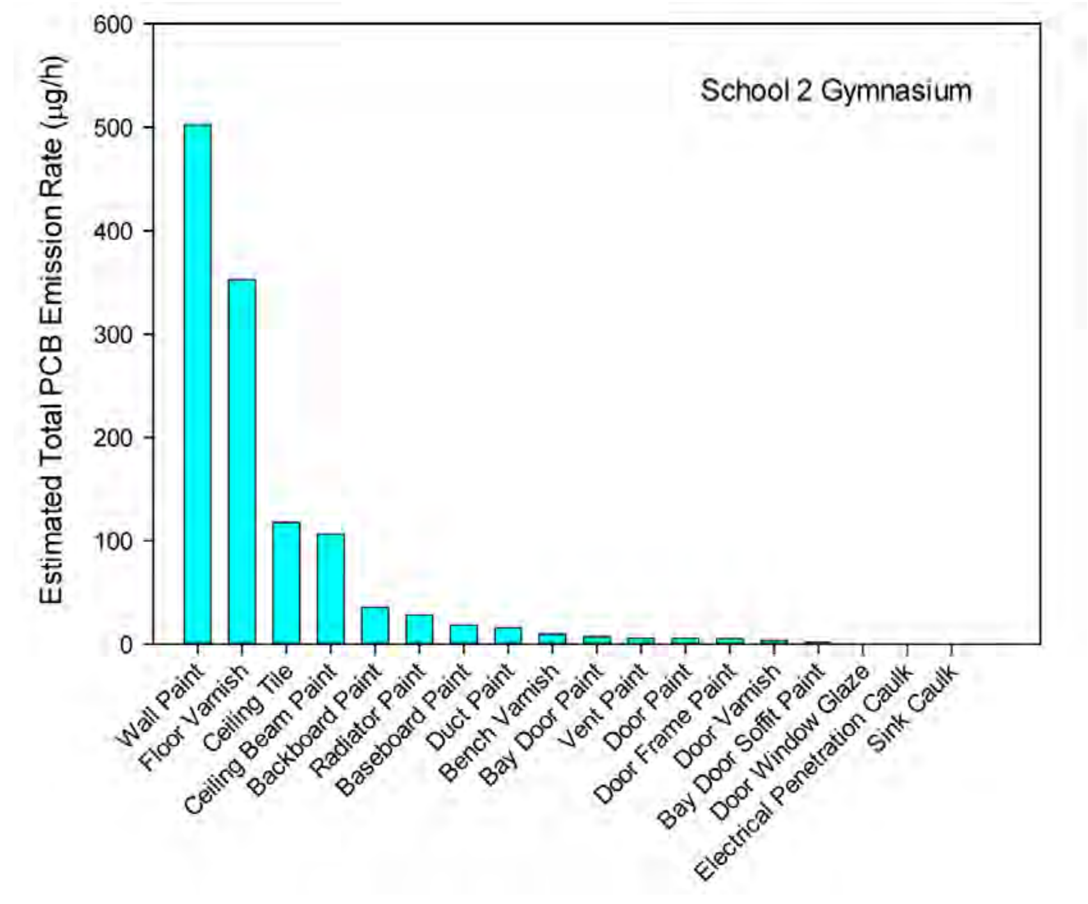


Figure 4-5. Screening-level estimates of total PCB emission rates from materials in a classroom in School 6

Aroclor 1254. We have performed additional calculations (not shown) based on our estimated emission rates, and for reasonable initial total PCB concentrations that are within the range that have been measured in caulks now, substantial fractions of PCBs would still be present in the caulk after more than 40 years. Other research has shown that sealants with PCBs are an important contributor to PCB levels in indoor spaces. For example, the average total PCB concentration in indoor air in apartments with PCB-containing sealants was 1030 ng/m^3 (range 168 – 3843 ng/m^3) (Frederiksen et al., 2012). MacIntosh et al. (2012) reported an average indoor air total PCB concentration of 533 ng/m^3 (range 299 – 1800 ng/m^3) in an elementary school with PCB-containing sealants but no PCB-containing light ballasts. These results show that emissions of PCBs from caulk, in the absence of light ballast sources, are sufficient to create indoor air total PCB concentrations two orders of magnitude or more higher than outdoor ambient concentrations.

Estimates of PCB emissions from light ballasts were also made. These estimates are limited and some caution is recommended regarding their interpretation. Estimates were based on the testing of four intact light ballasts at multiple temperatures by Guo et al. (2011). One of the four ballasts showed substantially higher emissions than the other three, approximately 80-fold greater than the ballast with the lowest emissions. Thus, it is not certain what ballast-related emissions are likely to occur across the large number of ballasts that may be present in a building. If a larger percentage of ballasts emit at the highest rate, then emissions from intact ballasts alone could have an important impact on indoor air PCB concentrations. If most of the intact ballasts emit at the lower levels, then the impact on levels in air would be more modest. Perhaps most importantly, this work was not able to provide information on emissions resulting from failing ballasts and for light fixtures and other building components that may have been contaminated from previously failed ballasts. Ballast capacitors that burst or suddenly fail and leak their PCB contents will clearly have a substantial impact on PCB levels in indoor spaces. The impact of contaminated fixtures and other components is less certain but could be important. The New York City remedial investigation showed that remedial measures could substantially reduce indoor air PCB concentrations for schools with initially elevated levels, and a considerable part of that decrease occurred after a school cleaning step and removal of PCB-containing light fixtures (see Figure 4-11). The Agency has prepared a guide for school administrators and maintenance personnel titled “Proper Maintenance, Removal, and Disposal of PCB-Containing Fluorescent Light Ballasts” (http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/ballasts.htm) that recommends removal.

Another uncertainty regarding sources of PCBs in school buildings is that other primary sources of PCBs may have been used in school buildings that are no longer present today. For example, carbonless copy paper and PCB-containing capacitors in early computer video display terminals may have been present in school buildings during a period of the school’s history. The potential impact of previously removed sources on current PCB levels in building environments cannot be easily determined.

Importance of secondary sources for exposure – PCBs were found to be widespread throughout many materials collected in three buildings, mostly in the range of 4 to 100 ppm. Given the indoor air PCB concentrations and the chamber sink test results from Guo et al. (2012) these levels would appear to be consistent with the materials being sinks that have absorbed PCBs from the air over many years. A few of the paint samples had higher levels of PCBs, up to 718 ppm, and it can’t be ruled out that some of the materials contained PCBs when they were installed in the building. Regardless of their provenance, these materials represent a reservoir of PCBs in a building that might, in some cases, need to be considered as part of building mitigation efforts to reduce environmental levels of PCBs. While screening-level emission estimation approaches were used to assess the relative potential importance of various materials, the report is limited about what it can say quantitatively with regard to the impact these secondary sources will have on environmental levels of PCBs following removal or mitigation of primary sources. This is because the cumulative source-sink dynamics are difficult to predict for multiple widespread materials with various PCB concentrations, particularly given the lack of important diffusion and partition parameters for most of the materials and the range of PCB congeners.

Emission estimation uncertainties – Emission estimates in this report are largely based on the work of Guo et al. (2011) and their laboratory chamber testing of PCB-containing caulk and light ballasts, combined with measurements and characterization of PCBs in materials and components in the schools. Caulk emission rate parameters were determined by Guo et al. in the laboratory using micro-chambers because it was determined that large losses of PCB congeners to chamber walls were occurring for caulk emissions testing in larger chambers. This problem did not occur with the micro-chambers. Numerous samples of caulk obtained from older buildings were tested for emissions using the micro-chambers, and consistent congener emission parameters were obtained from the different caulks. Several light ballasts were obtained from older buildings and were tested in larger 55-L chambers. Four of these ballasts were tested at multiple temperatures. Congener emission rates were found to be variable across the different ballasts. Because these ballasts contained Aroclor 1242, with proportionately more volatile congeners, loss to chamber walls was less significant than for the less-volatile congeners from Aroclor 1254 in the caulks, but the emissions estimates from light ballasts in chamber tests may still be somewhat underestimated due to losses.

Because the caulk and light ballasts were tested in two different chamber systems, there could be some limitations in making direct comparisons using emission factors derived from the testing. However, the micro-chambers have been shown to produce emissions estimates comparable to those from larger chambers for VOCs and SVOCs (Scheff et al., 2000). Material/air boundary conditions are affected by surface air flow velocities and these could be different across the two types of chambers and between the chambers and the surfaces in school rooms (which are typically in the range of 2 to 25 cm/s). The micro-chamber manufacturer reports that air velocity is in a range of 0.5 cm/s at 50 mL/min and 5 cm/s at 350 mL/min. At caulk test flow rate of 449 mL/min, the estimated velocity would be about 6.4 mL/min. A published paper (Scheff et al., 2000) showed an empty micro chamber likely had velocities less than 10 cm/s. However, it is possible that the caulk testing configuration could have resulted in somewhat higher velocities.

Even if the boundary air flow conditions during caulk emissions testing in micro-chambers was substantially different than the surface air velocities across caulk in school spaces, the impact on estimated emissions likely would not be large. The rate determining step for evaporation of a chemical from a pure liquid into air is governed largely by mass transfer in the boundary layer immediately above the liquid. The depth of the boundary layer depends in part on the air velocity across the surface, and this can be an important factor in measuring and estimating emissions. For solid materials, the emission rate is controlled by two factors, the boundary layer conditions and the rate of chemical diffusion from inside the material to the surface of the material. The boundary layer affects the emission rate at early times of the emissions and the effect diminishes over time. For long-term emissions, particularly for SVOCs, the internal diffusion becomes more important as the rate-determining step and the boundary layer has more limited effect on the emission rate (Qian et al., 2007).

Efforts were made to better understand whether the predicted caulk emission rates were realistic as compared to estimates of PCB emissions from evaporation from pure PCB liquids. Emission estimates from caulks in school buildings in this report would appear to higher than would be expected based on an early QSAR-based estimate of the evaporation rate of pure Aroclor 1254 (U.S. EPA, 1976) but would not overestimate evaporation rates derived from more recent modeling approaches (Hummel et al., 1996; Guo, 2000) (data not shown).

There are still considerable limitations and uncertainties regarding the predicted emission rates and air concentration estimates presented in this report. The actual emission rates were not directly measured and the estimations were based on a number of assumptions. For caulk, it was assumed that the PCB emission parameters for the school caulks were the same as those in the chamber testing and estimates were based on an assumed temperature equivalent to that used in the chamber testing. The chamber testing showed that PCB emissions from caulk were sensitive to temperature, with an approximate six-fold increase in emissions for a 10°C increase in temperature. In estimating room air concentrations resulting from caulk, many other assumptions were made that might not be true or might change from time to time in a school building. Assumptions include:

- well mixed air in room
- constant temperature
- temperature equivalent to chamber conditions that generated caulk emission parameters (23°C)
- constant ventilation rate
- steady-state emission
- steady state and approximately equal absoption/desorption of PCBs in other materials in the room
- no chemical reactions of PCBs
- PCBs from other school spaces are not impacting the levels in air for the room of interest
- emission parameters for caulk in the room are the same as for the caulk tested in lab chambers

Because congener-specific measurements were not performed for most of the caulk samples, we estimated total PCB emission rates by first assuming that the caulk contained an un-aged Aroclor 1254 mixture. It is likely that over time the congener composition has changed and current emission rates may not match those made assuming an un-aged Aroclor 1254. We examined this where we had congener specific data and found that the emission rate estimated using actual congener composition was 45% lower than using an assumption of un-aged Aroclor 1254. Also, in the emissions testing by Guo et al., three caulks were tested to assess the effects of having freshly cut surfaces. Emissions from freshly cut surfaces were, on average, about 19% higher than those from the original surface. To limit potential overestimation of PCB emissions from caulk, we elected to adjust (reduce) the total PCB emission rates by 55% based on the available information. However, this adjustment factor was based on limited data.

As noted earlier, the information available for estimating PCB emissions from light ballasts was limited, and it is not clear how well those emission rates apply to the hundreds of ballasts in the schools. Likewise, the emissions of PCBs from contaminated light fixtures and other components have not been characterized, so it is possible that screening-level estimates of PCB concentrations school room air could be underestimated. Most of the assumptions listed for air concentrations estimated from caulk emissions also apply to estimates from light ballasts.

4.3 PCBs in Environmental Media

PCBs are semi-volatile organic chemicals and may experience transport from sources into and throughout the environment in and around school buildings where they can become available for human contact and exposure. In order to understand the potential for exposure and ranges of possible exposures, it is important to characterize PCB concentrations in environmental media. Indoor air, surface wipe, and outdoor soil samples were collected from multiple locations at the six schools. Indoor dust samples were collected from multiple locations in one school building. Outdoor air samples were collected at all school buildings. At the five NYC schools, indoor air and surface wipe samples were collected before and following different remedial actions. Measurement results are summarized here to characterize the magnitude, range, and within- and between-school variability in PCB concentrations in school environments. A summary of total PCB concentrations for indoor and outdoor air, surface wipes, soil, and dust is shown in Table 4-17.

4.3.1 Indoor Air

Indoor air samples were collected in several locations in each school. Collection locations included classrooms, cafeterias, gymnasiums, and transitory spaces. The median indoor air total PCB concentration based on 64 measurements across six schools was 318 ng/m^3 (interquartile range of 59.4 – 732 ng/m^3) with a maximum concentration of 2920 ng/m^3 (Table 4-18). These samples were collected prior to any of the reported remedial activities as shown in Table 4-2. There was considerable variability between schools with median air levels at individual schools ranging from <50 ng/m^3 at School 4 to 807 ng/m^3 at School 2. The distribution of indoor air PCB concentrations is shown in Figure 4-6. There was considerable variability within schools; for example, indoor air levels ranged from 236 to 2920 ng/m^3 in different rooms at School 3.

Indoor air concentrations at these schools can be compared to measurements at other buildings. MacIntosh et al. (2012) reported a median pre-remediation value of 429 ng/m^3 at a U.S. primary school for samples collected in nine indoor locations. Concentrations ranging from 2 to 310 ng/m^3 were measured in a U.S. secondary school (TRC, 2006). Coughlan et al., (2002) reported indoor concentrations ranging from 111 to 393 ng/m^3 in a U.S. university building. Indoor PCB concentrations measured at three of the six schools in this report had higher concentrations than those reported by MacIntosh et al., TRC, and Herrick et al., while the indoor levels for the other three schools in this report were similar to or below those previously reported.

The U.S. EPA developed information in 2009 on public health levels of PCBs in school indoor air (Figure 4-7). If school indoor air levels are kept below these concentrations,

Table 4-17. Summary of environmental media total PCB measurement results for six schools[a]

				Total PCB Levels[b,c]		
Environmental Medium (units)	**N[d]**	**% > QL[e]**	**Mean QL**	**Median**	**Inter-Quartile Range**	**Overall Range**
Indoor Air (ng/m^3)	64	77	47	318	59.4 - 732	<QL - 2920
Indoor Surface Wipes (µg/100cm^2)						
High-contact surfaces	72	62	0.100	0.147	<QL - 0.330	<QL – 2.84
Low-contact surfaces	78	80	0.100	0.201	0.128 - 0.419	<QL – 2.30
Indoor dust (ppm)	7	100	3.0	22.0	16.6 - 53.4	11.6 – 86.8
Outdoor Soil (ppm)						
0.5' from building; 0 – 2" soil depth	99	48	0.5	<QL	<QL - 2.13	<QL - 211
3' from building; 0 – 2" soil depth	102	28	0.5	<QL	<QL - 0.548	<QL – 20.6
8' from building; 0 – 2" soil depth	105	21	0.5	<QL	<QL - <QL	<QL – 5.28
Outdoor Air (ng/m^3)	6	0	47	<QL	<QL	<QL

[a] Air, wipe, and soil measurements at six schools; dust measurements from one school.
[b] Reported as total PCBs from Aroclor measurements.
[c] When duplicate samples were collected, the average of the duplicates was used.
[d] Number of samples.
[e] Quantitation limit.

Table 4-18. Indoor air total PCB measurement results at six schools

				Total PCB Levels in Air[a,b]		
School/ Condition	N[c]	Mean QL[d] ng/m³	% > QL	Median ng/m³	Inter-Quartile Range ng/m³	Overall Range ng/m³
All Six Schools	64	47	77	318	59.4 - 732	<QL - 2920
School 1	11	49	54	58	<QL - 121	<QL - 194
School 2	12	50	100	807	674 - 874	414 - 1460
School 3[e]	14	51	100	504	271 - 960	236 - 2920
School 4	9	50	44	<QL	<QL - 154	<QL - 674
School 5	11	50	54	154	<QL - 425	<QL - 867
School 6	7	24	100	679	520 - 700	359 - 953

[a] Reported as total PCBs from Aroclor measurements in indoor air.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number of samples and number of rooms sampled.

[d] QL = Quantitation limit.

[e] Does not include a second day of pre-remediation air results for School 3.

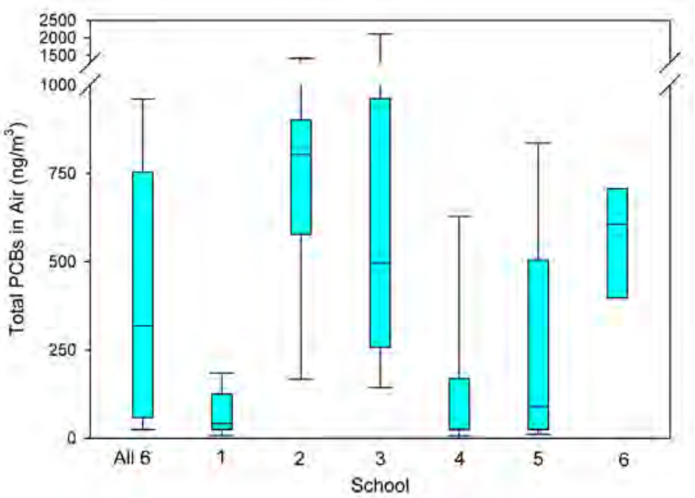


Figure 4-6. Distributions of indoor air total PCB concentrations across all six schools and at each individual school. The box plots show the median, 25th, and 75th percentiles. The whiskers show the 10th and 90th percentiles

and if background exposures to PCBs are typical, then the total exposure would be expected to remain below the Aroclor 1254 reference dose of 0.020 µg/kg/day. Median indoor air concentrations exceeded the 300 ng/m³ public health level for 6 – 11 year-old children at several schools. PCB concentrations in many individual classrooms were higher than the public health levels for their age group. The effectiveness of remedial actions in reducing indoor air concentrations is shown later in Section 4.4.6.

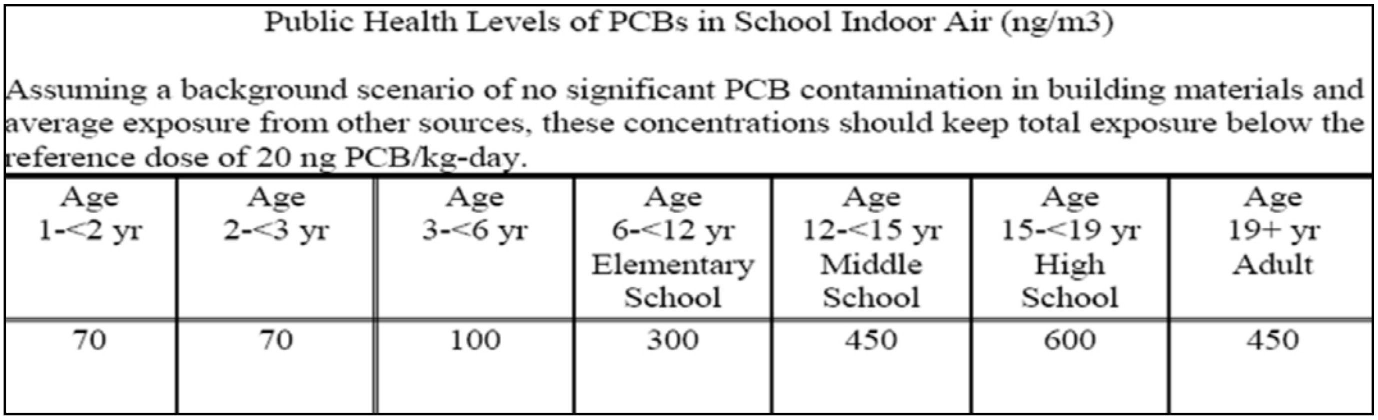
4.3.2. Outdoor Air

Outdoor air measurement results are shown in Table 4-19. All outdoor air PCB concentrations were below the QL; however, the QL was relatively high (approximately 50 ng/m³) at five schools and 17 ng/m³ at School 6. Outdoor air total PCB concentrations are typically much lower than these QL values. Based on the congener analysis measurement result, the outdoor air PCB concentration was 7.7 ng/m³ at School 6 (see Section 4.5).

4.3.3 Surface Wipes

Surface wipe samples were collected from high-contact (desks, tables) and low-contact (walls, floors, window sills) surfaces at six schools. Measurement results are shown in Table 4-20. Measurement concentration distributions are shown in Figure 4-8. Median total PCB concentrations were 0.147 µg/100cm² (interquartile range <0.100 – 0.330 µg/100cm²) for 72 high-contact surfaces and 0.201 µg/100cm² (interquartile range 0.128 – 0.419 µg/100cm²) for 78 low-contact surfaces. Concentrations ranged from not detected to 2.84 µg/100cm² for high contact surfaces and not detected to 2.30 µg/100cm² for low-contact surfaces. Median high-contact wipe levels ranged from <0.001 to 0.380 µg/100cm² at individual schools. School 1 had the lowest overall surface PCB concentrations and this school also had the lowest indoor air levels. There was no consistent difference between median high-contact and low-contact concentrations across the six schools.

Wipe samples collected on building surfaces may provide information regarding the availability of PCBs in those materials at the material surface. High contact surface measurements can provide information regarding PCB levels most relevant for potential exposure. Since the high-contact wipe samples are collected on horizontal surfaces they may collect both settled dust and PCB residue at the material surface. Wipe sampling can extract PCBs from within materials near the surface because of the use of hexane as the wipe wetting agent.



Public Health Levels of PCBs in School Indoor Air (ng/m3)

Assuming a background scenario of no significant PCB contamination in building materials and average exposure from other sources, these concentrations should keep total exposure below the reference dose of 20 ng PCB/kg-day.

Age 1-<2 yr	Age 2-<3 yr	Age 3-<6 yr	Age 6-<12 yr Elementary School	Age 12-<15 yr Middle School	Age 15-<19 yr High School	Age 19+ yr Adult
70	70	100	300	450	600	450

Figure 4-7. Public health levels of PCBs in school indoor air developed in 2009 by the U.S. EPA (http://www.epa.gov/pcbsincaulk/maxconcentrations.htm)

Table 4-19. Outdoor air total PCB measurement results at six schools[a]

School/ Condition	N	Mean QL[b] ng/m³	% >QL	Total PCB Levels in Air ng/m³
School 1	1	49	0	<QL
School 2	1	50	0	<QL
School 3	1	51	0	<QL
School 4	1	50	0	<QL
School 5	1	49	0	<QL
School 6	1	17	0	<QL[c]

[a] Reported as total PCBs from Aroclor measurements in outdoor air.

[b] QL = quantitation limit.

[c] The result for the congener-specific analysis was 7.7 ng/m³.

PCB concentrations measured in this study were somewhat lower than the 0.49 µg/100 cm² geometric mean calculated from extant data (Appendix D). Several of the extant measurement results were greater than 10 µg/100 cm² while the maximum value for the six schools in Table 4-20 was 2.84 µg/100 cm².

4.3.4 Indoor Dust

Indoor dust samples were collected only at School 6. Measurement results are shown in Table 4-21 for the 25th, 50th, and 75th percentiles. The median total PCB concentration was 22 ppm (interquartile range 16.6 – 53.4 ppm) across samples collected in seven rooms. At the time of sample collection, School 6 had not been cleaned for five weeks. It is possible that PCB concentrations in the dust were higher than they would have been under routine cleaning because the dust had more time for contact with PCBs in the indoor air. School and college building dust measurement results available from extant sources (Appendix D) had a geometric mean level of 4.4 ppm ranging up to about 80 ppm. The median concentration at School 6 was larger, at 22 ppm, but the maximum value of 86.8 ppm is similar to the maximum in the extant data. Estimates of dust total PCB concentrations based on the measured air concentrations and estimated solid/air partition coefficients are shown in Appendix E.

4.3.5 Soil

Soil samples were collected at six schools at a depth 0 to 5 cm (0 to 2 inches) and at distances of 0.15, 0.91, and 2.44 m (0.5, 3, and 8 feet) from the building. Only 33% of the samples had PCB concentrations above the quantifiable limit (Table 4-22). The median total PCB concentration across all 309 soil samples was less than the quantifiable limit. The 75th percentile concentration was 0.98 ppm and the maximum value was 211 ppm. The 75th percentiles of

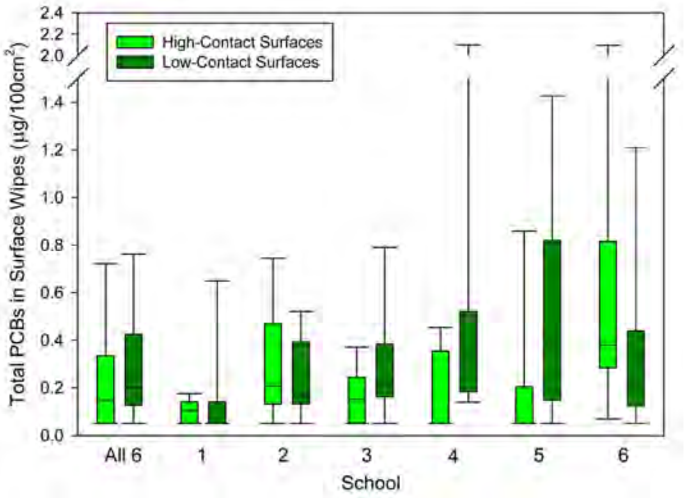


Figure 4-8. Distributions of surface wipe total PCB concentrations collected from high-contact and low-contact surfaces across all six schools and at each individual school. The box plots show the median, 25th, and 75th percentiles. The whiskers show the 10th and 90th percentiles.

Table 4-20. Surface wipe total PCB measurement results at six schools

			Total PCB Levels in Surface Wipes[a,b]		
School/Condition	N[c]	% > QL[d]	Median µg/100cm²	Inter-Quartile Range µg/100cm²	Overall Range µg/100cm²
All Six Schools					
High-contact surfaces	72	62	0.147	<QL - 0.330	<QL – 2.84
Low-contact surfaces	78	80	0.201	0.128 - 0.419	<QL – 2.30
School 1					
High-contact surfaces	11	54	0.106	<QL - 0.128	<QL – 0.177
Low-contact surfaces	11	46	<QL	<QL - 0.135	<QL – 0.716
School 2					
High-contact surfaces	12	83	0.207	0.141 - 0.328	<QL – 0.748
Low-contact surfaces	12	83	0.165	0.139 - 0.369	<QL – 0.570
School 3					
High-contact surfaces	14	57	0.154	<QL - 0.214	<QL – 0.396
Low-contact surfaces	14	86	0.208	0.175 - 0.305	<QL – 0.864
School 4					
High-contact surfaces	9	44	<QL	<QL - 0.288	<QL – 0.454
Low-contact surfaces	9	100	0.328	0.213 - 0.407	0.140 – 2.10
School 5					
High-contact surfaces	12	33	<QL	<QL - 0.182	<QL – 1.10
Low-contact surfaces	12	83	0.388	0.166 - 0.749	<QL – 1.51
School 6					
High-contact surfaces	14	93	0.380	0.303 - 0.723	<QL – 2.84
Low-contact surfaces	20	80	0.206	0.127 - 0.431	<QL – 2.30

[a] Reported as total PCBs from Aroclor measurements in surface wipes.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number samples and number of rooms sampled, except for School 6 where two high-contact and three low contact samples were collected in most rooms.

[d] QL = Quantitation limit; 0.100 µg/100 cm² for all samples.

Table 4-21. Indoor dust total PCB measurement results at School 6

School	N[c]	% > QL[d]	Total PCB Levels in Indoor Dust[a,b] Median ppm	Inter-Quartile Range ppm	Overall Range ppm
School 6[e]	7	100	22.0	16.6 - 53.4	11.6 – 86.8

[a] Reported as total PCBs from Aroclor measurements in dust.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number of samples and number of rooms sampled.

[d] QL = Quantitation limit; ranged from 0.54 to 14.2 ppm depending on sample size

[e] This school building had not been cleaned in the approximately 5 weeks prior to sample collection; the residence time for PCB absorption may have been longer than for most school situations.

Table 4-22. Soil total PCB measurement results at six schools

School/Condition	N[c]	% > QL[d]	Total PCB Levels in Soil[a,b]		
			Median ppm	Inter-Quartile Range ppm	Overall Range ppm
<u>All Six Schools</u>					
All soil samples	309	33	<QL	<QL - 0.975	<QL – 211
0.15m from building; 0–5cm depth	99	48	<QL	<QL - 2.13	<QL - 211
0.91m from building; 0–5cm depth	102	28	<QL	<QL - 0.548	<QL – 20.6
2.44m from building; 0–5cm depth	105	21	<QL	<QL - <QL	<QL – 5.28
School 1					
0.15m from building; 0–5cm depth	12	50	0.910	<QL - 4.27	<QL - 211
0.91m from building; 0–5cm depth	12	8	<QL	<QL - <QL	<QL – 4.74
2.44m from building; 0–5cm depth	26	8	<QL	<QL - <QL	<QL – 0.795
School 2					
0.15m from building; 0–5cm depth	30	13	<QL	<QL - <QL	<QL – 1.03
0.91m from building; 0–5cm depth	29	7	<QL	<QL - <QL	<QL – 1.34
2.44m from building; 0–5cm depth	27	11	<QL	<QL - <QL	<QL – 2.48
School 3					
0.15m from building; 0–5cm depth	8	100	9.60	6.10 - 15.4	5.70 – 32.7
0.91m from building; 0–5cm depth	9	100	5.84	4.89 - 9.43	2.31 – 20.6
2.44m from building; 0–5cm depth	14	100	2.14	1.66 - 2.57	0.797 – 5.28
School 4					
0.15m from building; 0–5cm depth	35	49	<QL	<QL - 1.38	<QL – 7.67
0.91m from building; 0–5cm depth	38	18	<QL	<QL - <QL	<QL – 3.17
2.44m from building; 0–5cm depth	31	0	<QL	<QL - <QL	<QL
School 5					
0.15m from building; 0–5cm depth	12	92	3.68	2.16 - 16.0	<QL – 36.0
0.91m from building; 0–5cm depth	12	67	1.75	<QL - 5.46	<QL – 13.4
2.44m from building; 0–5cm depth	5	40	<QL	<QL - 0.72	<QL – 1.62
3.7/4.9m from building; 0–5cm depth	2	100	1.21	1.21	0.674 – 1.75
School 6					
0.15m from building; 0–5cm depth	2	100	1.87	--	1.69 – 2.05
0.91m from building; 0–5cm depth	2	100	0.267	--	0.186 – 0.348
2.44m from building; 0–5cm depth	2	50	<QL	--	<QL – 0.132
15.2m from building; 0–5cm depth	1	0	<QL	--	--

[a] Reported as total PCBs from Aroclor measurements in soil.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number of samples.

[d] QL = Quantitation limit; 0.5 ppm for Schools 1 – 5 and from 0.05 to 0.58 ppm for School 6.

total PCB concentrations across six schools at 0.15, 0.91, and 2.44 m from the building were 2.13, 0.55, and <0.5 ppm respectively. Soil PCB concentrations decreased with increasing distance from the school building. There was considerable variability between schools; for example one school had only 10% of the PCB levels above the quantifiable limit while another school had 100%. Distributions of the soil concentrations are shown by school in Figure 4-9 where there were sufficient measurable results.

Additional soil samples were collected from the 5 to 10 cm (2 to 4 inch) depth at School 1. A comparison of the results from the 0 - 5 and 5 – 10 cm samples are shown in Table 4-23. The results are difficult to interpret. At both the 0.15 and 0.91 m distances, the median concentration at the 5 – 10 cm depth was greater than the median concentration at the 0 – 5 cm depth. On the other hand, the maximum concentrations at the 0 – 5 cm depth were greater than the maximum values at the 5 – 10 cm depth for samples collected 0.15 and 2.44 m from the building. Concentrations at the 0 – 5 cm depth are likely to be more relevant for assessing exposure potential.

The geometric mean total PCB concentration for school soils from extant data (Appendix D) was 0.98 ppm with a range up to about 80 ppm. The median value for the six schools in this report was less than the QL (a value of 0.5 ppm for most samples), lower than the extant data geometric mean. On the other hand, the maximum value from these schools (211 ppm) was greater than the extant data maximum. There are few reports of PCB levels in urban soils in the United States. One recent report from Cedar Rapids, IA showed a mean total PCB level of 0.056 ± 0.16 ppm with a maximum value of 1.2 ppm (Martinez et al., 2012). The authors report that the mean is about 10 times higher than the world-wide background levels based on the sum of 29 congeners. The 75th percentile level of PCBs in soils adjacent to school buildings in this study is considerably higher than the 0.045 ppm 75th percentile value for urban soils in Cedar Rapids, and much greater than background non-urban levels.

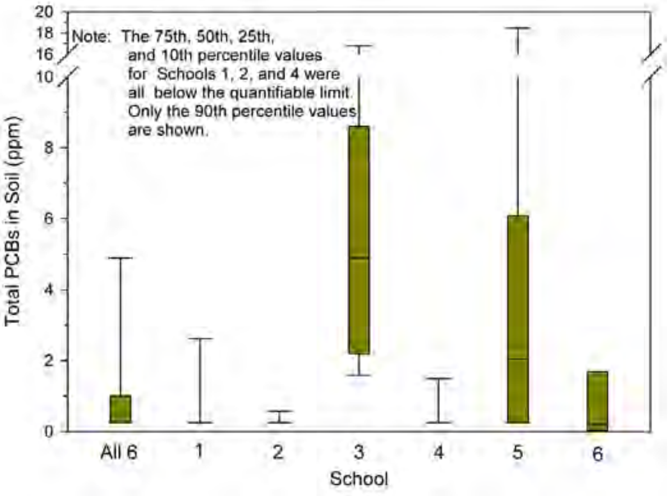


Figure 4-9. Distributions of outdoor soil total PCB concentrations across all six schools and at each individual school. The box plots show the median, 25th, and 75th percentiles. The whiskers show the 10th and 90th percentiles.

4.3.6 Pre- and Post-Remediation Air and Wipes

As part of the NYC SCA remedial pilot investigation, various remedial actions for reducing potential exposures to PCBs were examined in five NYC schools. These

Table 4-23. Soil total PCB measurement results for two soil depths at School 1

			Total PCB Levels in Soil [a,b]		
School/Condition	**N[c]**	**% >QL[d]**	**Median ppm**	**Inter-Quartile Range ppm**	**Overall Range ppm**
School 1					
0.15m from building; 0–5cm depth	12	50	0.910	<QL - 4.27	<QL - 211
0.15m from building; 5–10cm depth	12	67	1.43	<QL - 4.78	<QL – 19.4
0.91m from building; 0–5cm depth	12	8	<QL	<QL - <QL	<QL – 4.74
0.91m from building; 5–10cm depth	12	58	0.780	<QL - 1.48	<QL – 7.00
2.44m from building; 0–5cm depth	26	8	<QL	<QL - <QL	<QL – 0.795
2.44m from building; 5–10cm depth	26	12	<QL	<QL - <QL	<QL – 0.662

[a] Reported as total PCBs from Aroclor measurements in soil.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number of samples.

[d] QL = Quantitation limit; 0.5 ppm for School 1.

remedial activities are briefly summarized in Table 4-2. It is not within the scope of this report to examine and explain the remedial activities and results in detail. That information has been well described in other reports (NYC SCA 2011; NYC SCA 2012). However, it is of interest to understand how the changes in school environment PCB concentrations resulting from remedial actions may impact the potential exposures to building occupants. Pre-remediation and post-remediation air and surface wipe measurement results at selected remedial time points were assembled for use in the SHEDS modeling effort.

Summaries of the indoor air PCB concentrations at pre- and post-remediation time points for five schools are shown in Table 4-24. Distributions of indoor air PCB levels at pre- and post-remediation time points are shown in Figure 4-10. (The post-remediation air values in Table 4-24 and in Figure 4-10 are based on the time point following light fixture removal at Schools 1 – 3 and the final remediation time point for Schools 4 and 5; see Table 4-2 for details). Across all five schools, the median indoor air concentrations decreased 72% from the pre- to post-remediation time point and average levels decreased 74%. The magnitude of the decrease was different across the five schools. For example, at School 3 the median levels decreased from 504 ng/m^3 to < 50 ng/m^3 while at School 5 the median value decreased from 154 to 76 ng/m^3. The pre-remediation indoor air levels at School 1 were relatively low at 58 ng/m^3 and showed only a small decrease. However, problems were found with the HVAC outdoor air intake controls at School 1and it is not clear whether ventilation conditions were the same at both the pre- and post-remediation time points.

Table 4-24. Pre- and post-remediation indoor air total PCB measurement results at five schools

				Total PCB Levels in Air[a,b]		
School/Condition	N[c]	Mean QL[d] ng/m^3	% >QL	Median ng/m^3	Inter-Quartile Range ng/m^3	Overall Range ng/m^3
All Five Schools						
Pre-Remediation	57	50	74	257	<QL - 763	<QL - 2920
Post-Remediation	163	48	58	73	<QL - 209	<QL - 480
School 1						
Pre-Remediation	11	49	54	58	<QL - 121	<QL - 194
Post-Remediation	16	48	50	42	<QL - 120	<QL - 227
School 2						
Pre-Remediation[e]	12	50	100	807	674 - 874	414 - 1460
Post-Remediation	59	48	97	224	192 - 262	<QL - 362
School 3						
Pre-Remediation	14	51	100	504	271 - 960	236 - 2920
Post-Remediation	68	48	29	<QL	<QL - 56	<QL - 331
School 4						
Pre-Remediation	9	50	44	<QL	<QL - 154	<QL - 674
Post-Remediation	9	49	44	<QL	<QL - 138	<QL - 299
School 5						
Pre-Remediation	11	50	54	154	<QL - 425	<QL - 867
Post-Remediation	11	49	54	76	<QL - 173	<QL - 480

[a] Reported as total PCBs from Aroclor measurements in indoor air.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number of samples and number of rooms sampled.

[d] QL = Quantitation limit.

[e] Does not include a second day of pre-remediation air results for School 2.

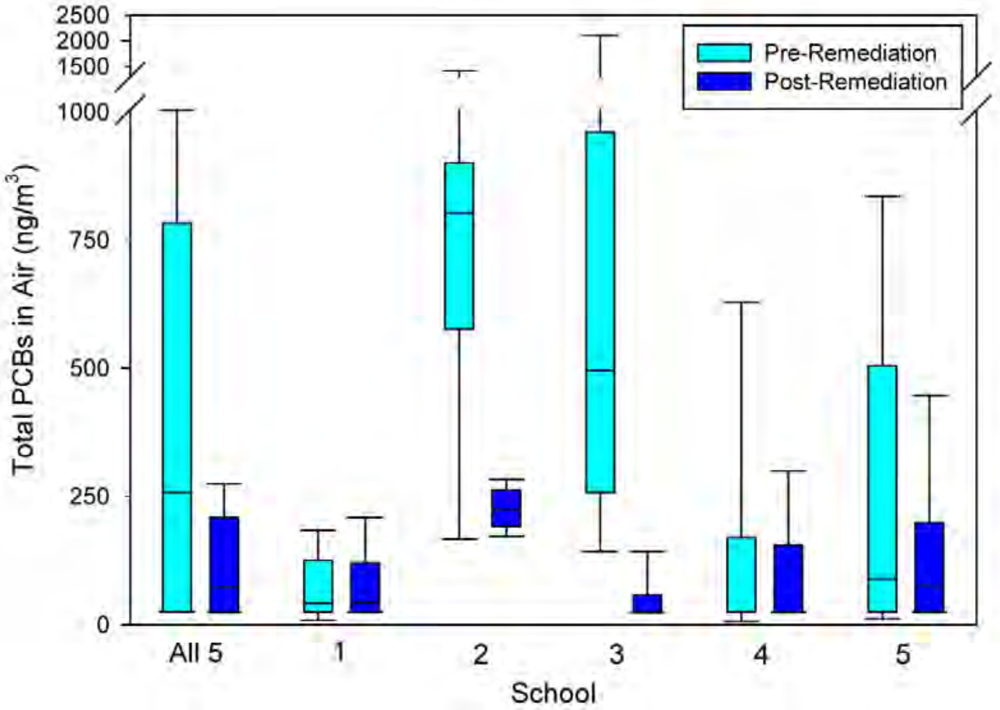


Figure 4-10. Pre- and post-remediation indoor air total PCB concentrations across five schools and at each individual school. The box plots show the median, 25th, and 75th percentiles. The whiskers show the 10th and 90th percentiles.

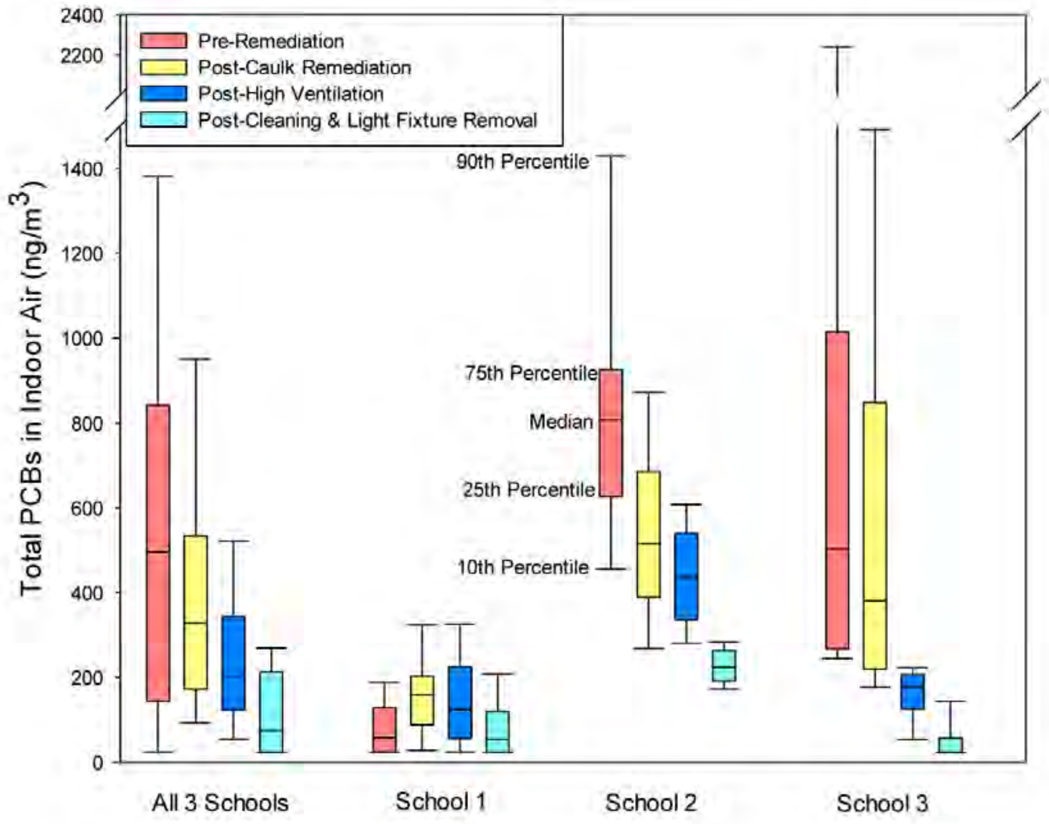


Figure 4-11. Pre- and post-remediation indoor air total PCB concentrations across three schools with several different remedial activities.

Air measurements were conducted at several stages of remedial activities at at the three 2010 NYC pilot schools. Summaries of the indoor air total PCB levels in air are shown in Figure 4-11. For School 1, pre-remediation concentrations were relatively low as compared to Schools 2 and 3, but appeared to increase somewhat at two remedial time points. This may have been a result with problems subsequently found in the ventilation system outside air inlet. For Schools 2 and 3, there appeared to be substantial reductions in indoor air levels at each stage of remedial action. Caulk remediation included removal at School 2 and encapsulation at School 3, but only in those spaces that had indoor air measurements. It appeared that cleaning/ventilation steps and light fixture removal also contributed to decreased indoor air levels at subsequent time points in these buildings. The reductions in air concentrations occurred based on measurements taken within days or weeks following the specific remedial activities.

Pre- and post-remediation results for surface wipe samples are shown in Table 4-25. (The post-remediation wipe samples were collected following the caulk remediation step, while the air results shown in Table 4-24 and Figure 4-11 were collected following the additional ventilation, cleaning, and light removal steps). There was no clear pattern of pre- to post-remediation change in surface wipe measurement results. Median measurement values across the five schools showed virtually no change from pre- to post-remediation for the high-contact surfaces, while the median and 75th percentile values at the post-remediation samples were approximately 40% lower than pre-remediation levels for low-contact surfaces. PCBs collected by the surface wipes may reflect PCB concentrations in the underlying materials which could serve as reservoirs for longer time periods that the few weeks between the pre- and post-remediation sample collection. PCB concentrations in many materials were reported in Section 4.3. Based on modeling estimates by Guo et al. (2012) it is likely that PCB concentrations in these secondary sources will persist for some time following removal of primary sources. This may be a factor in the lack of large differences in pre- and post-remediation surface wipe concentrations measured over this time frame. On the other hand, the surface wipe measurements were generally low even at the pre-remediation time point.

4.3.7 Relationships Between School Environment PCB Concentrations

Relationships between total PCB concentrations in different school environmental media can be examined for those situations with sufficient numbers of samples collected from the same school building rooms at the same time. A total of 64 sets of collocated indoor air, high-contact surface wipe, and low-contact surface wipe samples were collected across the six schools. Modest but significant correlations were found between indoor air PCB concentrations and high-contact surface wipe levels for samples collected at the six schools (Table 4-26). Higher correlation values were found for the Spearman correlation approach, which uses rank orders and may be more appropriate for data exhibiting logarithmic distributions. While some association was shown to exist, it is difficult to interpret in a larger exposure context because the air levels are relatively large and the surface wipe levels relatively low. Most of the exposure comes from the indoor air, not contact with surfaces. It is also not certain whether higher indoor air levels lead to associated higher surface concentrations or vice-versa, and whether the relationship might suggest some level of dynamic equilibrium between PCBs in the air and at surface boundaries.

A total of seven sets of collocated indoor air, surface wipe, and dust samples were collected at School 6. Pearson and Spearman correlation coefficients among these media are reported in Table 4-26. The correlations between indoor air and high-contact surface wipe PCB levels was similar to those for all six schools, but with only seven samples the correlation was not significant. High and significant Pearson correlations were found between indoor air and dust levels, and between high-contact and low-contact surface wipe values. On the other hand, Spearman correlations were lower and not significant for these media combinations. Pearson correlations for small sample sizes must be interpreted cautiously because they can be highly influenced by one or two measurements.

Table 4-25. Pre- and post-remediation surface wipe total PCB measurement results at five schools

			Total PCB Levels in Surface Wipes[a,b]		
School/Condition	**N[c]**	**% > QL[d]**	**Median µg/100cm²**	**Inter-Quartile Range µg/100cm²**	**Overall Range µg/100cm²**
All Five Schools					
Pre-Remediation (H)[e]	58	55	0.121	<QL - 0.214	<QL – 1.10
Pre-Remediation (L)	58	79	0.201	0.131 - 0.407	<QL – 2.10
Post-Remediation (H)	58	50	<QL	<QL - 0.213	<QL – 0.947
Post-Remediation (L)	58	55	0.123	<QL - 0.218	<QL – 11.0[f]
School 1					
Pre-Remediation (H)	11	54	0.106	<QL - 0.128	<QL – 0.177
Pre-Remediation (L)	11	46	<QL	<QL - 0.135	<QL – 0.716
Post-Caulk Remediation (H)	11	9	<QL	<QL - <QL	<QL – 0.180
Post-Caulk Remediation (L)	11	54	0.125	<QL - 0.191	<QL – 0.538
School 2					
Pre-Remediation (H)	12	83	0.207	0.141 - 0.328	<QL – 0.748
Pre-Remediation (L)	12	83	0.165	0.139 - 0.369	<QL – 0.570
Post-Caulk Remediation (H)	12	75	0.130	0.100 - 0.177	<QL – 0.806
Post-Caulk Remediation (L)	12	92	0.192	0.132 - 0.240	<QL – 11.0[f]
School 3					
Pre-Remediation (H)	14	57	0.154	<QL - 0.214	<QL – 0.396
Pre-Remediation (L)	14	86	0.208	0.175 - 0.305	<QL – 0.864
Post-Caulk Remediation (H)	14	57	0.128	<QL - 0.259	<QL – 0.947
Post-Caulk Remediation (L)	14	43	<QL	<QL - 0.274	<QL – 0.753
School 4					
Pre-Remediation (H)	9	44	<QL	<QL - 0.288	<QL – 0.454
Pre-Remediation (L)	9	100	0.328	0.213 - 0.407	0.140 – 2.10
Post-Caulk & Light Remediation (H)	9	33	<QL	<QL - 0.161	<QL – 0.788
Post-Caulk & Light Remediation (L)	9	33	<QL	<QL - 0.124	<QL – 0.928
School 5					
Pre-Remediation (H)	12	33	<QL	<QL - 0.182	<QL – 1.10
Pre-Remediation (L)	12	83	0.388	0.166 - 0.749	<QL – 1.51
Post-Caulk & Light Remediation (H)	12	67	0.135	<QL - 0.271	<QL – 0.592
Post-Caulk & Light Remediation (L)	12	50	<QL	<QL - 0.158	<QL – 0.546

[a] Reported as total PCBs from Aroclor measurements in surface wipes.

[b] When duplicate samples were collected, the average of the duplicates was used.

[c] Number of samples and number of rooms sampled.

[d] QL = Quantitation limit; 0.100 µg/100 cm² for all samples.

[e] (H) = high contact surfaces (desks/tables); (L) = low contact surfaces (walls, floors, windowsills).

[f] A wipe sample with an elevated PCB level (97.6 µg/100 cm2) was collected from the gymnasium at School 2. Eight other low-contact samples were also collected from the gym with results ranging from not detected to 0.202 µg/100 cm2. An average of the nine results (10.97 µg/100 cm2) was used.

Table 4-26. Correlations between total PCB concentrations in selected school environment samples[a,b]

		Pearson Correlation		Spearman Correlation	
Schools/Sample Media	**N**	**r**	**p-value**	**r**	**p-value**
Schools 1 - 6					
Indoor Air High-Contact Surface Wipe	64	0.256	0.041	0.531	<0.001
Indoor Air Low-Contact Surface Wipe	64	0.104	0.415	0.247	0.050
High-Contact Surface Wipe Low-Contact Surface Wipe	64	0.270	0.031	0.220	0.081
School 6					
Indoor Air High-Contact Surface Wipe	7	0.258	0.577	0.500	0.253
Indoor Air Low-Contact Surface Wipe	7	0.270	0.558	0.500	0.253
Indoor Air Dust	7	0.805	0.029	0.536	0.215
High-Contact Surface Wipe Low-Contact Surface Wipe	7	0.840	0.018	0.357	0.432
High-Contact Surface Wipe Dust	7	0.170	0.716	0.393	0.383
Low-Contact Surface Wipe Dust	7	0.010	0.983	-0.179	0.702

[a] Based on total PCBs from Aroclor measurements.

[b] When duplicate samples were collected, the average of the duplicates was used.

4.4 Congener and Homolog Measurements

Examining patterns of individual congeners can provide insight regarding relationships between PCBs sources and environmental media, and can also provide information useful in exposure and risk assessment. Individual PCB congeners were measured in all of the air samples and in a subset of surface wipe, indoor dust, soil, caulk, and other building material samples collected at School 6.

Many of the building measurements that have been performed for PCB assessment have used an Aroclor analysis approach as a way to keep costs and complexity relatively low as compared to performing congener-specific analysis. There is concern, however, that building environmental media and materials may not contain PCB congeners in the mixture proportions found in Aroclors. Congener mixtures in indoor air may reflect changes associated with vapor pressure and the resulting emission differences from sources such as caulk. PCBs in both materials and soil may show characteristics of "weathering" where the congener mixture has changed over time due to losses or perhaps even depletion of more volatile components over the 40 – 60 year residence time. It is possible that analyzing building environmental media and materials as Aroclors could provide an inaccurate result for total PCB concentrations because of the way analytical quantitation is done for Aroclor analyses. It is possible that Aroclor results could be biased high or low, depending on the specifics of which congeners are used for quantitation and how the quantitation is handled. Because of the improved information obtained from congener analysis, and because of the potential biases in applying Aroclor analysis to environmentally altered mixtures, congener specific analysis would be preferred in most situations.

A comparison can be made for the total PCB concentration determined by analysis using both Aroclor and congener quantitation approaches for the samples collected at School 6. Results are shown in Table 4-27 for the several types of samples that were collected. Analysis of sample extracts for congeners resulted in total PCB concentrations that were approximately 20% lower (range 14 to 46% lower) than the analysis of the same sample extracts using an Aroclor method. The indoor air analysis results are of greatest interest because it is likely, if emissions from PCBs in caulk with an un-weathered Aroclor 1254 pattern are the primary source, that the congener pattern in air would be substantially different than the Aroclor 1254 pattern. This effect was seen in chamber emissions testing of caulk (Guo et al., 2011) where the pattern in chamber air was shifted substantially towards higher weight percentages of more volatile congeners.

Averages of the congener-specific measurement results are shown for 45 selected congeners in Table 4-28 for all of the different types of samples that were analyzed. The 45 congeners were selected to represent a wide range of chlorination and vapor pressures; because they are congeners that have been widely reported in other studies; and because the sum of the congeners accounted for 82.9% or more of the sum of all 209 congeners. Table 4-28 shows the individual congener concentrations, the sum of all 209 congeners, the sum and weight percent of the 45 congeners in the table, the sum and weight percent of the 12 dioxin-like congeners (which are often used as a comparative toxicity estimate), and calculated toxic equivalence concentration for the 12 dioxin-like congeners (U.S. EPA, 2010; WHO, 2006). Results for the congener measurements calculated as weight percents are shown in Table 4-29. The weight percent results allow an easier comparison of patterns across the different sample types. Congener measurement results are reported in more detail by sample type in Appendix C.

A comparison of the measured congener concentration pattern in the PCB-containing exterior caulk collected at School 6 to the congener weight percent pattern in Aroclor 1254 as reported by Frame et al. (1996) is shown in Figure 4-12. The congener pattern in caulk appears to be shifted towards higher percentages of congeners with lower vapor pressure as compared to Aroclor 1254. It is not known with any certainty whether this is a result of weathering over 43 years or possibly because the original congener mixture was different than Aroclor 1254. However, the pattern did not appear to be similar to 1260; for example the weight percent of the 7-chlorine congeners in the caulk was 4.8% whereas it is 38% in Aroclor 1260. The analysis laboratory reported the result of the Aroclor analysis as Aroclor 1254 with an altered Aroclor pattern, and that is consistent with the congener specific results shown in Figure 4-12.

Table 4-27. Comparison of Aroclor and congener measurement results for total PCBs at School 6

Measurement	N	Units	Aroclor Analysis Mean ± SD	Congener Analysis Mean ± SD	% Difference[a]
Indoor Air	7	ng/m^3	633 ± 189	500 ± 154	21
Surface Wipe	10	µg/100 cm^2	0.507 ± 0.404	0.407 ± 0.379	20
Indoor Dust	4	ppm	36.0 ± 24.6	30.9 ± 18.6	14
Outdoor Soil	3	ppm	1.50 ± 1.38	1.09 ± 0.95	27
Interior Caulk	5	ppm	21.2 ± 12.3	11.5 ± 5.9	46
Exterior Caulk	3	ppm	143000 ± 8180	114000 ± 2230	20
Other Materials	18	ppm	47.2 ± 25.2	36.9 ± 19.9	22

[a] Calculated as (Aroclor Mean – Congener Mean)/Aroclor Mean) × 100.

Table 4-28. Summary of average PCB congener concentrations at School 6

PCB Congener #	Indoor Air N = 7 ng/m^3	Outdoor Air N = 1 ng/m^3	Surface Wipe N = 10 µg/100 cm^2	Indoor Dust N = 4 ppm	Outdoor Soil N = 3 ppm	Interior Caulk N = 5 ppm	Exterior Caulk N = 3 ppm	Other Materials N = 18 ppm
4	0.34	<QL	<QL	<QL	<QL	<QL	<QL	0.009
8	1.5	<QL	<QL	<QL	<QL	0.007	<QL	0.018
17	2.1	<QL	<QL	0.001	<QL	0.011	11	0.041
18	3.8	<QL	<QL	0.003	<QL	0.029	11	0.080
28	3.8	<QL	0.0010	0.018	<QL	0.048	46	0.18
31	3.7	<QL	0.0007	0.018	<QL	0.046	52	0.16
44	19	0.24	0.0066	0.29	0.0027	0.309	1300	0.85
47	4.8	0.06	0.0015	0.073	0.0003	0.077	340	0.21
49	15	0.17	0.0043	0.15	0.0026	0.19	770	0.46
52	45	0.45	0.0133	0.59	0.0087	0.70	3100	1.5
56	2.6	0.08	0.0019	0.13	0.011	0.063	350	0.27
64	5.5	0.04	0.0015	0.087	0.0007	0.085	380	0.25
66	6.9	0.09	0.0037	0.23	0.0043	0.14	770	0.51
70	25	0.39	0.0108	0.73	0.011	0.42	2600	1.2
74	12	0.18	0.0051	0.34	0.0053	0.20	1200	0.58
82	3.9	0.11	0.0035	0.40	0.0102	0.12	1200	0.45
84	14	0.24	0.0072	0.51	0.0078	0.29	1800	0.85
85	5.4	0.11	0.0044	0.42	0.012	0.15	1300	0.46
87	17	0.34	0.0144	1.4	0.031	0.48	2900	1.5
91	5.8	0.15	0.0032	0.19	0.0033	0.11	770	0.30
92	10	0.15	0.0057	0.46	0.011	0.22	1800	0.57
95	50	0.72	0.0180	1.3	0.020	0.77	5200	2.0
97	11	0.22	0.0086	0.74	0.017	0.28	2500	0.85
99	15	0.24	0.0136	1.1	0.031	0.48	3900	1.3
101	54	0.86	0.0336	2.6	0.064	1.1	9600	3.0
105	5.5	0.11	0.0108	1.2	0.053	0.27	3900	0.95
110	39	0.49	0.0270	2.7	0.069	0.87	8900	2.8
118	19	0.52	0.0242	2.6	0.095	0.64	8300	2.1
128	1.4	<QL	0.0043	0.51	0.034	0.10	2200	0.35
130	0.83	<QL	0.0018	0.19	0.011	0.043	730	0.14
132	6.6	0.23	0.0112	1.0	0.038	0.25	3600	0.98
138	8.3	0.23	0.0226	2.1	0.11	0.45	8200	1.6
141	2.2	0.07	0.0057	0.44	0.022	0.099	1600	0.42
146	1.2	0.03	0.0023	0.26	0.012	0.059	860	0.21
149	13	0.24	0.0188	1.5	0.050	0.42	5100	1.5
151	5.8	0.12	0.0070	0.49	0.015	0.16	1700	0.55
153	9.6	0.23	0.0225	1.7	0.075	0.40	6200	1.4
156	0.49	<QL	0.0027	0.28	0.023	0.058	1500	0.17
158	1.2	0.03	0.0033	0.30	0.014	0.065	1200	0.23
163	1.4	0.04	0.0039	0.36	0.020	0.078	1400	0.28
170	0.24	<QL	0.0030	0.15	0.016	0.032	970	0.13
174	0.70	<QL	0.0044	0.18	0.011	0.037	720	0.24

Table 4-28. Summary of average PCB congener concentrations at School 6 (continued)

PCB Congener #	Indoor Air N = 7 ng/m^3	Outdoor Air N = 1 ng/m^3	Surface Wipe N = 10 $\mu g/100\ cm^2$	Indoor Dust N = 4 ppm	Outdoor Soil N = 3 ppm	Interior Caulk N = 5 ppm	Exterior Caulk N = 3 ppm	Other Materials N = 18 ppm
180	0.76	<QL	0.0089	0.28	0.020	0.057	1400	0.35
187	0.83	<QL	0.0052	0.14	0.012	0.033	500	0.25
206	0.19	<QL	0.0068	0.008	0.0024	0.008	<QL	0.051
Σ 209 Cong.[a]	500	7.7	0.407	30.9	1.09	11.5	114000	36.9
Σ 45 Cong.[b]	456	7.20	0.359	28.1	0.96	10.5	101000	32.5
Σ DLC Cong.[c]	26	0.64	0.039	4.3	0.18	1.0	14500	3.4
DLC TEQ[d]	7.88E-04	1.91E-05	1.19E-06	1.29E-04	5.53E-06	3.08E-05	0.436	1.05E-04
% 45 Cong.[e]	91.0	93.2	90.4	89.5	82.9	91.7	89.2	87.6
% DLC Cong.[f]	5.0	8.2	9.8	12.2	13.7	8.7	12.8	8.6

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the 12 dioxin-like congeners.

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table 4-29. Summary of average PCB congener weight percents at School 6[a]

PCB Congener #	Indoor Air N = 7	Outdoor Air N = 1	Surface Wipe N = 10	Indoor Dust N = 4	Outdoor Soil N = 3	Interior Caulk N = 5	Exterior Caulk N = 3	Other Materials N = 18
4	0.07	<QL	<QL	<QL	<QL	<QL	<QL	0.02
8	0.3	<QL	<QL	<QL	<QL	0.06	<QL	0.05
17	0.4	<QL	<QL	<QL	<QL	0.1	0.01	0.1
18	0.8	<QL	<QL	0.01	<QL	0.2	0.01	0.2
28	0.8	<QL	0.2	0.06	<QL	0.4	0.04	0.5
31	0.7	<QL	0.2	0.06	<QL	0.4	0.05	0.4
44	3.8	3.1	1.6	1.0	0.2	2.7	1.2	2.3
47	1.0	0.8	0.4	0.2	0.02	0.7	0.3	0.6
49	3.0	2.2	1.1	0.5	0.2	1.6	0.7	1.2
52	8.9	5.9	3.3	1.9	0.8	6.0	2.8	4.2
56	0.5	1.0	0.5	0.4	1.0	0.6	0.3	0.7
64	1.1	0.6	0.4	0.3	0.06	0.7	0.3	0.7
66	1.4	1.2	0.9	0.8	0.4	1.3	0.7	1.4
70	5.1	5.1	2.7	2.4	1.0	3.6	2.3	3.3
74	2.4	2.4	1.3	1.1	0.5	1.7	1.1	1.6
82	0.8	1.4	0.9	1.3	0.9	1.1	1.1	1.2
84	2.8	3.2	1.8	1.6	0.7	2.6	1.6	2.3
85	1.1	1.4	1.1	1.4	1.1	1.3	1.2	1.2
87	3.5	4.4	3.5	4.4	2.8	4.2	2.6	4.1
91	1.2	2.0	0.8	0.6	0.3	1.0	0.7	0.8
92	2.1	1.9	1.4	1.5	1.0	1.9	1.5	1.6
95	10	9.3	4.4	4.1	1.9	6.7	4.5	5.5
97	2.2	2.8	2.1	2.4	1.6	2.4	2.2	2.3
99	3.0	3.2	3.4	3.6	2.9	4.2	3.5	3.5
101	11	11	8.3	8.4	5.9	10	8.4	8.2
105	1.1	1.5	2.7	3.9	4.8	2.3	3.4	2.6
110	7.8	6.4	6.6	8.7	6.3	7.6	7.8	7.5
118	3.7	6.8	5.9	8.3	8.7	5.6	7.3	5.8
128	0.3	<QL	1.1	1.6	3.1	0.9	1.9	1.0
130	0.2	<QL	0.4	0.6	1.0	0.4	0.6	0.4
132	1.3	3.0	2.8	3.4	3.5	2.2	3.2	2.6
138	1.6	3.0	5.6	6.8	10	3.9	7.2	4.3
141	0.4	0.9	1.4	1.4	2.0	0.9	1.4	1.1
146	0.2	0.3	0.6	0.9	1.1	0.5	0.8	0.6
149	2.5	3.1	4.6	4.8	4.6	3.7	4.5	4.0
151	1.2	1.6	1.7	1.6	1.4	1.4	1.5	1.5
153	1.9	3.0	5.5	5.5	6.9	3.4	5.4	3.9
156	0.1	<QL	0.7	0.9	2.1	0.5	1.3	0.5
158	0.2	0.4	0.8	1.0	1.3	0.6	1.1	0.6
163	0.3	0.5	1.0	1.2	1.8	0.7	1.3	0.8

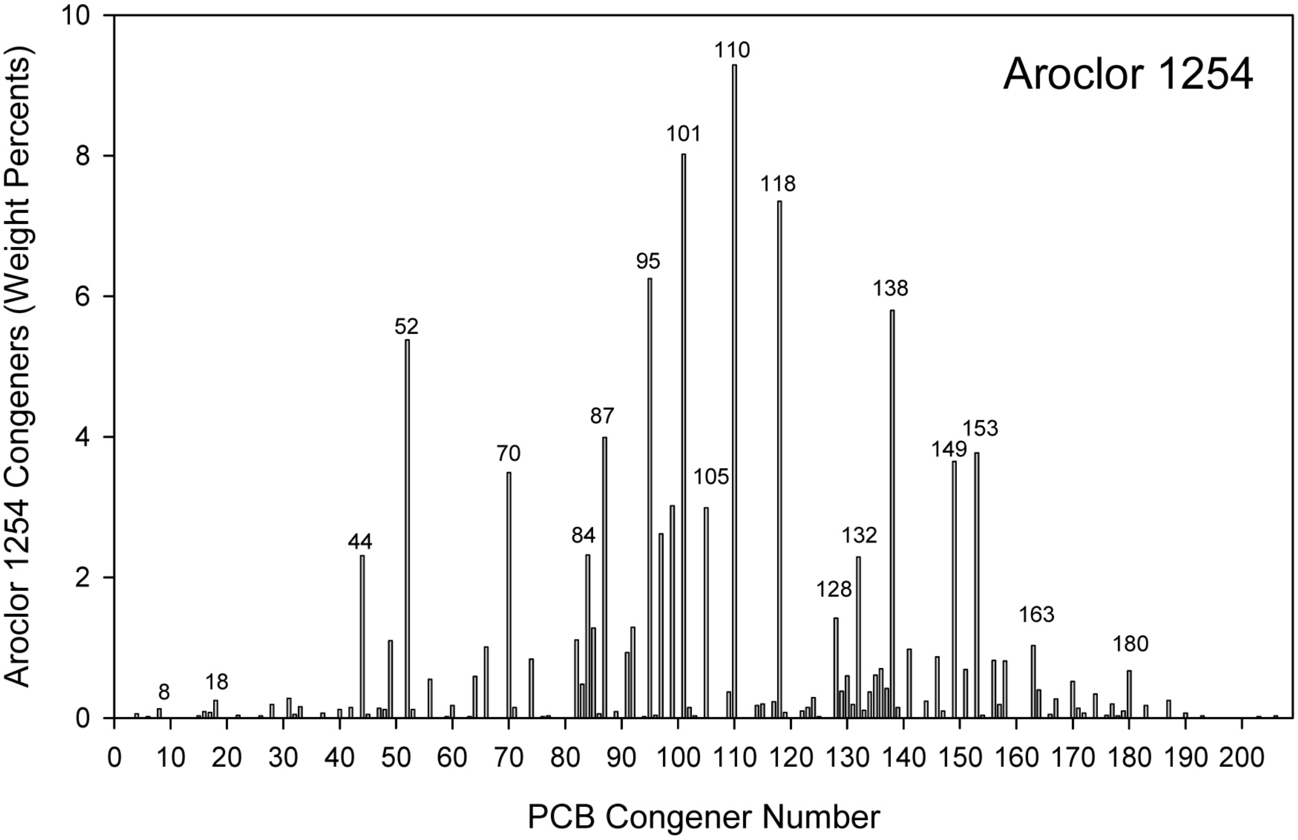
Table 4-29. Summary of average PCB congener weight percents at School 6[a] (continued)

PCB Congener #	Indoor Air N = 7	Outdoor Air N = 1	Surface Wipe N = 10	Indoor Dust N = 4	Outdoor Soil N = 3	Interior Caulk N = 5	Exterior Caulk N = 3	Other Materials N = 18
170	0.05	<QL	0.7	0.5	1.5	0.3	0.8	0.4
174	0.1	<QL	1.1	0.6	1.0	0.3	0.6	0.6
180	0.2	<QL	2.2	0.9	1.8	0.5	1.2	0.9
187	0.2	<QL	1.3	0.5	1.1	0.3	0.4	0.7
206	0.04	<QL	1.7	0.03	0.2	0.07	<QL	0.1
Σ 45 Cong. %[b]	91	93	90	90	83	92	89	88
	ng/m^3	ng/m^3	µg/100 cm^2	ppm	ppm	ppm	ppm	ppm
Σ 209 Cong.[c]	500	7.7	0.407	30.9	1.09	11.5	114000	36.9

[a] Each congener's percent of the total concentration of all 209 congeners.

[b] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[c] Sum of the measured concentrations for all 209 congeners, including those not shown in this table.



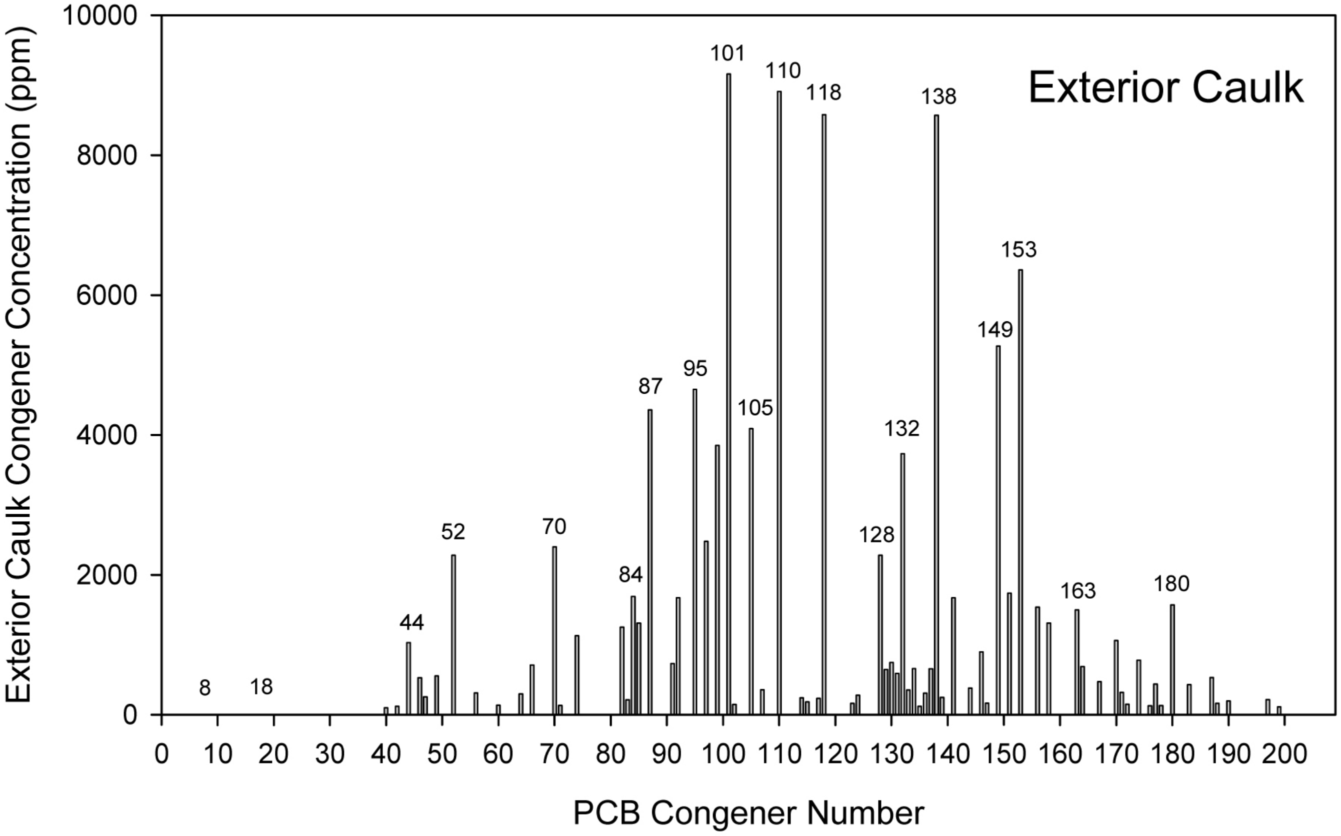


Figure 4-12. Patterns of congeners in Aroclor 1254 (top) and exterior caulk collected at School 6

Figure 4-13 shows congener concentration patterns for indoor air and dust samples collected in School 6. The indoor air pattern appears to be shifted toward higher percentages of congeners with higher vapor pressures as compared to the dust, caulk, and Aroclor 1254 congener patterns. This is consistent with vapor emission as a source of the PCBs in air.

Comparisons of congener patterns between indoor air, the exterior caulk, and Aroclors 1242 and 1254 are shown in Figure 4-14 for selected congeners ordered by decreasing vapor pressure. The congeners are shown on a weight percent basis so direct comparisons can be made. Once again, the comparison shows congeners in indoor air shifted towards more volatile congeners and those in caulk shifted towards less volatile congeners as compared to the Aroclor 1254 pattern. The indoor air pattern does not match the overall Aroclor 1242 pattern, but some contribution of the more volatile Aroclor 1242 congeners in air can't be ruled out. Congener weight percent patterns are shown for a number of different sample media in Figure 4-15. The congener pattern in paint more closely matches the Aroclor 1254 pattern than does the caulk. As Guo et al., (2012) demonstrated in chamber studies, this might be expected as a result of greater emission of more volatile PCBs from caulk, but preferential absorption of less volatile PCBs into the paint, resulting in a pattern that looks remarkably like Aroclor 1254. Surface wipe and dust samples had lower percentages of more volatile congeners as compared to indoor air and Aroclor 1254 but as the congener vapor pressures decreased their patterns became more similar to the Aroclor 1254 pattern.

Another way to examine patterns and differences in patterns of PCBs in different types of environmental media and materials is by examining PCB homologs. Congener measurement results can be used to calculate PCB homolog concentrations by summing all of the results for congeners with the same number of chlorines. A summary of the average chlorine-number homolog measurement results is shown as weight percents in Table 4-30. Results for the individual sample types are shown in more detail in Appendix C.

Homolog weight percents for the PCB-containing exterior caulk and the indoor building materials are compared to homolog patterns in Aroclors 1242 and 1254 and indoor air in Figure 4-16. The caulk contains higher fractions of 6- and 7-chlorine homologs as compared to Aroclor 1254 and a smaller fraction of 4-chlorine homologs compared both to Aroclor 1254 and the other materials. Homolog patterns for the air, wipe, dust, and soil samples are compared to patterns for Aroclors 1242 and 1254 in Figure 4-17. The indoor air has substantially higher percentages of the 2-, 3-, and 4-chlorine homologs and less of the 6-, 7-, and 8-chlorine homologs compared to wipes, dust, soil, and Aroclor 1254. Surface wipe and dust patterns look similar, which is not surprising since the wipes likely have a dust component. The higher fraction of 6-chlorine homolog in dust as compared to air shows, as expected, that higher molecular weight congeners are more likely to be particle-bound. The outdoor soil has higher fractions of the 6-, 7-, and 8-chlorine homologs than Aroclor 1254 and the other media, possibly as a result of weathering loss of the more volatile congeners over time.

Estimates of PCB emissions from caulk were reported in Section 4.2.1 based on an assumption that the congener pattern in the caulk was the same as the congener pattern in Aroclor 1254. This was a requirement since only Aroclor measurement results were available for most of the caulk samples. However, the availability of congener specific measurements for caulk at School 6 allows examination of the assumption. Table 4-31 shows a comparison of the estimated emission rates for selected congeners and total PCBs using first using the assumption that an Aroclor 1254 pattern is present, and then again using the actual measured congeners in the exterior caulk.

Because the relative concentrations of the more volatile congeners such as congener 52 were lower in the caulk than in Aroclor 1254, the assumed approach leads to higher emission estimates for the more volatile congeners. The opposite is true for the less volatile congeners such as congener 153. Overall, the estimated total PCB emission rate assuming an Aroclor 1254 mixture was 80% higher than the rate using the actual measurements of congener concentrations in the caulk. The impact is illustrated in Figure 4-18, which shows the estimated congener emission rates using the assumption of an Aroclor 1254 mixture and the measured congener concentrations in the caulk. Figure 4-19 shows the congener emission rates based on the congeners measured in the exterior caulk at School 6 and the concentration of congeners measured in indoor air. The indoor air pattern more closely matches the pattern using the measured congener concentrations than for the estimated emission rates assuming an un-weathered Arcolor 1254 mixture as shown in Figure 4-18. A caution is warranted in this assessment. It is not certain whether the most volatile congeners were not detected in the School 6 caulk because they were not present or because of the level of dilution that was used for these sample extracts (due to the very high PCB concentrations). If those more volatile congeners were actually present but unmeasured, the total PCB emission rate could be underestimated.

A summary of the key findings from the assessment of congener and homolog data using samples collected at one school is provided below.

- The pattern of congeners in indoor air was more heavily weighted towards more volatile congeners as compared to Aroclor 1254 and compared to the PCB-containing caulk at the building. The pattern of congeners in air was not as heavily weighted towards more volatile congeners as would be predicted if they were from vapor emissions from caulk alone, suggesting that a portion of the PCBs in air may be associated with airborne particles, but this could also reflect in part a higher proportion of less volatile congeners in the caulk.

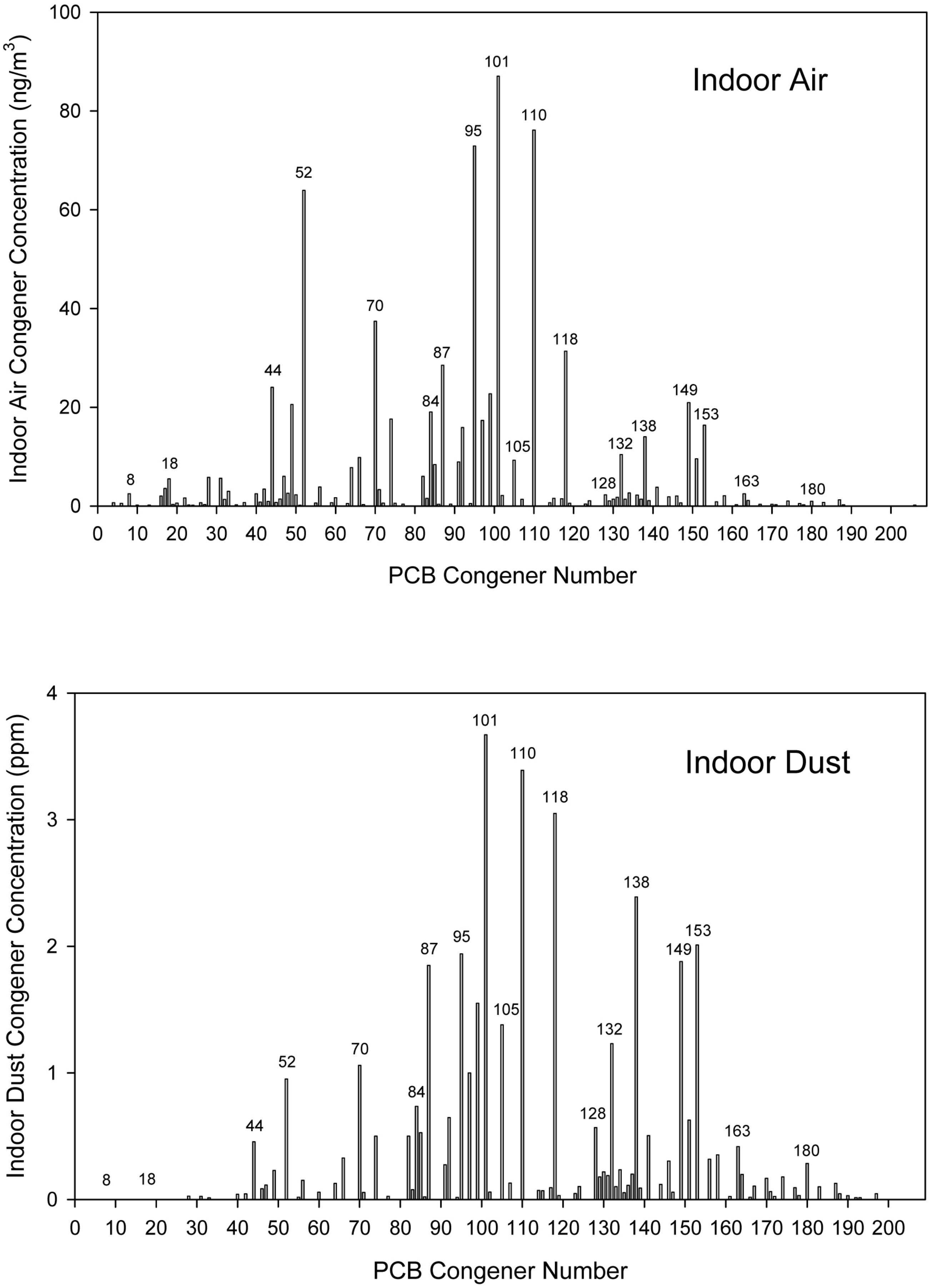
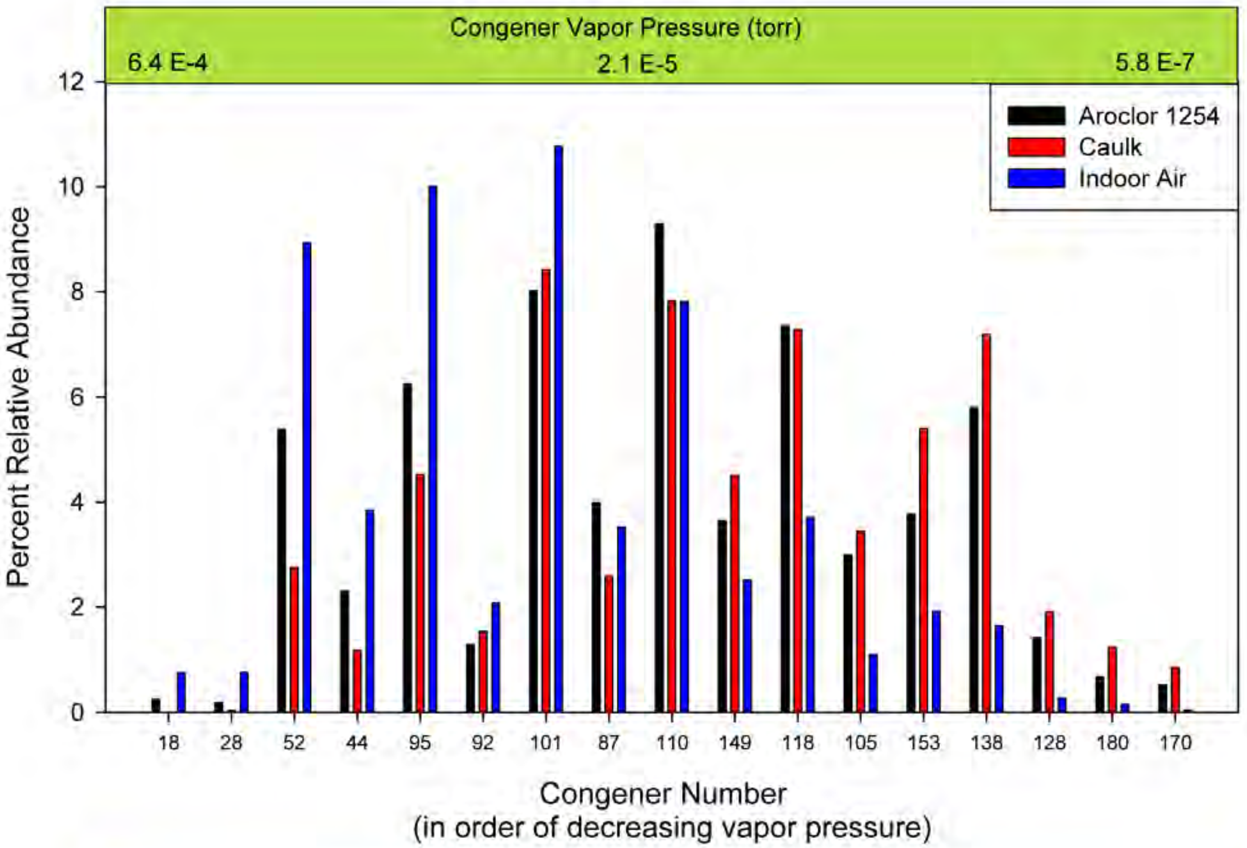


Figure 4-13. Patterns of congeners in indoor air (top) and indoor dust collected at School 6



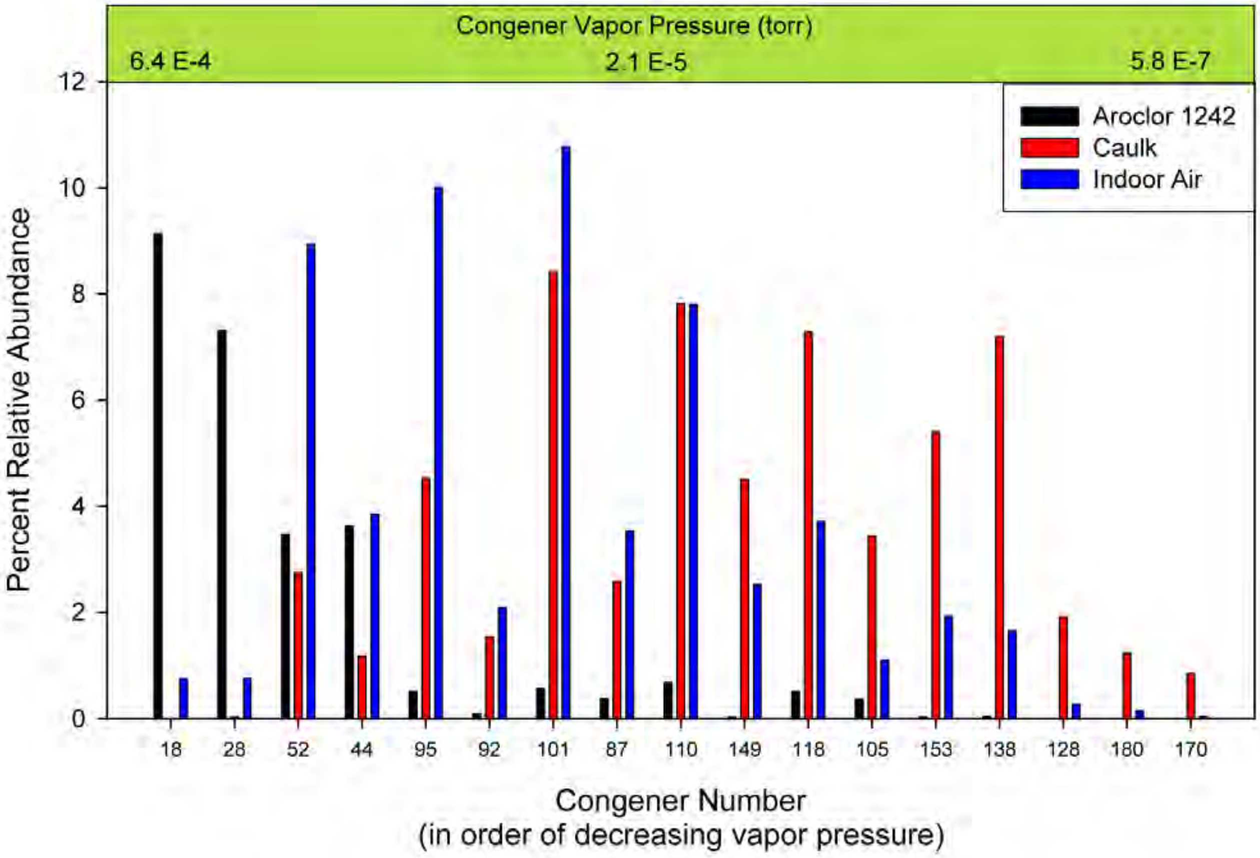
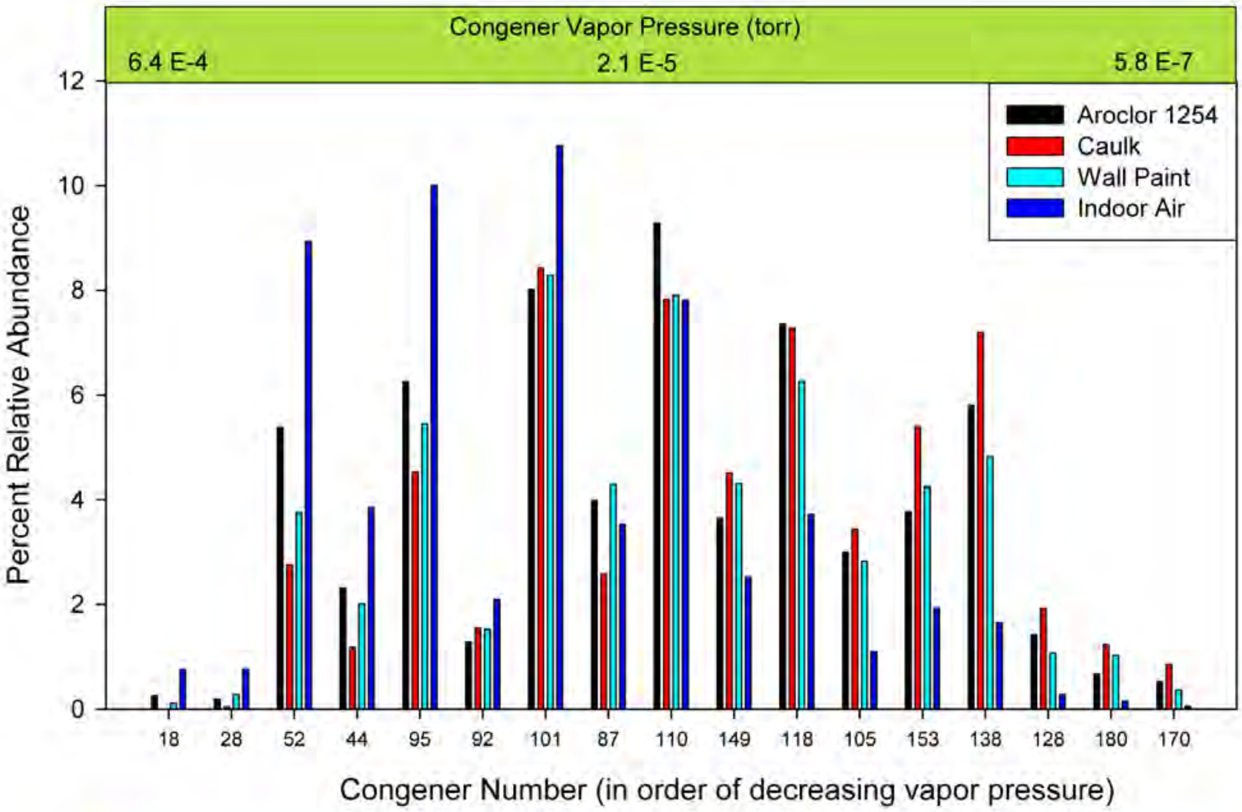


Figure 4-14. Patterns of relative weight percent for selected congeners in Aroclor 1254 (top) and Aroclor 1242 (bottom) compared to averages for exterior caulk and indoor air at School 6



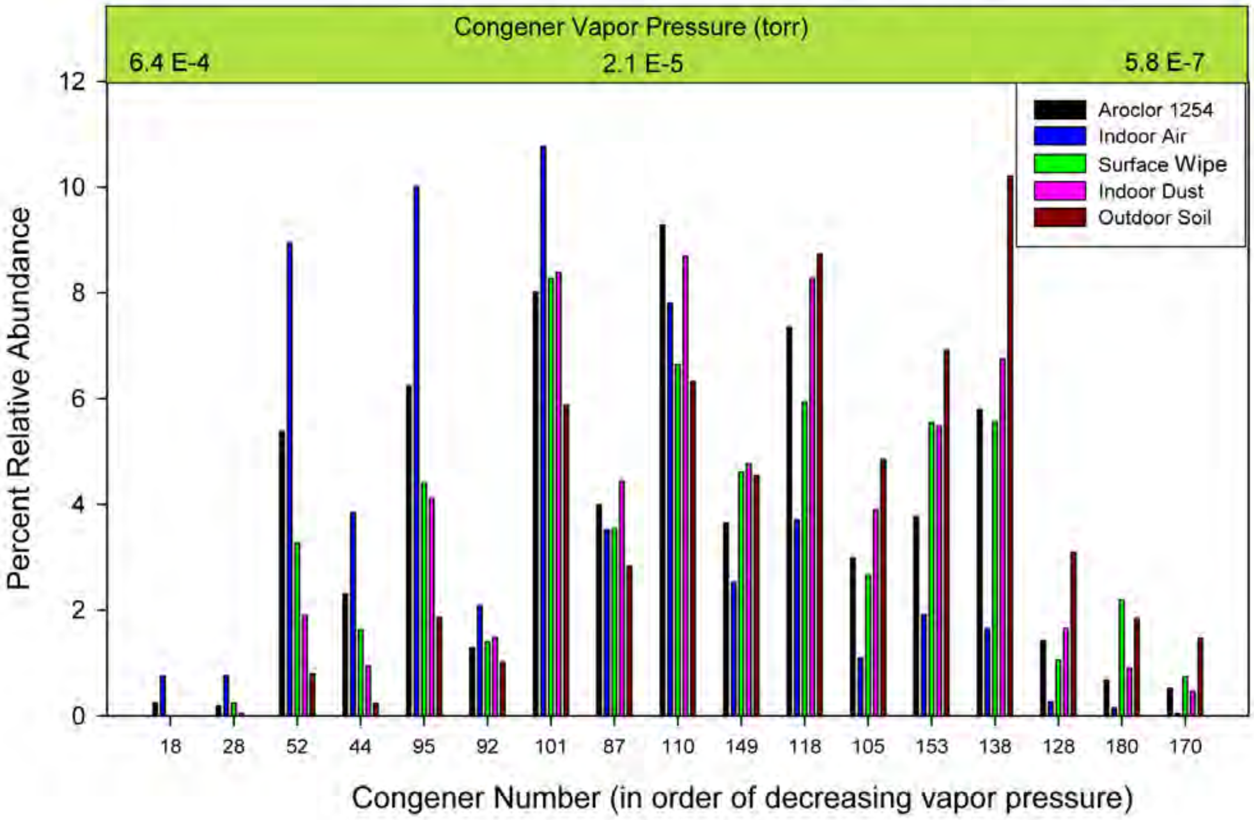


Figure 4-15. Patterns of relative weight percent for selected congeners in Aroclors 1254 compared to average values for indoor air, paint, and exterior caulk (top), and indoor air, surface wipes, dust, and soil (bottom) at School 6

Table 4-30. Summary of average PCB homolog weight percents at School 6[a]

PCB Homolog	Indoor Air N = 7	Outdoor Air N = 1	Surface Wipe N = 10	Indoor Dust N = 4	Outdoor Soil N = 3	Interior Caulk N = 5	Exterior Caulk N = 3	Other Materials N = 18
1-Chlorine	0.02	<QL	<QL	<QL	<QL	<QL	<QL	<QL
2-Chlorine	0.6	<QL	<QL	<QL	<QL	0.1	<QL	0.1
3-Chlorine	4.3	<QL	1.1	0.4	0.2	1.8	0.1	2.6
4-Chlorine	31.1	26.4	11.6	11.3	14.4	21.8	10.5	19.9
5-Chlorine	51.1	56.6	44.8	50.8	34.6	53.4	49.6	47.4
6-Chlorine	11.9	17.0	30.4	31.6	40.6	21.0	34.8	24.5
7-Chlorine	0.8	<QL	7.1	5.4	8.2	1.7	4.8	4.6
8-Chlorine	0.1	<QL	1.7	0.5	1.0	0.1	0.2	0.6
9-Chlorine	0.04	<QL	3.3	0.1	1.0	0.1	<QL	0.2
10-Chlorine	<QL	<QL	<QL	<QL	<QL	<QL	<QL	<QL
Σ 209 Cong.[b]	ng/m^3	ng/m^3	µg/100 cm^2	ppm	ppm	ppm	ppm	ppm
	500	7.7	0.407	30.9	1.09	11.5	114000	36.9

[a] Each chlorine-number homolog's percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

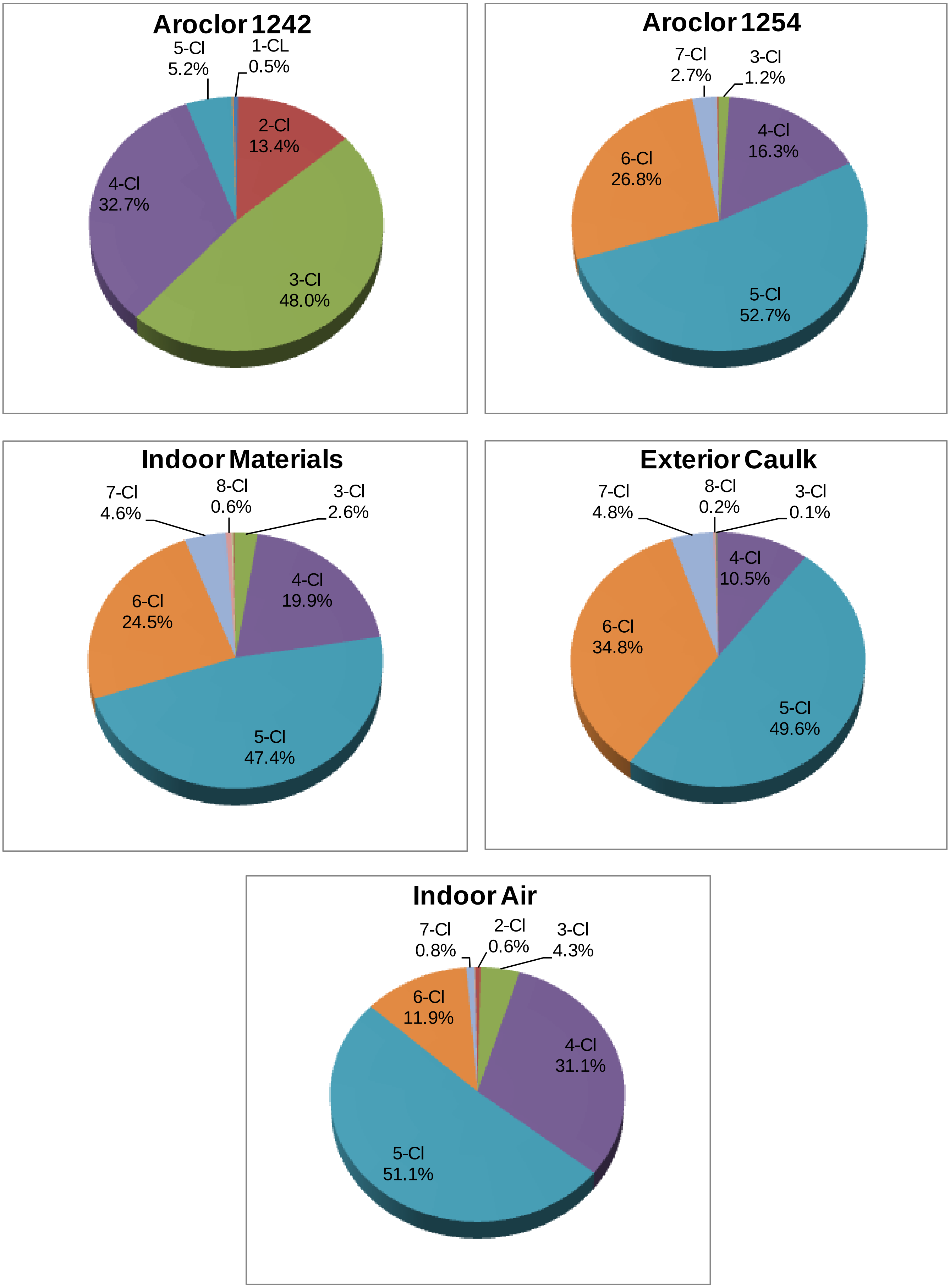


Figure 4-16. Relative weight percents of PCB chlorine-number homologs for Aroclors 1242 and 1254 compared to the averages of the exterior PCB-containing caulk, the indoor building materials, and indoor air

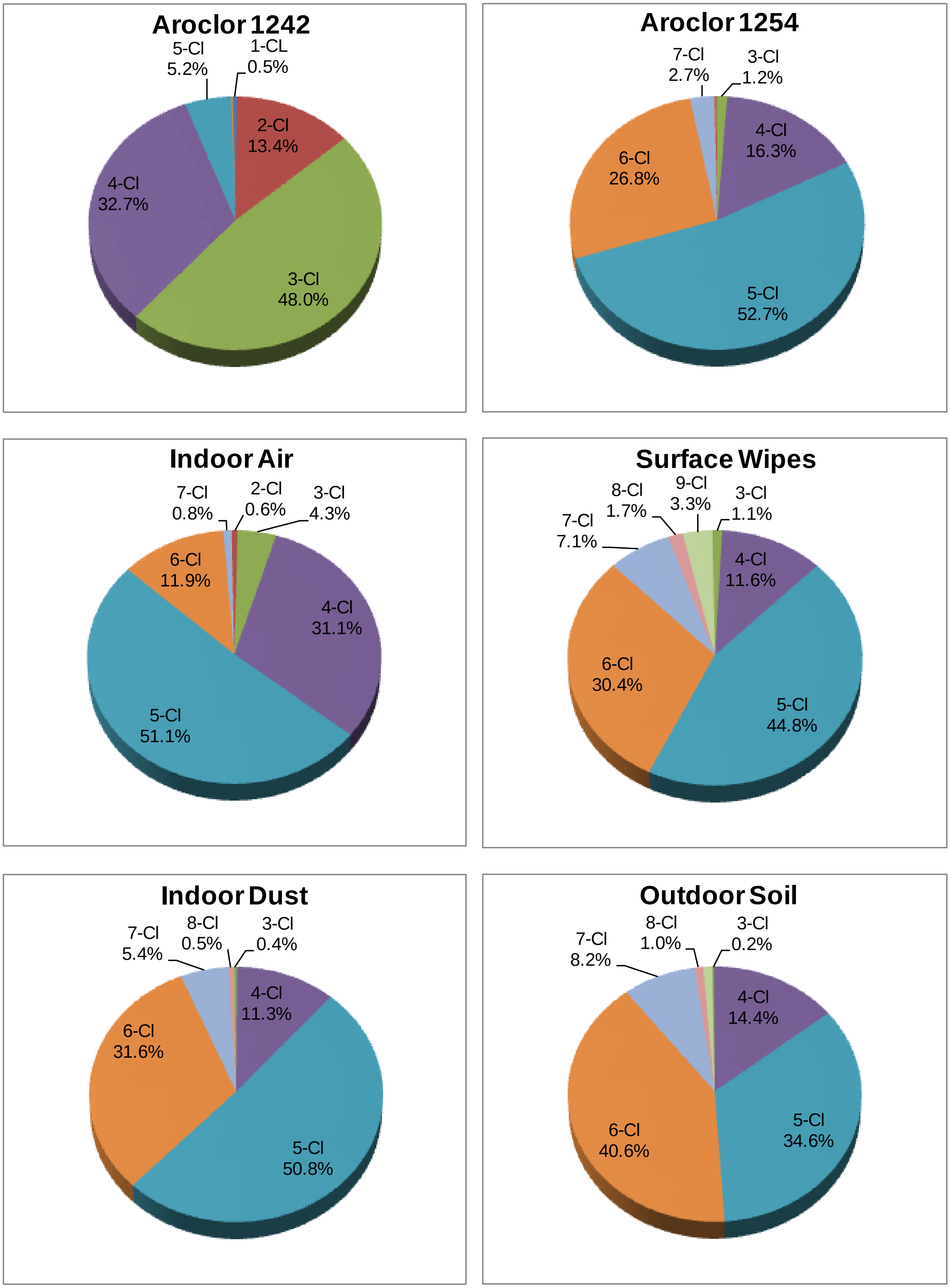
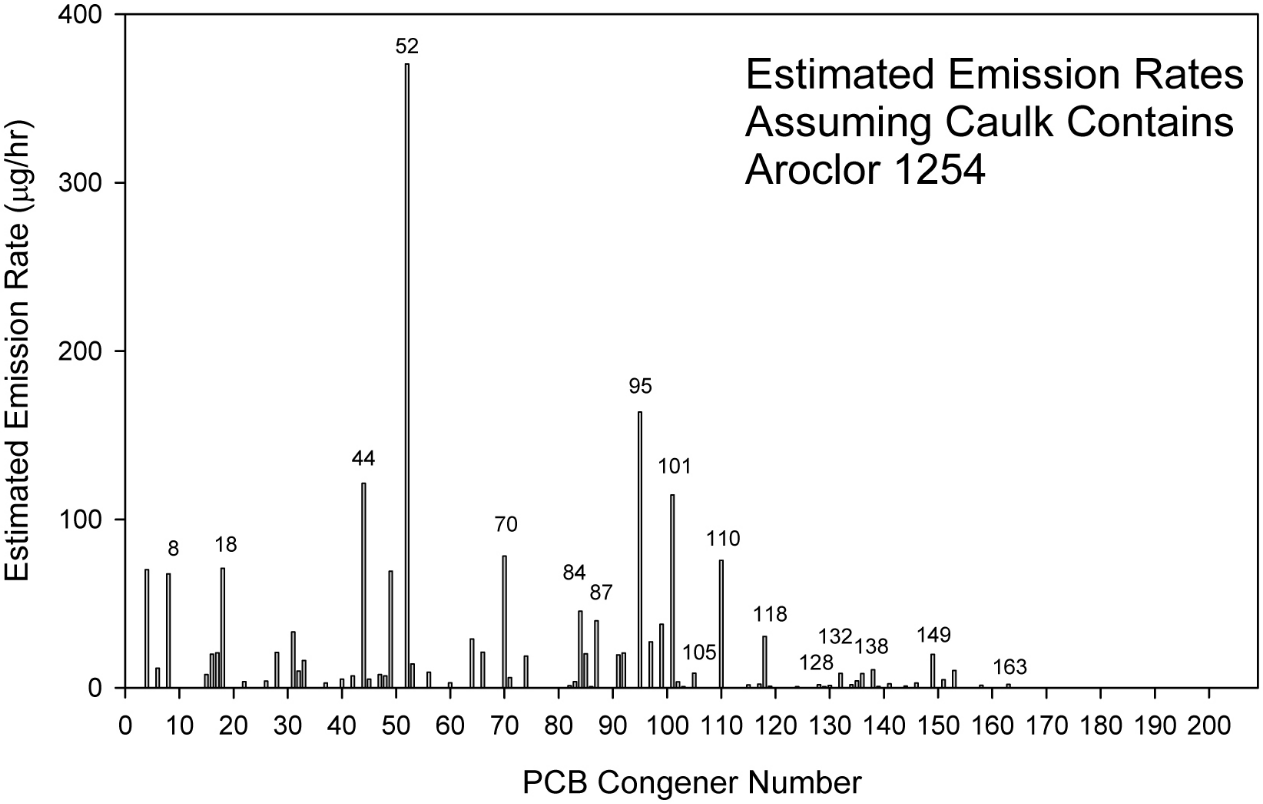


Figure 4-17. Relative weight percents of PCB chlorine-number homologs for Aroclors 1242 and 1254 compared to the averages of the environmental media

Table 4-31. Differences in PCB congener emission estimates from exterior caulk assuming an un-weathered Aroclor 1254 pattern vs. measured congener concentrations

Congener	Congener Weight Percent	Concentration In Caulk ppm	Estimated Emission Rate µg/hr
Assuming Caulk Contains Aroclor 1254 Congener Mixture, Total PCBs 112,000 ppm, Surface Area 0.271 m^2			
8	0.13	146	67.6
18	0.25	280	70.9
28	0.19	213	21.0
44	2.31	2,590	121
52	5.38	6,030	370
70	3.49	3,910	78.1
110	9.29	10,400	75.6
153	3.77	4,220	10.2
180	0.67	750	0.31
Σ209 Cong.	100	112,000	1,841
Using Congeners Measured in Exterior Caulk with Total PCBs 112,000 ppm, Surface Area 0.271 m^2			
8	<QL	<QL	--
18	<QL	<QL	--
28	<QL	<QL	--
44	0.92	1,030	48.3
52	2.04	2,280	140
70	2.15	2,400	48.0
110	7.98	8,910	64.8
153	5.70	6,360	15.4
180	1.41	1,570	0.66
Σ209 Cong.	100	112,000	1,020
Ratios of Assumed/Measured			
8	--	--	--
18	--	--	--
28	--	--	--
44	2.51	2.51	2.51
52	2.64	2.64	2.64
70	1.62	1.63	1.63
110	1.16	1.17	1.17
153	0.66	0.66	0.66
180	0.48	0.48	0.47
Σ209 Cong.	1.00	1.00	1.80



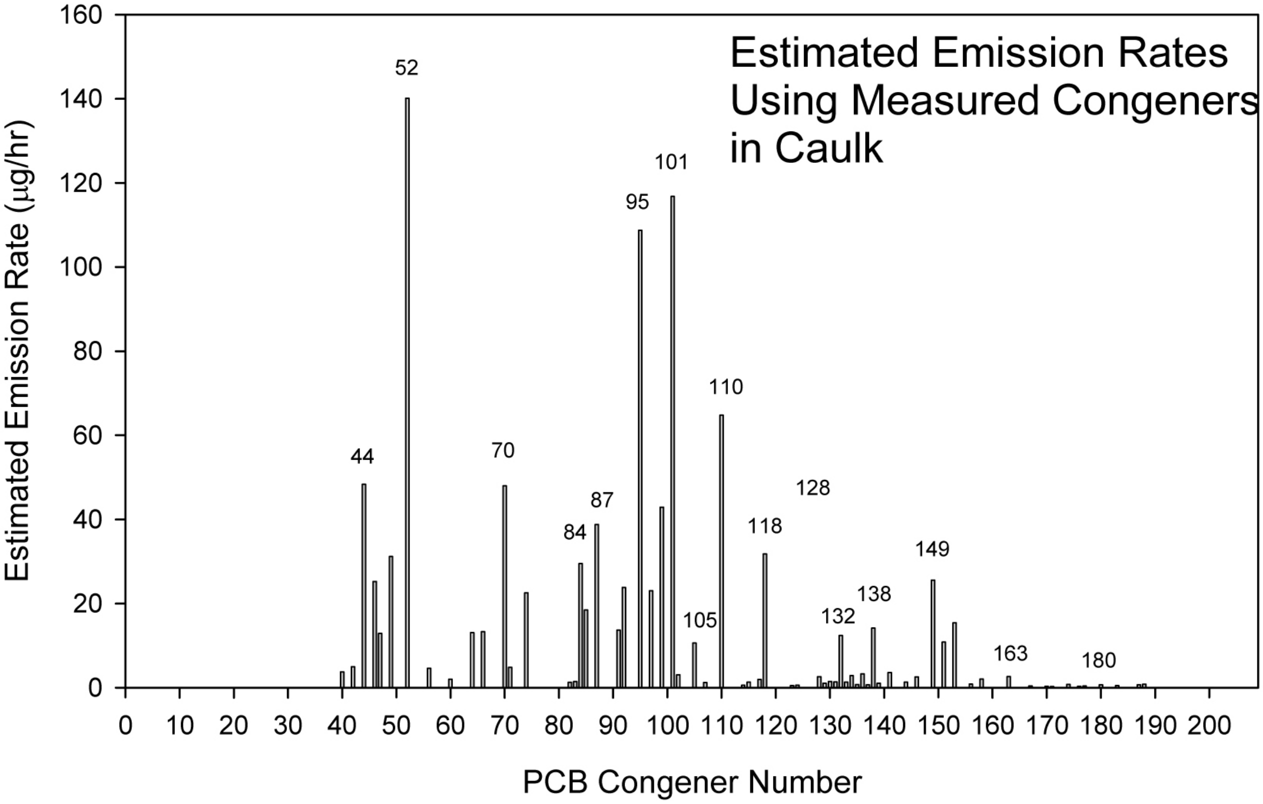


Figure 4-18. Patterns of estimated emission rates from exterior caulk collected at School 6 assuming the caulk contains congeners in an Aroclor 1254 proportions (top) and using congener values measured in the caulk (bottom)

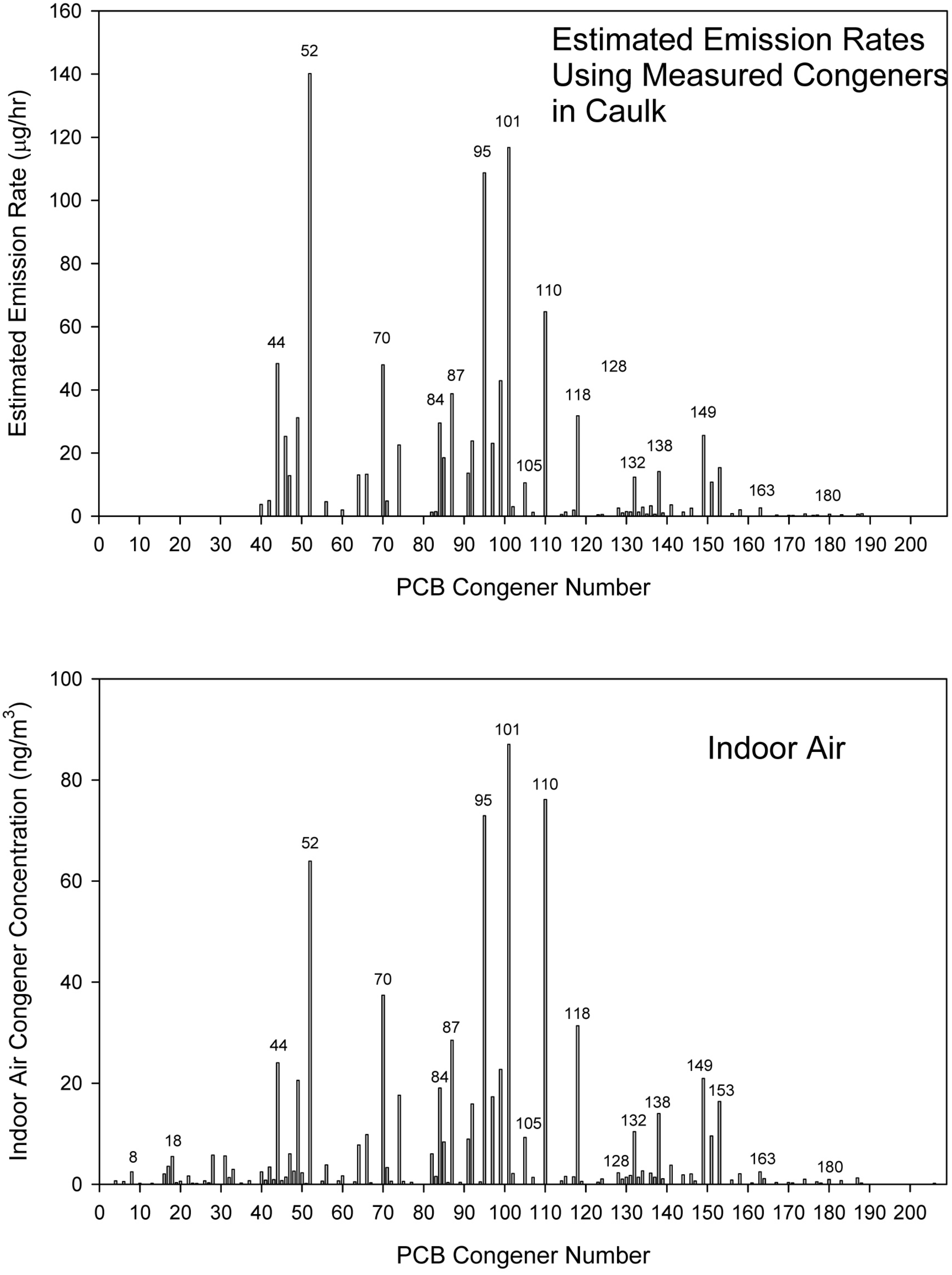


Figure 4-19. Patterns of estimated emission rates from exterior caulk collected at School 6 (top) versus the congeners measured in indoor air (bottom)

- The congener pattern in the PCB-containing caulk was somewhat more heavily weighted towards less volatile congeners as compared to Aroclor 1254. It is possible that the more volatile congeners have been depleted from sources such as the exterior caulk over a period of 43 years.
- The congener pattern in indoor air in this school did not resemble Aroclor 1242, the Aroclor most likely to be present in light ballasts. However, the oil content in the ballasts in this school was not measured and Aroclor 1254 can't be ruled out given that Aroclor 1254 was found in a ballast in one of the NYC schools.
- Congener patterns in surface wipe, indoor dust, and other building materials were generally similar to Aroclor 1254 and to the PCB-containing caulk.
- Soil samples had a congener pattern weighted towards less volatile congeners as compared to the PCB-containing caulk and Aroclor 1254, possibly as a result of weathering.
- The congener patterns in some environmental media, particularly indoor air, did not match typical congener patterns in the source materials. Total PCBs measured as Aroclors were approximately 20% higher than total PCBs based on congener analysis. A homolog analysis approach could provide more accurate total PCB measurements than Aroclor measurements, but at a somewhat higher cost. Homolog measurements are likely to be less costly than full congener-specific analyses.
- Congener-specific analysis provides information that can be used in risk assessment. For example, between 5% (indoor air) and 14% (soil) of the total amount of PCBs were comprised of the sum of the 12 dioxin-like congeners. However, the congener analysis was limited to samples from one school. This was not sufficient for probabilistic analysis in the SHEDS model.

4.5 SHEDS Exposure Modeling

4.5.1 Distributions of Exposure Estimates

The Stochastic Human Exposure and Dose Simulation (SHEDS) model was used to generate estimated PCB absorbed dose distributions resulting from exposures to environmental levels measured at the six schools. The model was run for four age groups (4-5, 6-10, 11-14, and 14-18 years old). Mean estimates of absorbed dose, and the estimated absorbed doses across selected percentiles of the modeled distribution are shown in Table 4-32. For the 6-10 year-old age group, the estimated absorbed dose was 0.022 µg/kg/day at the 50th percentile of the distribution and 0.041 µg/kg/day at the 95th percentile. Estimated absorbed dose levels were lower for the other three age groups relative to the 6-10 year old group, and were 55% and 56% lower for the 14 – 18 year old age group at the 50th and 95th percentiles, respectively.

Estimates of absorbed PCB doses were generated using environmental measurements at five schools with available pre- and post-remediation measurements. Mean estimates of total absorbed dose, and the estimated absorbed doses across selected percentiles of the modeled distribution are shown for the four age groups at pre- and post-remediation time points in Table 4-33. The ratios of post-remediation to pre-remediation absorbed dose estimates are shown in Table 4-34. For the 6-10 year-old age group the post-remediation absorbed dose estimates were 64% lower than pre-remediation at the 50th percentile and 69% lower at the 95th percentile. Similar pre- to post-remediation decreases in estimated absorbed dose were found for all age groups. Box plots of the pre- and post-remediation estimated absorbed doses by age group are shown in Figure 4-20 and percentile distribution plots are shown for the 6-10 year-old group in Figure 4-21.

These results indicate that remedial actions are likely to result in decreased exposures. At the pre-remediation time point, 25 to >75% of the distribution was lower than the adjusted RfD value of 17 ng/kg/day, depending on age group. At the post-remediation time point, >95 to >99% of the distribution was less than the adjusted RfD, for school-related exposures only. It is important to remember that different types and scales of remedial action were taken at each of the five schools (see Table 4-2) and that different relative decreases in indoor air levels were seen across the schools (see Table 4-24). It is possible that other factors, such as differences in temperature and ventilation conditions at the pre- and post-remediation time points could have affected the environmental concentrations and estimated exposures.

Estimates of absorbed PCB doses were also generated using environmental measurements at three schools with available pre- and post-remediation measurements taken during the same year and with subsequent pre-remediation indoor air and surface wipe measurements taken the following year. The purpose of this assessment is to evaluate whether reductions in exposure may be expected to be sustained over time following remedial actions. SHEDS model estimates of absorbed doses using measurements from the second-year post-remediation time point were not performed because the indoor air and surface wipe pre- and post remediation results were not significantly different (NYC SCA, 2012). Mean estimates of absorbed dose, and the estimated absorbed doses across selected percentiles of the modeled distribution are shown for the four age groups at the three time points in Table 4-35. Percentile distribution plots are shown for the 6-10 year-old group in Figure 4-22. Overall, the estimated absorbed dose levels for the pre-remediation time point in the second year were slightly higher than the post-remediation time point from the first year, but were still substantially lower than the first year pre-remediation time point. These results suggest reductions in exposure resulting from remedial actions may be retained over time. It is important to remember that different types and scales of remedial action were taken at these three schools and that some activities were performed between the first year post-remediation time point and the second year pre-remediation time point (see Table 4-2). It is also possible that differences in temperature and ventilation conditions at the different time points could have affected the environmental concentrations and estimated exposures, although temperatures were generally within 6°F or less across the time points (see Table 4-3).

SHEDS model estimates of PCB total absorbed dose generated using the environmental measurement data from the six schools examined in this report were compared to estimates generated using extant PCB data not associated with the six schools measurements. These data were gleaned from several reports and internet sources in 2009 and included measurements for indoor air, dust, surface wipes, and soil (see Appendix D for the data sources and environmental measurement distributions). The estimated absorbed doses using the other extant data are shown in Table 4-36 for comparison with results generated using results from the six schools in this report. Comparisons were made only for the 6-10, 11-13, and 14-18 year old age groups. In general, the estimated absorbed doses using data from the six schools are similar to estimates using other data. Overall, the mean and median estimated absorbed doses were similar for the two sets of data when comparisons are for the pre-remediation time point for the six school sets of measurements in this report. The fraction of absorbed dose resulting from inhalation was higher for the results used in this report than for the other school data at most percentile levels largely because the indoor air PCB concentrations in the six schools were about 3-fold higher at the median than the other extant school data. On the other hand, concentrations in wipe samples in the six schools were about one-third of the levels obtained from the other extant school data, with the dermal and non-dietary ingestion representing a lower proportion of the intake at the six schools used in this report.

4.5.2 Estimated Exposures by Exposure Route

Information on the relative importance and contribution of different exposure pathways to the total exposure can help inform mitigation decision-making. The SHEDS model provides estimates of the school PCB exposure from each relevant route. Table 4-37 shows the apportionment of

Table 4-32. Distributions of total absorbed PCB dose estimated by SHEDS based on measurement data from six schools (units: µg/kg/day)

Child Age Group	Mean	SD	Percentiles of the Distribution of Dose Estimates p5	p25	p50	p75	p95	p99
4 – 5 year olds	0.023	0.012	0.012	0.017	0.021	0.026	0.036	0.061
6 – 10 year olds	0.027	0.032	0.015	0.019	0.022	0.027	0.041	0.125
11 – 13 year olds	0.015	0.005	0.009	0.012	0.015	0.018	0.022	0.028
14 – 18 year olds	0.011	0.005	0.004	0.007	0.010	0.014	0.018	0.023

Table 4-33. Distributions of total absorbed PCB dose estimated by SHEDS based on measurement data from five schools[a] at pre-remediation and post-remediation time points (units: µg/kg/day)

Child Age Group	Mean	SD	Percentiles of the Distribution of Dose Estimates p5	p25	p50	p75	p95	p99
4 – 5 year olds								
Pre-remediation	0.019	0.006	0.010	0.016	0.019	0.022	0.029	0.032
Post-remediation	0.007	0.002	0.004	0.006	0.007	0.008	0.010	0.014
6 – 10 year olds								
Pre-remediation	0.023	0.015	0.014	0.018	0.021	0.025	0.037	0.071
Post-remediation	0.008	0.004	0.005	0.006	0.007	0.009	0.012	0.018
11 – 13 year olds								
Pre-remediation	0.014	0.004	0.008	0.011	0.013	0.016	0.021	0.023
Post-remediation	0.005	0.001	0.003	0.004	0.005	0.006	0.007	0.009
14 – 18 year olds								
Pre-remediation	0.010	0.004	0.003	0.007	0.010	0.013	0.018	0.022
Post-remediation	0.003	0.002	0.001	0.002	0.003	0.005	0.006	0.008

[a] Schools 1, 2, 3, 4, and 5.

Table 4-34. Post-remediation/pre-remediation ratios of total absorbed PCB dose estimates based on measurement data from five schools

Child Age Group	Mean	Post/Pre-Remediation Ratio for the Distribution of Dose Estimates p5	p25	p50	p75	p95	p99
4 – 5 year olds	0.37	0.37	0.37	0.37	0.38	0.35	0.43
6 – 10 year olds	0.34	0.37	0.36	0.36	0.35	0.31	0.26
11 – 13 year olds	0.37	0.37	0.36	0.37	0.37	0.36	0.38
14 – 18 year olds	0.35	0.34	0.34	0.35	0.36	0.36	0.35

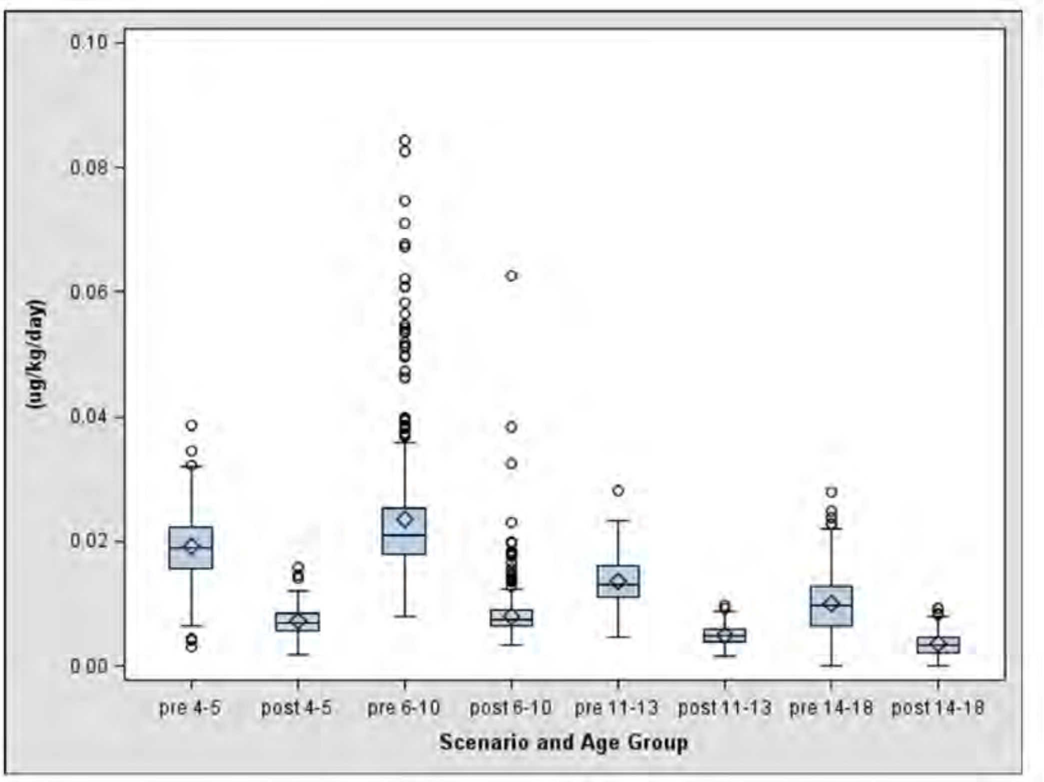


Figure 4-20. Distributions of estimated absorbed total PCB doses from exposures at school for four age groups at five schools for pre- and post-remediation time points. The box plots show the median, 25th, and 75th percentiles. The whiskers show the 10th and 90th percentiles.

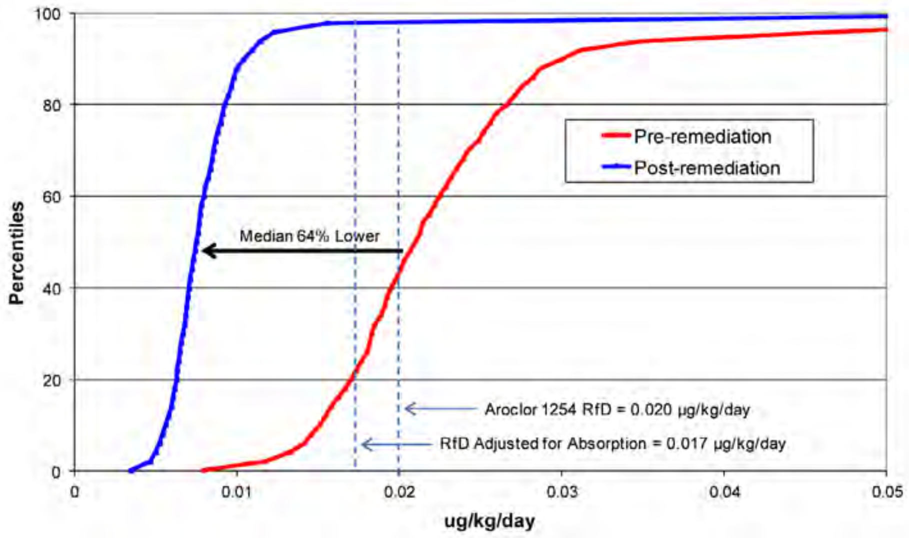


Figure 4-21. Distributions of estimated absorbed total PCB doses from exposures at school for the 6 – 10 year old age group at five schools for pre- and post-remediation time points

inhalation, dermal absorption, and non-dietary ingestion routes for the estimated PCB absorbed doses for the 6-10 year old age group based on pre- and post-remediation measurements at five schools. The results in Table 4-37 were estimated using several estimates of PCB pulmonary absorption since the actual value is not well known. Figures 4-23 and 4-24 show contributions from different exposure routes at different percentiles of the distributions for the 6-10 year-old age group.

Overall, the inhalation pathway would appear to be the predominant route of exposure based on data from these schools. Inhalation exposures would account for over 73% of the total absorbed dose for 6-10 year-olds at the pre-remediation time point (when PCB concentrations in air were greatest) if pulmonary absorption fractions are 70% or higher. If pulmonary absorption were as low as 30%, then inhalation would be esimtated to account for 47% of the total absorption, with dust/soil ingestion accounting for 41% and dermal absorption 12%. At the post-remediation time point, the fraction from each exposure route was similar, in most cases, to the pre-remedition time point, although the relative contribution for non-dietary ingestion decreased when 30% pulomonary absorption is assumed. Similar patterns were seen for the other age groups. The contribution of non-dietary ingestion was not modeled for the two older age groups due to the lack of hand-to-mouth data, but would be expected to be lower than for 6-10 year olds because of reduced hand-to-mouth activity.

Assuming a 70% pulmonary absorption, the fraction of the overall absorbed dose from non-dietary ingestion of PCBs in dust an soil remained relatively small (≤ 12%) for 6 – 10 year-olds for most of the percentiles of the distribution of estimated absorbed doses (Figures 4-23 and 4-24). However, in the highest 10% of the distribution, over 50% of the pre-remediation total absorbed dose is predicted to result from non-dietary ingestion, greater than the amount from inhalation. This result occurs because of a combination of relatively high dust ingestion at the upper end of the activity distribution for the 6 – 10 year-old age group and relatively high PCB concentrations in dust and soil in the upper ends of the distributions. This could represent a relatively highly exposed sub-group of children, as the total estimated absorbed dose is also higher at the upper end of the distribution. Some caution is needed in interpreting the upper ends of modeled exposure distributions, and more information would be needed to determine whether more highly exposed sub-groups of children occur.

4.5.3 Sensitivity Testing

Model sensitivity analyses are used to assess the relative impact and importance of uncertainties in model parameters and input data. Limited sensitivity analysis was conducted for two important but uncertain parameters used in the SHEDS PCB model. These include the fraction of pulmonary absorption of PCBs following inhalation, and the concentration of PCBs in dust and soil in the schools.

To the best of our knowledge, the pulmonary absorption fraction for PCBs following inhalation has not been determined for humans. Extant rat data for PCBs and dioxin in the vapor phase, and dioxin bound to soil, suggest that the pulmonary absorbed fraction is likely to be high (Hu et al., 2010; Dilberto et al., 1996 Nessel et al, 1992 - all resulted in values >80%). On the other hand, three biomonitoring studies suggest that people exposed to PCBs in contaminated buildings may show increases in blood levels of the more volatile congeners, but overall circulating blood levels of total PCBs had only small differences compared to those in unexposed groups (Herrick et al., 2011; Liebel et al., 2004; Gabio et al., 2000). A value of 70% pulmonary absorbed fraction was assumed for the SHEDS PCB analysis.

To examine the modeled absorbed dose estimate sensitivity associated with uncertainty in pulmonary absorbed fraction, sensitivity testing was performed on the impact of using 30%, 80%, or 100% values for pulmonary absorbed fraction for 6-10 year-olds at the pre- and post-remediation time points for five schools (Table 4-38). Using a pulmonary

Table 4-35. Distributions of total absorbed PCB dose estimated by SHEDS based on measurement data from three schools[a] at three time points (units: µg/kg/day)

			Percentiles of the Distribution of Dose Estimates					
Child Age Group	**Mean**	**SD**	**p5**	**p25**	**p50**	**p75**	**p95**	**p99**
4 – 5 year olds								
Pre-first-year remediation	0.025	0.009	0.013	0.020	0.024	0.029	0.039	0.052
Post-first-year remediation	0.007	0.002	0.004	0.006	0.007	0.008	0.011	0.012
Pre-second-year remediation	0.009	0.003	0.005	0.008	0.009	0.011	0.015	0.019
6 – 10 year olds								
Pre-first-year remediation	0.031	0.031	0.017	0.022	0.026	0.031	0.051	0.141
Post-first-year remediation	0.008	0.003	0.005	0.006	0.007	0.009	0.012	0.017
Pre-second-year remediation	0.011	0.007	0.007	0.009	0.010	0.012	0.016	0.030
11 – 13 year olds								
Pre-first-year remediation	0.018	0.005	0.010	0.014	0.018	0.021	0.026	0.033
Post-first-year remediation	0.005	0.002	0.003	0.004	0.005	0.006	0.008	0.010
Pre-second-year remediation	0.007	0.002	0.004	0.005	0.007	0.008	0.011	0.012
14 – 18 year olds								
Pre-first-year remediation	0.012	0.006	0.004	0.008	0.012	0.016	0.023	0.026
Post-first-year remediation	0.004	0.002	0.001	0.002	0.004	0.005	0.006	0.007
Pre-second-year remediation	0.005	0.002	0.002	0.003	0.005	0.006	0.008	0.010

[a] Schools 1, 2, and 3.

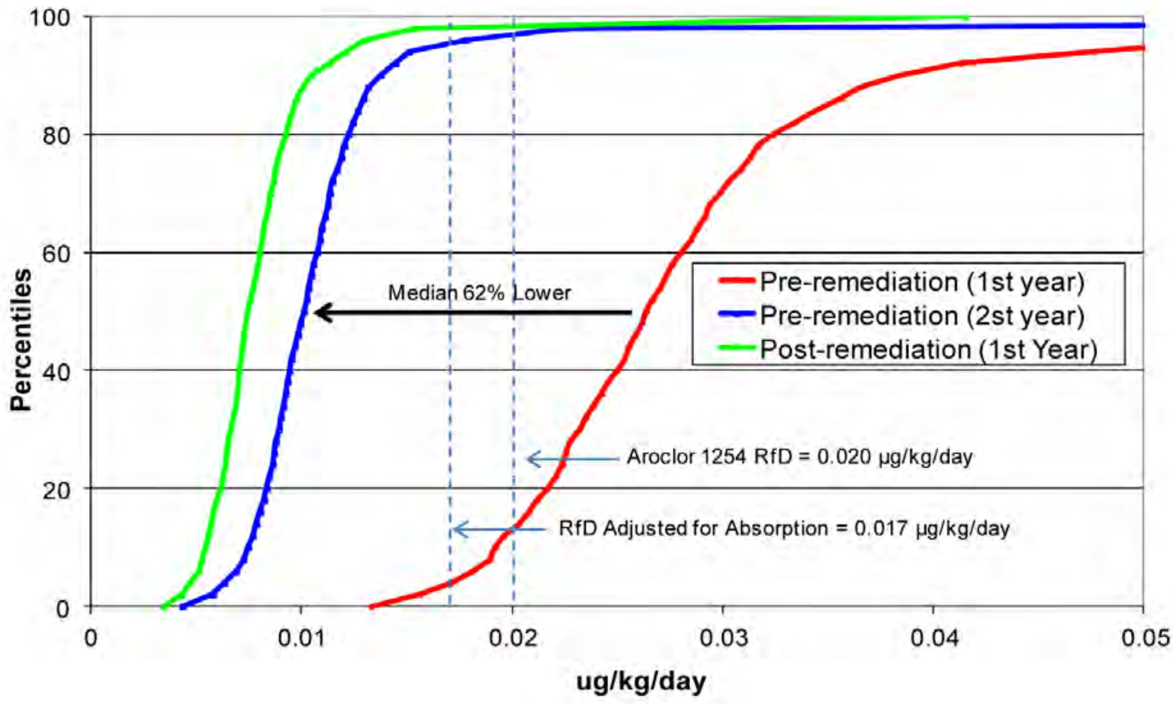


Figure 4-22. Distributions of estimated absorbed total PCB doses from exposures at three schools for the 6 – 10 year old age group at three pre- and post-remediation time points across two years

Table 4-36. Distributions of total absorbed PCB dose estimated by SHEDS based on measurement data from six schools in this report and from extant measurement data[a] (units: µg/kg/day)

Child Age Group	Mean	SD	Percentiles of the Distribution of Dose Estimates					
			p5	p25	p50	p75	p95	p99
6 – 10 year olds								
6 schools, this report	0.027	0.032	0.015	0.019	0.022	0.027	0.041	0.125
Extant data (Appx. D)	0.021	0.009	0.012	0.016	0.019	0.024	0.037	0.054
11 – 13 year olds								
6 schools, this report	0.015	0.005	0.009	0.012	0.015	0.018	0.022	0.028
Extant data (Appx. D)	0.016	0.006	0.009	0.012	0.015	0.019	0.027	0.034
14 – 18 year olds								
6 schools, this report	0.011	0.005	0.004	0.007	0.010	0.014	0.018	0.023
Extant data (Appx. D)	0.011	0.005	0.004	0.008	0.011	0.014	0.020	0.028

[a] Extant data and data sources shown in Appendix D.

Table 4-37. Proportion of mean estimated total absorbed PCB dose for 6 – 10 year olds for inhalation, non-dietary ingestion, and dermal absorption routes of exposure based on measurements from five schools

	Inhalation %	Non-Dietary Ingestion %	Dermal Absorption %
Pre-remediation			
30% inhalation absorption	47	41	12
70% inhalation absorption (baseline)	74	18	8
100% inhalation absorption	78	15	6
Post-remediation			
30% inhalation absorption	52	30	19
70% inhalation absorption (baseline)	74	15	12
100% inhalation absorption	79	13	8

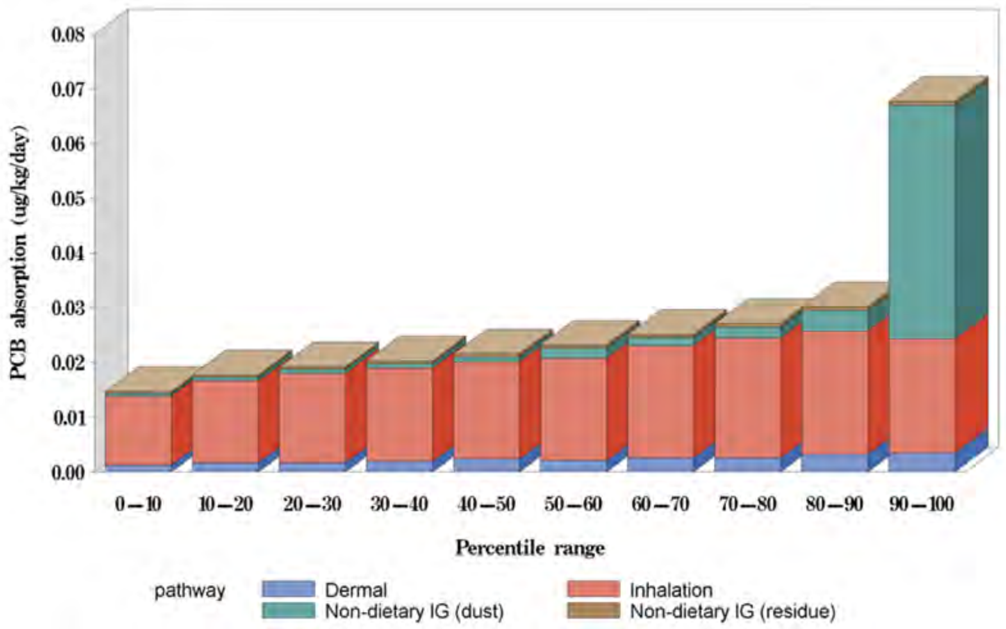


Figure 4-23. Contributions of different exposure routes towards total estimated absorbed PCB doses for the 6 – 10 year old age group at different percentiles of the total dose estimate based on measurements at six schools (assuming 70% pulmonary absorption)

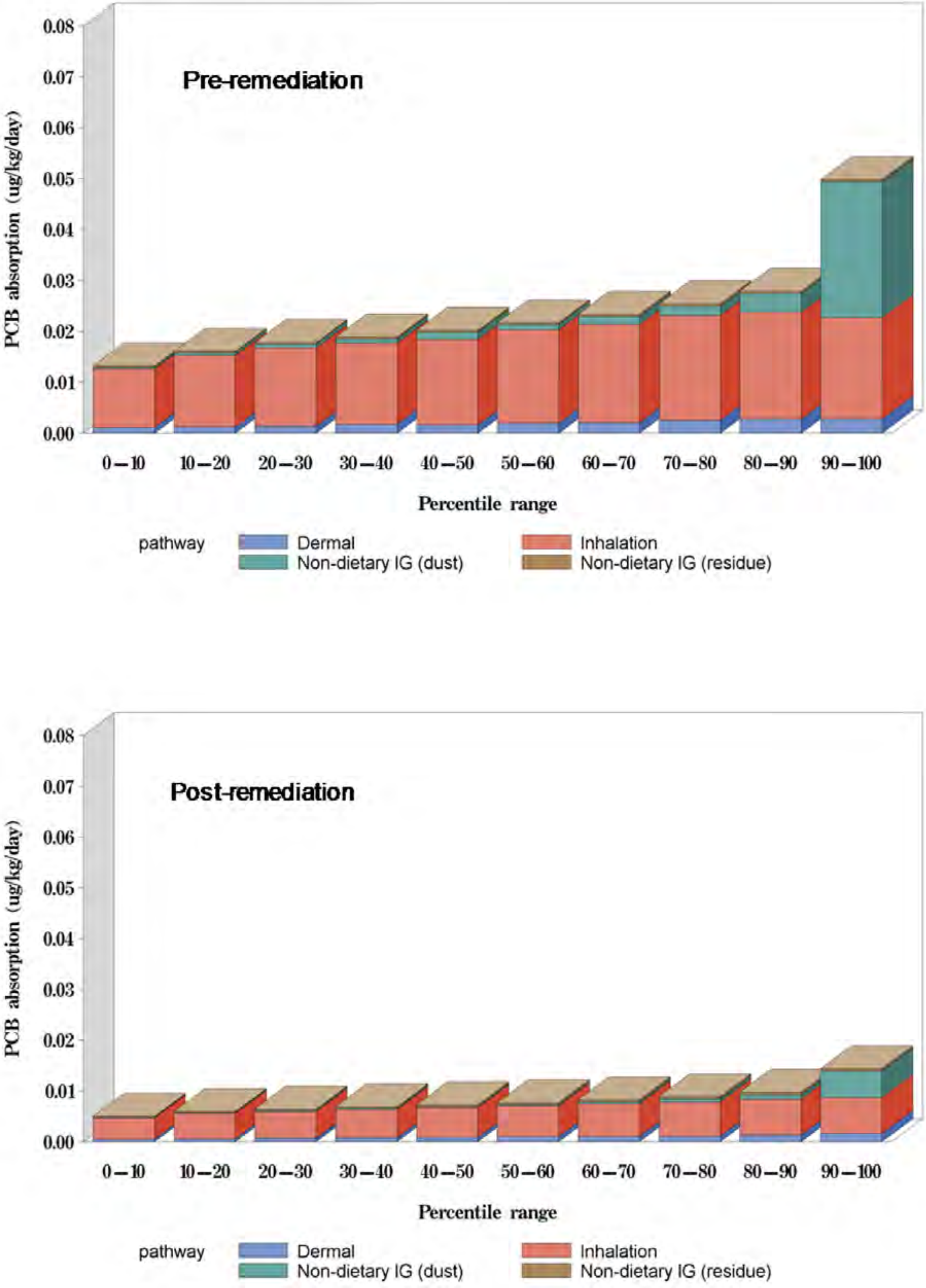


Figure 4-24. Contributions of different exposure routes towards total estimated absorbed PCB doses for the 6 – 10 year old age group at different percentiles of the total dose estimate based on pre-remediation (top) and post-remediation (bottom) measurements at five schools (assuming 70% pulmonary absorption)

absorption fraction of 30% at the pre-remediation time point resulted in a 49% decrease in the estimated absorbed dose at the 50th percentile and a 25% decrease at the 95th percentile. At the post-remediation time point, using the 30% pulmonary absorption fraction resulted in a 45% decrease in the estimated absorbed dose at the 50th percentile and a 23% decrease at the 95th percentile. The changes were smaller at the post-remediation time point because the contribution of inhalation to total exposure was lower due to the decreases in indoor air concentrations.

Using a pulmonary absorption fraction of 100% at the pre-remediation time point resulted in an increase in the estimated absorbed dose of 35% at the 50th percentile and a 23% increase at the 95th percentile. At the post-remediation time point using a pulmonary absorption fraction of 100% resulted in an increase in the estimated absorbed dose of 32% at the 50th percentile and 35% at the 95th percentile. The Public Health Levels were derived using an assumption of 100% pulmonary absorption.

Modeled estimates of total PCB absorbed dose resulting from exposure to PCBs in the school environment was sensitive to the value used for pulmonary absorption fraction based on environmental PCB levels for the schools used in this assessment. While the available literature suggests that the pulmonary absorbed fraction is likely to be >80%, the available biomonitoring data do not necessarily support the high fraction. This is further complicated because the assumption for SHEDS modeling is that all congeners in Aroclor 1254 will have the same absorption fraction. However, the different congeners have different physical properties that affect both their absorption in pulmonary tissues as well as the fractions that will be found in vapor and particle-phase in indoor air and in different human tissues. This complicates both the understanding of pulmonary exposure and absorption and interpretation in biomonitoring measurements with regard to distribution and relative storage in different body tissues versus the relative fractions in

Table 4-38. Sensitivity test results of different pulmonary absorption rates on the distributions of estimated total absorbed PCB dose for 6 – 10 year olds based on pre- and post-remediation measurements from five schools[a]

			Percentiles of the Distribution					
Model Paramter	**Mean**	**SD**	**p5**	**p25**	**p50**	**p75**	**p95**	**p99**
			Estimated Absorbed Dose µg/kg/day					
Pre remediation								
30% absorption	0.016	0.040	0.007	0.009	0.011	0.013	0.028	0.122
70% absorption (baseline)	0.023	0.015	0.014	0.018	0.021	0.025	0.037	0.071
80% absorption	0.026	0.021	0.015	0.019	0.023	0.028	0.043	0.106
100% absorption	0.032	0.024	0.018	0.024	0.028	0.033	0.046	0.101
Post remediation								
30% absorption	0.005	0.004	0.003	0.003	0.004	0.005	0.009	0.019
70% absorption (baseline)	0.008	0.004	0.005	0.006	0.007	0.009	0.012	0.018
80% absorption	0.009	0.005	0.006	0.007	0.008	0.010	0.013	0.033
100% absorption	0.011	0.004	0.007	0.008	0.010	0.012	0.016	0.029
			Ratio of Estimated Doses at 30, 80, and 100% to Baseline of 70%					
Pre remediation								
30% absorption	0.66		0.49	0.49	0.51	0.52	0.75	1.71
80% absorption	1.13		1.10	1.09	1.09	1.09	1.16	1.50
100% absorption	1.35		1.31	1.34	1.35	1.31	1.23	1.43
Post remediation								
30% absorption	0.60		0.52	0.53	0.55	0.56	0.77	1.05
80% absorption	1.15		1.09	1.12	1.13	1.12	1.13	1.82
100% absorption	1.31		1.30	1.32	1.32	1.29	1.35	1.58

[a] Schools 1, 2, 3, 4, and 5.

circulating blood across the range of congeners. Differences in congener metabolism are likely to further complicate the interpretation of blood-based biomonitoring. On the other hand, congener-specific information can provide information about the various environmental and dietary sources, as well as potential toxicity when such information is available.

Dust can be an important source of exposure for children. Indoor dust samples were not collected from the five NYC schools. Dust samples were collected from the sixth school, but since the school had not been routinely cleaned in the preceding five weeks it is not known if the dust concentrations were typical for this school. Therefore, in the SHEDS model analyses estimates of dust concentrations in each room with an air measurement were made using partition estimates (see Appendix E). Using this approach, the estimated concentrations of PCBs in dust were lower at the post-remediation time point due to the lower air concentrations. However, there were reasons to assess the sensitivity of modeled PCB exposures for lower dust and soil ingestion. First, given that schools are often regularly cleaned, child exposures to dust in school may be lower than those in residences. Second, the soil at the five NYC schools was remediated first by restricted access followed by removal of soils with > 1ppm PCBs. So the post-remediation exposures to PCBs in soil were likely to be lower.

Sensitivity tests were run by decreasing the dust and soil concentrations by 70% and by 90% to examine the impact on SHEDS model absorbed dose estimates. Sensitivity test results for decreased dust and soil levels are reported in Table 4-39 for 6-10 year-olds at the post-remediation time points using measurement information from five schools. For an assumed 70% reduction in dust and soil concentrations at the post-remediation time point, there was a 7% decrease in estimated absorbed dose at the 50th percentile and a 15% decrease at the 95th percentile. For an assumed 90% reduction in dust and soil levels the decreases in estimated absorbed doses were 9% and 21% at the 50th and 95th percentiles, respectively. Although the pre-remediation time point sensitivity was not examined, the impact would have been less due to the higher proportion of total exposure from inhalation at that time point.

4.5.4 Exposure Modeling Uncertainties and Limitations

Models can be useful tools for estimating human exposure to chemicals in the environment, but it is important to understand the limitations and uncertainties associated with model inputs and outputs. Exposure models are designed to use information about concentrations of chemical in environmental media, and a person's contact with chemicals in that environment to estimate the amount of exposure that may occur. Simple point-estimation models often do not incorporate variability in environmental levels and human contact and do not characterize the range of exposures likely to be encountered by a human population or sub-population. The SHEDS model incorporates variability in chemical concentrations and some aspects of human activity (e.g., time spent in different locations and activities, distributions of contact rates) in order to estimate distributions of exposure and absorbed dose. However, there are uncertainties in some of the assumptions and exposure pathways/scenarios modeled (e.g., ingestion of caulk was not modeled), the information available for input into the model, and in some of the underlying model parameters. Also, while SHEDS includes sophisticated exposure algorithms, the dose estimation module in SHEDS is a simple 1-compartment PK model based on daily absorption rates, and is intended for screening purposes; it can be linked to PBPK models for more sophisticated tissue dose modeling if sufficient data are available (but they are not available at this time for PCBs; thus, the SHEDS PK model was used in this study).

Table 4-39. Sensitivity test results for post-remediation decreases in dust and soil PCB concentrations on the distributions of estimated total absorbed PCB dose for 6 – 10 year olds based on measurements from five schools[a]

Model Parameter	Mean	SD	Percentiles of the Distribution					
			p5	p25	p50	p75	p95	p99
			Estimated Absorbed Dose µg/kg/day					
Post remediation								
Baseline	0.008	0.004	0.005	0.006	0.007	0.009	0.012	0.018
70% reduction in dust/soil	0.007	0.002	0.005	0.006	0.007	0.008	0.010	0.014
90% reduction in dust/soil	0.007	0.001	0.005	0.006	0.007	0.008	0.009	0.010
	Ratio of Estimated Doses at 70 and 90% Reductions to Baseline Estimate							
Post remediation								
70% reduction in dust/soil	0.89		0.92	0.94	0.93	0.91	0.85	0.74
90% reduction in dust/soil	0.85		0.90	0.92	0.91	0.86	0.79	0.57

[a] Schools 1, 2, 3, 4, and 5.

While there are uncertainties in the SHEDS absorbed dose estimates, the probabilistic modeling approach provides estimates for the range of absorbed doses based on variability in concentrations and activity. Such information can inform risk assessments by characterizing not only the average absorbed dose, but also the upper end of exposures and absorbed doses in a population. It is also important to recognize that many of the uncertainties in parameters for the SHEDS model would also apply to other absorbed dose estimation approaches, including point-estimation models.

Some of the limitations and uncertainties important for modeling PCB exposures in school environments are described below. In many of these areas, uncertainties can be reduced in the future through collection of additional data or information.

Estimated Adult PCB Absorbed Dose - Exposure estimation was not performed for adults, including teachers and staff, as part of this effort due to the lack of personal activity data at schools such as those available for children in the Consolidated Human Activity Database. It is anticipated that adults would spend more time in school buildings, which would tend to lead to higher doses, while less contact with dust and soil and higher relative body masses would lead to lower doses. The absorbed doses experienced by adults in school environments with PCB levels found in the six schools may be similar to those estimated for the 14 – 18 year old age group, but good adult activity information would need to be applied in the model to determine if that is the case.

Levels of PCBs in school dust – Interior dust samples were not collected as part of the NYC remedial pilot investigation. Dust can be an important source of exposure through inhalation, non-dietary ingestion, and dermal contact. PCB concentration data were not available for dust. For the purposes of this modeling effort, the dust concentrations were estimated for each room with an indoor air PCB measurement using an estimated solid/air partition coefficient (see Appendix E). Wipe sample data were not used as the surrogate for dust because the wipes likely contained some distribution of dust-bound and surface-residue PCBs, but that distribution cannot be defined from the measurement. Also, the µg/100 cm^2 units for wipes cannot be simply translated to the µg/kg units for dust. The uncertainty in concentrations of PCBs in dust can be reduced by collection of dust samples; protocols for future sampling should including bulk dust sample collection and should include both concentration and loading where possible.

Building ventilation conditions – Air samples were collected at multiple locations (including classrooms, gymnasiums, cafeterias, transitional spaces) at several time points at multiple schools under different conditions. Air concentrations of indoor pollutants are strongly impacted by ventilation rates in a building or in a room. Actual rates of ventilation with outdoor air and with air from adjoining spaces are difficult to measure in individual rooms in older buildings. While the air PCB measurements certainly incorporated some level of variability in ventilation effects, it is not possible to quantitatively characterize the impact of ventilation on air concentrations from the available data. Exposures (and doses) might be substantially different under different ventilation conditions. Doubling the outdoor air ventilation rate to a room would result in an approximately 50% decrease in indoor air PCB concentrations if all other factors were unchanged, while reducing the outdoor air ventilation rate by half would approximately double indoor air PCB levels. Uncertainties due to ventilation effects can be reduced by collection of baseline data on ventilation and, where successive measurements are performed, making those measurements under similar ventilation conditions. However, it will remain difficult to accurately assess air flows between a room and other adjacent spaces in older buildings that may also contain PCBs, limiting the ability to fully account for ventilation impacts on PCBs in indoor air.

Temperature conditions – Both laboratory and building studies have demonstrated that PCB emissions increase with increasing temperature, and that temperature can affect indoor air PCB concentrations (Guo et al, 2011; MacIntosh et al., 2012). The measurements used in this study were based primarily on measurements made during the summer when ambient temperatures are highest. Indoor air levels and estimated exposures may be somewhat lower during colder months. There was some information to suggest a relationship between indoor air PCB concentrations and ambient temperature with one of the NYC schools (NYC SCA, 2012). However, Hazrati and Harrad (2006) showed no seasonal variations in indoor PCB concentrations as, in effect, any increased volatilization in summer may be offset by increased ventilation.

Dermal contact and non-dietary ingestion rates – Dermal contact rates with potentially contaminated surfaces have not been directly assessed for children in school environments. Likewise, non-dietary ingestion rates of PCBs have not been directly characterized for children in school environments. Thus, values from the literature based on other studies were used as model inputs. These values are the best available information at this time.

Pulmonary absorption of PCBs – Limited information is available to determine the pulmonary absorption of PCBs through the lungs; thus, a value of 70% absorption was assumed for this purpose and sensitivity tests were performed using values of 30%, 80%, and 100% absorption to examine the impact on estimates of absorbed dose. Because a majority of the modeled absorbed dose resulted from the inhalation pathway, the value selected for pulmonary absorption can have an important impact on absorbed dose estimates. Sensitivity analyses indicated that the median absorbed dose estimate for 6 – 10 year-old children would be 49% lower assuming pulmonary absorption of 30%, and 35% higher assuming pulmonary absorption of 100%.

Dermal absorption of PCBs – Some animal and human cadaver skin absorption data are available for selected Aroclors. However, dermal absorption may be affected by a number of factors including skin conditions; dermal loading rates; and how much of the PCBs are bound to soil, dust, or caulk particles. There remains uncertainty in absorption rates in natural environments under different conditions. The default values from the literature are the best available information for estimating dermal absorption at this time.

Estimation of dose as Aroclor 1254 – Most of the available absorption data is based on Aroclor 1254, and the environmental data generated at five of the schools was only available as Aroclor measurements (primarily reported as Aroclor 1254 with an altered Aroclor pattern). Thus, the SHEDS results are based on modeling total PCBs as Aroclor 1254. This is appropriate since the RfD of 0.020 µg/kg/d is based on Aroclor 1254 as well. However, it is likely that the actual congener concentrations in environmental media did not exactly match an Aroclor 1254 pattern. The analytical results suggested the mixture in school air was similar to a modified Aroclor 1254 pattern. Congener-specific results showed that the pattern in air was weighted more towards the more volatile congeners, but not as much as would be predicted from vapor emissions alone, suggesting inhalation of dust with a congener pattern similar to Aroclor 1254. The absorption rates for all congeners may not be well characterized when testing is done with Aroclor 1254 mixtures. Norstrom et al. (2010) showed predictions of exposure to PCBs in ambient air and predicted inhalation leads to greater exposures of lower-chlorinated congeners as compared to dietary intake of more highly chlorinated congeners.

Comparisons of dose estimates within and between schools - The strength of the SHEDS model is its ability to estimate the distribution of exposures in a population or sub-population that incorporates variability in chemical concentrations in multiple media and variability in human activities that contribute to exposure. Its ability to characterize exposure distributions is improved as more data become available for more locations and/or scenarios, and it relies on relatively large sample sizes to generate useful estimates for relevant populations. In this study, SHEDS modeling has been performed using measurements at up to six schools, providing some range of variability in concentrations that may, or may not represent well the larger universe of older school buildings with PCB sources. Due to the relatively small number of measurements at each school, SHEDS was not applied to estimate exposures on a school-by-school basis. It is clear from the air measurements of total PCBs that differences in exposures among individuals might be expected both between schools, and also within schools. SHEDS incorporates this variability in its distributional estimates, but is not well suited for comparison of exposure levels across different rooms in a school or between schools given the small number of schools and small number of measurements within each school.

Dietary and residential exposure to PCBs – SHEDS modeling estimates in this report are limited to estimates of absorbed doses (and exposure pathway analysis) resulting from school environments. A more complete model assessment would include the contribution from dietary sources as well as contributions from residential and outdoor exposures away from school. The evaluation of dietary exposures is important because dietary intake is often characterized as the primary route of exposure to PCBs in the general population. Summaries of estimated children's PCB dietary intake based on FDA Total Dietary Study data for the years 1991 through 1997 show considerable variability across quarters and an average intake of 0.008 µg/kg/day, with the most recent 1997 estimate of 0.003 µg/kg/day for 6 and 10-year old children (ATSDR 2000). These values can be compared to the median estimates of 0.020 µg/kg/day (pre-remediation) and 0.008 µg/kg/day (post-remediation) time points for 6 – 10 year-old children based on the measurement results for five schools. It is possible that PCB levels in foods have continued to decrease since 1997. Given the small number of samples with measurable PCB results in the most recent Total Diet Study, it is not clear whether there are sufficient U.S. data to support development of distributional parameters for SHEDS modeling of total dietary exposure. In addition, there may be segments of the population with above average dietary intakes, particularly for high fish consumers. Residential indoor air levels have been found in a range of a few to about 14 ng/m^3, much lower than the levels found in schools with PCB sources. Outdoor air levels are typically lower than those in indoor residential air. Additional time and effort are needed to examine the extant PCB dietary data (including recent Total Diet Study data from the FDA) as well as residential and ambient air data to determine their suitability for incorporation into the SHEDS model. However, the current extant data available for assessing background exposures is limited and may not be sufficiently robust for probabilistic estimates in the general population. Initial work is focusing on dietary intake of PCBs from fish and seafood.

The factors discussed above, as well as other model inputs, contribute to uncertainty in modeled exposure and absorbed dose estimates resulting from PCBs in school environments. Sensitivity testing for two important parameters helps define some of the range of uncertainty. Uncertainty around SHEDS absorbed dose estimation distributions could be better characterized given sufficient data. However, there is still insufficient school measurement data for a full uncertainty characterization for SHEDS PCB modeling of school exposures. Collection of additional data or information is likely to help reduce uncertainties and allow for better uncertainty characterizations in the future.

5.0
Conclusions

5.1 Sources of PCBs in School Buildings

PCB-containing caulk is a primary source of PCBs in and around school buildings. PCB emissions from caulk can potentially result in concentrations from hundreds to over a thousand nanograms per cubic meter in indoor air. PCBs from exterior caulks around windows and ventilation intakes can lead to elevated concentrations in indoor spaces. PCBs in exterior caulk are likely to enter the soil near school buildings. Caulk containing PCBs was found to be mostly intact and still somewhat flexible, but visual examination alone may not be adequate for determining if PCBs are present and testing is needed to determine if caulk or other sealants in a building contain PCBs.

PCB-containing fluorescent light ballasts remain in use in some older school buildings and are a primary source of PCBs. Emissions from intact ballast capacitors can lead to the presence of PCBs in school environments. PCB residues from previously failed ballast capacitors may remain in fixtures even if the ballast is replaced. Leaking or bursting capacitors are likely to substantially elevate PCB levels in indoor environments when they fail. Because these ballasts have exceeded their expected operational lifetimes, failure and possible leakage will continue and is likely to increase for ballasts remaining in place.

Several paint samples had total PCB concentrations above 100 ppm, up to 718 ppm. PCBs were used as plasticizers or flame retardants in some paints, so it is possible that these paints may have incorporated PCB when they were originally applied. Thus, it is possible that paints could be primary sources of PCBs in buildings based on our definition. Although they were not encountered in our study, window glazing and ceiling tile surface coatings containing PCBs have been reported in school buildings and would be considered primary sources.

Other primary sources of PCBs may have been used in school buildings but are no longer present today. For example, carbonless copy paper and PCB-containing capacitors in early computer video display terminals may have been used in school buildings. The potential impact of previously removed sources on current PCB levels in building environments cannot be easily determined.

Many of the building and furnishing materials in schools with apparent primary PCB sources contain PCB levels in the 4 to 100 ppm range. It appears likely that these materials have absorbed PCBs that have been emitted from primary sources. While primary sources remain in buildings these other materials are likely to be in quasi-dynamic equilibrium when temperature and ventilation conditions remain relatively constant. However, when primary sources are removed these materials may serve as secondary sources for emissions of PCBs into air in the building. Paints may be the most significant secondary sources given their large surface areas and relatively high PCB concentrations, but other materials may be important as well. Following mitigation of primary sources it may, in some cases, be necessary to consider mitigation actions for secondary sources.

5.2 School Environment PCB Levels and Exposures

PCBs are present in indoor air, dust, and on surfaces in school buildings with PCB-containing source materials, and are likely to be present in the soil near buildings with exterior PCB-containing caulk. Building occupants are exposed to PCBs through contact with these environmental media.

Estimated average total absorbed doses that could occur from the PCBs in school buildings with environmental levels that were found in these six schools were near the reference dose levels for Aroclor 1254 (0.020 µg/kg/day). Because the Aroclor 1254 reference dose is based on an oral applied dose, a more direct comparison with the SHEDS absorbed dose might be the RfD adjusted by a gastrointestinal absorption factor. Using the 85% absorption factor applied in SHEDS, the adjusted RfD would be 0.017 µg/kg/d. Over 50% of the estimated distribution of absorbed doses exceeded the adjusted reference dose level for the two younger age groups. These estimates do not include the additional background exposures to PCBs that occur outside of the school environment, including exposures from dietary intake and inhalation of PCBs in outdoor and indoor air at non-school locations.

Pre-remediation PCB concentrations in indoor air were found to exceed EPA's 2009 public health guidance levels (ranging from 70 to 600 ng/m^3 depending on age) in many of the rooms at the six schools that were evaluated. Inhalation was estimated to be responsible for over 70% of the exposure that could occur in buildings with environmental levels of PCBs that were found in these six schools. Mitigation efforts that focus on reducing indoor air PCB concentrations are likely to have the greatest impact on reducing exposures, although cleaning to reduce dust levels will also have an impact. Based on information from the five New York City schools, it appears that mitigation efforts can be successful in substantially reducing indoor air concentrations and exposures to PCBs.

5.3 Complexity of PCBs in School Buildings

PCBs in school buildings present a complex problem from exposure assessment, risk assessment, and mitigation decision-making perspectives. Different aspects of this complexity are summarized below.

There may be multiple primary sources of PCBs in school buildings. Numerous different kinds of caulks and sealants may be present and widespread across many building locations and they must be sampled to determine whether they contain PCBs. Fluorescent light ballasts containing PCBs may be present and light fixtures may be contaminated with residues from ballasts that have previously failed.

PCBs are semi-volatile organic chemicals with a wide range of vapor pressures that will vaporize from primary sources and can be transported throughout indoor and outdoor environments. They are absorbed by dust and soil which can result in additional transport and exposure.

PCBs absorb into numerous materials in a building resulting in a reservoir that remains even after primary sources are removed or otherwise mitigated. These secondary sources may result in continuing exposures following removal or remediation of primary sources.

Over 120 different PCB congeners have been measured in indoor air. These different congeners have a wide range of physical properties.

Ventilation with outdoor air is an important factor in the indoor air PCB concentrations that will result from source emissions. However, ventilation in older school buildings is often poor, difficult to assess, and difficult to improve.

An illustration of complexity of the situation that could be faced in a school classroom with different sources of PCBs is shown in Figure 5-1. Multiple primary sources of PCBs may be emitting PCBs into the air, onto surfaces, into dust and soil. Some of the PCBs are absorbed into other building materials that serve both as sources and sinks for PCBs. Ventilation occurs both from exchange with outdoor air and from exchange with air in other building spaces. PCBs can be carried between these school spaces. Finally, it is likely that there may be over 100 different PCB congeners present, with a range of vapor pressures and other physical and chemical properties that affect transport and absorption.

5.4 Study Limitations

There are important limitations and uncertainties in the information included in this report. Key limitations and uncertainties are summarized below.

PCB measurement results were available from only six schools. It is not known if these results are representative of older schools nationwide, both in terms of the presence of PCB-containing materials and components and the environmental concentrations measured in and around the school buildings.

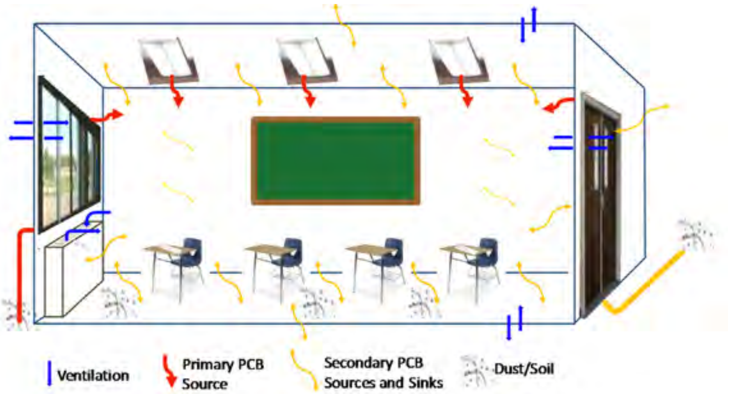


Figure 5-1. Illustration of the complexity of PCBs in school buildings

Materials and components containing PCBs were likely to have been used in buildings other than schools. This report does not address whether and to what extent PCBs may be a potential problem in other types of buildings, and if so, whether environmental concentrations and exposures are likely to be similar.

PCB emissions from materials and light ballasts were not directly measured at the six schools. Modeled emission estimates and the resulting predictions of indoor air concentrations have considerable uncertainties. Emission parameters are likely to vary across different materials and for different temperature and ventilation conditions. Two different types of chambers were used to test caulk and light ballasts emissions, possibly impacting comparability. Emissions from light ballasts are likely to vary depending on the lighting fixture design and the condition of the ballast and capacitor. Emissions from light fixtures contaminated from previously leaking or failed ballasts could not be evaluated.

Attributing the relative impact of PCB emissions from caulk and light ballasts on PCB levels in the schools was difficult because both sources were present in most buildings, and the Aroclor mixture used in every light ballast was not identified. Several paint samples were found to have several hundred ppm of PCBs, and it is not clear whether these contained PCBs when installed and might be considered primary sources.

There is uncertainty in modeled estimates of PCB exposures due to uncertainties in key model parameters. In particular, there is limited information for pulmonary absorption fraction from the range of PCB congeners in vapor and particle-bound forms. There is also uncertainty in total PCB exposures because of the lack of robust data for background exposures from diet and other non-school sources.

6.0
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Appendix A.
PCB Congener Information

Table A-1. Information for the 209 PCB congeners

Congener Number	Chlorine Positions	No. of Chlorines	Dioxin-Like Congener	Vapor Pressure (torr)	Vapor Pressure Ref.[a-e]	Weight % of Congener in Aroclor 1242[f]	Weight % of Congener in Aroclor 1254[f]	Weight % of Homolog in A1242	Weight % of Homolog in A1254
1	2	1				0.34		0.47	0
2	3	1				0.02			
3	4	1		2.07E-03	a	0.11			
4	2-2	2		2.72E-03	b	2.71	0.06	13.42	0.24
5	23	2		1.22E-03	b	0.11			
6	2-3	2		1.33E-03	b	1.24	0.02		
7	24	2		1.46E-03	b	0.18			
8	2-4	2		1.19E-03	b	6.48	0.13		
9	25	2		1.53E-03	b	0.4			
10	26	2		2.60E-03	b	0.14			
11	3-3	2		6.85E-04	c				
12	34	2		5.56E-04	b	0.04			
13	3-4	2		6.24E-04	c	0.17			
14	35	2		9.44E-04	c				
15	4-4	2		5.82E-04	b	1.95	0.03		
16	23-2	3		4.96E-04	b	3.44	0.09	48.02	1.24
17	24-2	3		5.82E-04	b	3.29	0.08		
18	25-2	3		6.38E-04	b	9.14	0.25		
19	26-2	3		1.04E-03	b	0.84			
20	23-3	3		2.27E-04	b	0.77			
21	234	3		2.21E-04	b				
22	23-4	3		1.97E-04	b	3.08	0.04		
23	235	3		3.35E-04	b	0.01			
24	236	3		5.31E-04	b	0.13			
25	24-3	3		2.79E-04	b	0.61			
26	25-3	3		2.92E-04	b	1.38	0.03		
27	26-3	3		5.31E-04	b	0.44			
28	24-4	3		2.43E-04	b	7.31	0.19		
29	245	3		3.48E-04	d	0.08			
30	246	3		6.38E-04	b				

Table A-1. Information for the 209 PCB congeners (continued)

Congener Number	Chlorine Positions	No. of Chlorines	Dioxin-Like Congener	Vapor Pressure (torr)	Vapor Pressure Ref.[a-e]	Weight % of Congener in Aroclor 1242[f]	Weight % of Congener in Aroclor 1254[f]	Weight % of Homolog in A1242	Weight % of Homolog in A1254
31	25-4	3		2.60E-04	b	7.82	0.28		
32	26-4	3		4.42E-04	b	2.05	0.05		
33	34-2	3		2.21E-04	b	5.35	0.16		
34	35-2	3		3.35E-04	b	0.02			
35	34-3	3		9.66E-05	b	0.07			
36	35-3	3		1.43E-04	b				
37	34-4	3		8.61E-05	b	2.19	0.07		
38	345	3							
39	35-4	3		1.52E-04	c				
40	23-23	4		9.02E-05	b	0.79	0.12	32.71	16.4
41	234-2	4		9.02E-05	b	0.69	0.01		
42	23-24	4		1.01E-04	b	1.25	0.15		
43	235-2	4		1.43E-04	b	0.19			
44	23-25	4		1.14E-04	b	3.63	2.31		
45	236-2	4		2.21E-04	b	0.91	0.05		
46	23-26	4		1.16E-04	a	0.38			
47	24-24	4		1.22E-04	b	0.92	0.14		
48	245-2	4		1.27E-04	b	1.17	0.12		
49	24-25	4		1.36E-04	b	2.6	1.1		
50	246-2	4							
51	24-26	4		1.97E-04	b	0.23			
52	25-25	4		1.50E-04	b	3.47	5.38		
53	25-26	4		2.60E-04	b	0.71	0.12		
54	26-26	4		3.88E-04	d				
55	234-3	4		4.35E-05	c	0.11			
56	23-34	4		3.51E-05	b	1.85	0.55		
57	235-3	4							
58	23-35	4							
59	236-3	4		8.45E-06	e	0.32	0.02		
60	234-4	4		3.43E-05	b	1.17	0.18		
61	2345	4							
62	2346	4							
63	235-4	4		5.43E-05	b	0.11	0.02		
64	236-4	4		1.06E-04	b	1.68	0.59		
65	2356	4		1.14E-04	b				
66	24-34	4		4.42E-05	b	3.38	1.01		
67	245-3	4		5.31E-05	b	0.17			
68	24-35	4							

Table A-1. Information for the 209 PCB congeners (continued)

Congener Number	Chlorine Positions	No. of Chlorines	Dioxin-Like Congener	Vapor Pressure (torr)	Vapor Pressure Ref.[a-e]	Weight % of Congener in Aroclor 1242[f]	Weight % of Congener in Aroclor 1254[f]	Weight % of Homolog in A1242	Weight % of Homolog in A1254
69	246-3	4		1.43E-04	b				
70	25-34	4		4.73E-05	b	3.7	3.49		
71	26-34	4		8.61E-05	b	1.06	0.15		
72	25-35	4		7.53E-05	c	0.01			
73	26-35	4							
74	245-4	4		4.73E-05	b	1.76	0.84		
75	246-4	4		1.51E-04	d	0.03			
76	345-2	4		4.84E-05	b	0.08	0.02		
77	34-34	4	Yes	1.43E-05	b	0.33	0.03		
78	345-2	4		2.39E-05	c				
79	34-35	4		2.56E-05	c				
80	35-35	4		4.10E-05	c				
81	345-4	4	Yes	2.17E-05	c	0.01			
82	234-23	5		2.22E-06	e	0.22	1.11	5.17	52.95
83	235-23	5		1.53E-05	a	0.09	0.48		
84	236-23	5		4.12E-05	b	0.35	2.32		
85	234-24	5		3.31E-05	d	0.24	1.28		
86	2345-2	5		2.16E-05	b		0.06		
87	234-25	5		2.07E-05	b	0.38	3.99		
88	2346-2	5		4.84E-05	b				
89	234-26	5		2.22E-06	e	0.07	0.09		
90	235-24	5		2.60E-05	b				
91	236-24	5		4.42E-05	b	0.17	0.93		
92	235-25	5		3.35E-05	b	0.09	1.29		
93	2356-2	5		5.31E-05	b				
94	235-26	5		2.22E-06	e		0.02		
95	236-25	5		5.56E-05	b	0.51	6.25		
96	236-26	5		2.22E-06	e	0.02	0.04		
97	245-23	5		2.16E-05	b	0.31	2.62		
98	246-23	5		5.19E-05	b				
99	245-24	5		2.60E-05	b	0.36	3.02		
100	246-24	5							
101	245-25	5		2.99E-05	b	0.57	8.02		
102	245-26	5		5.00E-05	d	0.05	0.15		
103	246-25	5		4.62E-05	a		0.03		
104	246-26	5							
105	234-34	5	Yes	5.82E-06	b	0.37	2.99		
106	2345-3	5		9.89E-06	b				

Table A-1. Information for the 209 PCB congeners (continued)

Congener Number	Chlorine Positions	No. of Chlorines	Dioxin-Like Congener	Vapor Pressure (torr)	Vapor Pressure Ref.[a-e]	Weight % of Congener in Aroclor 1242[f]	Weight % of Congener in Aroclor 1254[f]	Weight % of Homolog in A1242	Weight % of Homolog in A1254
107	234-35	5		7.85E-06	a				
108	2346-3	5		1.06E-05	c				
109	235-34	5		2.22E-06	e	0.04	0.37		
110	236-34	5		1.68E-05	b	0.68	9.29		
111	235-35	5							
112	2356-3	5		2.37E-05	b				
113	236-35	5		1.80E-05	b				
114	2345-4	5	Yes	5.19E-06	a	0.03	0.18		
115	2346-4	5		1.68E-05	b	0.03	0.2		
116	23456	5		1.80E-05	b				
117	2356-4	5		1.93E-05	b	0.02	0.23		
118	245-34	5	Yes	8.42E-06	b	0.51	7.35		
119	246-34	5		2.16E-05	b		0.08		
120	245-35	5		1.52E-05	d				
121	246-35	5		3.76E-05	b				
122	345-23	5		7.45E-06	c		0.1		
123	345-24	5	Yes	7.00E-06	a	0.02	0.15		
124	345-25	5		4.62E-06	e	0.02	0.29		
125	345-26	5		1.50E-05	b	0.02	0.02		
126	345-34	5	Yes	2.32E-06	a				
127	345-35	5		5.85E-06	c				
128	234-234	6		2.48E-06	b		1.42	0.18	26.95
129	2345-23	6		3.51E-06	b		0.38		
130	234-235	6		4.32E-06	b		0.6		
131	2346-23	6		5.19E-06	a		0.19		
132	234-236	6		7.50E-06	b	0.03	2.29		
133	235-235	6		8.24E-06	d		0.11		
134	2356-23	6		9.89E-06	b		0.37		
135	235-236	6		1.36E-05	b		0.61		
136	236-236	6		2.48E-05	b		0.7		
137	2345-54	6		2.27E-06	b		0.42		
138	234-245	6		3.67E-06	b	0.05	5.8		
139	2346-24	6		9.44E-06	b		0.15		
140	234-246	6							
141	2345-25	6		4.84E-06	b		0.98		
142	23456-2	6							
143	2345-26	6		1.01E-05	b				
144	2346-25	6		7.85E-06	b		0.24		

Table A-1. Information for the 209 PCB congeners (continued)

Congener Number	Chlorine Positions	No. of Chlorines	Dioxin-Like Congener	Vapor Pressure (torr)	Vapor Pressure Ref.[a-e]	Weight % of Congener in Aroclor 1242[f]	Weight % of Congener in Aroclor 1254[f]	Weight % of Homolog in A1242	Weight % of Homolog in A1254
145	2346-26	6		2.32E-05	b				
146	235-245	6		6.38E-06	b		0.67		
147	2356-24	6					0.1		
148	235-246	6		2.08E-05	d				
149	236-245	6		1.11E-05	b	0.04	3.65		
150	236-246	6							
151	2356-25	6		1.43E-05	b		0.69		
152	2359-26	6							
153	245-245	6		5.43E-06	b	0.04	3.77		
154	245-246	6		1.36E-05	b		0.04		
155	246-246	6							
156	2345-34	6	Yes	1.22E-06	b		0.82		
157	234-245	6	Yes	1.19E-06	b		0.19		
158	2346-34	6		3.43E-06	b		0.81		
159	2345-35	6							
160	23456-3	6							
161	2346-35	6							
162	235-345	6							
163	2356-34	6		3.94E-06	b	0.02	1.03		
164	236-345	6		5.81E-07	e		0.4		
165	2356-35	6							
166	23546-4	6		5.81E-07	e		0.05		
167	245-345	6	Yes	1.76E-06	b		0.27		
168	246-345	6		5.16E-06	c				
169	345-345	6	Yes	5.07E-07	b				
170	2345-234	7		5.82E-07	b		0.52	0	2.65
171	2346-234	7		1.57E-06	b		0.14		
172	2345-235	7		1.06E-06	b		0.07		
173	23456-23	7		1.76E-06	d				
174	2345-236	7		2.07E-06	b		0.34		
175	2346-235	7		2.99E-06	b				
176	2346-236	7		5.43E-06	b		0.04		
177	2356-234	7		1.88E-06	b		0.2		
178	2356-235	7		3.43E-06	b		0.03		
179	2356-236	7		6.53E-06	b		0.1		
180	2345-245	7		9.02E-07	b		0.67		
181	23456-24	7		3.16E-06	d				
182	2345-246	7		2.79E-06	b				

Table A-1. Information for the 209 PCB congeners (continued)

Congener Number	Chlorine Positions	No. of Chlorines	Dioxin-Like Congener	Vapor Pressure (torr)	Vapor Pressure Ref.[a-e]	Weight % of Congener in Aroclor 1242[f]	Weight % of Congener in Aroclor 1254[f]	Weight % of Homolog in A1242	Weight % of Homolog in A1254
183	2346-245	7		2.43E-06	b		0.18		
184	2346-246	7							
185	23456-25	7		2.21E-06	b				
186	23456-26	7		5.66E-06	d				
187	2356-245	7		2.79E-06	b		0.25		
188	2356-345	7		1.12E-05	d				
189	2345-345	7	Yes	2.02E-07	a		0.01		
190	23456-34	7		5.31E-07	b		0.07		
191	2346-345	7		7.85E-07	b				
192	23456-35	7		1.06E-06	b				
193	2356-345	7		9.02E-07	b		0.03		
194	2345-2345	8		9.66E-08	a		0.01	0	0.04
195	23456-234	8		2.72E-07	b				
196	2345-2346	8		4.42E-07	b				
197	2346-2346	8		6.84E-07	a				
198	23456-235	8		5.31E-07	b				
199	2345-1256	8		1.06E-06	b		0.01		
200	23456-236	8		1.53E-06	b				
201	2346-2356	8		4.42E-07	b				
202	2356-2356	8		1.80E-06	b				
203	23456-245	8		4.22E-07	b		0.02		
204	23456-246	8		1.04E-06	b				
205	23456-345	8		2.18E-07	d				
206	23456-2345	9		1.15E-07	d		0.03	0	0.04
207	23456-2346	9		3.74E-07	d				
208	23456-2356	9		1.64E-07	a		0.01		
209	23456-23456	10		9.93E-08	d			0	0

[a] Fischer RC, Wittlinger R, and Ballschmiter K. (1992) – Method A.

[b] Fischer RC, Wittlinger R, and Ballschmiter K. (1992) – Method B.

[c] Foreman, W. T. and Bidleman, T. F. (1985) – Method A.

[d] Foreman, W. T. and Bidleman, T. F. (1985) – Method B.

[e] U.S. EPA Estimation Program Interface (EPI) Suite™. Accessed MPBPWIN™ module though ChemSpider at http://www.chemspider.com/.

[f] Frame et al., 1996; based on analysis of G3 Aroclor 1242 and G4 Aroclor 1254 standards.

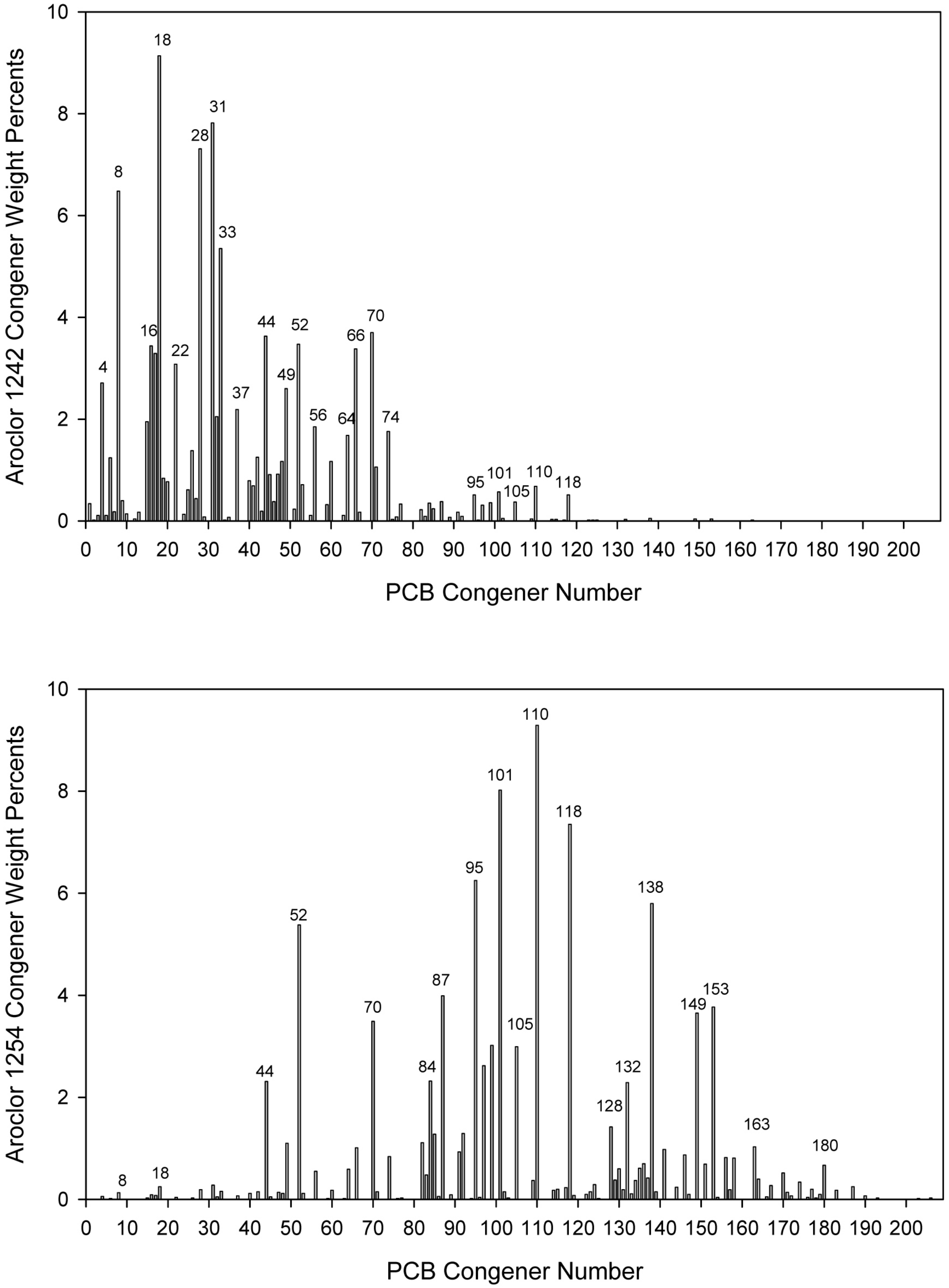

Figure A-1. Relative congener weight percents for Aroclors 1242 and 1254 (based on Frame et al. 1996)

Appendix B.
Source Measurement Results for Individual Schools

Table B-1. Interior caulk and window glaze total PCB measurement results by concentration category

Concentration Category	5 Schools Combined	School 1	School 2	School 3	School 5	School 6
				Number of Samples		
All samples	427	111	113	120	63	20
< 50 ppm	351	93	87	106	46	19
50 – 999 ppm	33	12	15	0	5	1
1,000 – 9,999 ppm	6	2	0	2	2	0
10,000 – 99,000 ppm	11	4	3	3	1	0
100,000 – 199,999 ppm	10	0	6	2	2	0
200,000 – 299,999 ppm	14	0	2	6	6	0
300,000 – 399,999 ppm	1	0	0	0	1	0
400,000 – 499,999 ppm	1	0	0	1	0	0
				Percentage of Samples		
< 50 ppm	82.2	83.8	77.0	88.3	73.0	95.0
50 – 999 ppm	7.7	10.8	13.3	0	7.9	5.0
1,000 – 9,999 ppm	1.4	1.8	0	1.7	3.2	0
10,000 – 99,000 ppm	2.6	3.6	2.7	2.5	1.6	0
100,000 – 199,999 ppm	2.3	0	5.3	1.7	3.2	0
200,000 – 299,999 ppm	3.3	0	1.8	5.0	9.5	0
300,000 – 399,999 ppm	0.2	0	0	0	1.6	0
400,000 – 499,999 ppm	0.2	0	0	0.8	0	0

Table B-2. Exterior caulk and window glaze total PCB measurement results by concentration category

Concentration Category	3 Schools Combined	School 4	School 5	School 6
		Number of Samples		
All samples	73	15	49	9
< 50 ppm	27	8	18	1
50 – 999 ppm	5	1	4	0
1,000 – 9,999 ppm	11	2	9	0
10,000 – 99,000 ppm	5	3	0	2
100,000 – 199,999 ppm	9	0	3	6
200,000 – 299,999 ppm	11	1	10	0
300,000 – 399,999 ppm	5	0	5	0
400,000 – 499,999 ppm	0	0	0	0
		Percentage of Samples		
< 50 ppm	37.0	53.3	36.7	11.1
50 – 999 ppm	6.8	6.7	8.2	0
1,000 – 9,999 ppm	15.1	13.3	18.4	0
10,000 – 99,000 ppm	6.8	20.0	0	22.2
100,000 – 199,999 ppm	12.3	0	6.1	66.7
200,000 – 299,999 ppm	15.1	6.7	20.4	0
300,000 – 399,999 ppm	6.8	0	10.2	0
400,000 – 499,999 ppm	0	0	0	0

Table B-3. Total PCB measurement results for selected materials by school

			Total PCB Levels in Other Materials[a,b]		
Material Category	N	% > QL[c]	Median ppm	Mean ± SD ppm	Range ppm
Paint					
School 2	93	100	46.5	75.8 ± 102	3.43 - 718
School 3	37	100	27.5	31.7 ± 28.1	3.31 - 135
School 6	13	100	64.9	59.3 ± 19.7	35.1 - 92.2
Fiberboard					
School 2	25	100	33.2	30.8 ± 15.2	2.85 - 54.8
School 3	3	100	13.0	14.8 ± 5.48	10.5 - 21.0
School 6	0	--	--	--	--
Particle Board					
School 2	18	100	14.8	15.2 ± 5.92	6.88 - 28.8
School 3	1	100	12.9	--	--
School 6	0	--	--	--	--
Varnish					
School 2	29	97	11.0	15.1 ± 12.9	<QL - 48.2
School 3	0	--	--	--	--
School 6 (gym floor)	1	100	61.5	--	--
Mastics (Tile and Molding)					
School 2	31	97	6.84	19.2 ± 36.6	<QL - 188
School 3	29	86	8.71	19.3 ± 42.6	<QL - 230
School 6	5	100	1.61	2.82 ± 3.09	0.98 - 8.33
Ceiling Tile					
School 2	6	100	11.3	9.17 ± 4.73	2.11 - 14.0
School 3	0	--	--	--	--
School 6	2	100	2.45	2.45 ± 0.56	2.06 - 2.85
Laminate					
School 2	29	76	5.35	41.1 ± 58.7	<QL - 199
School 3	0	--	--	--	--
School 6	0	--	--	--	--
Floor Tile					
School 2	27	89	4.60	5.04 ± 3.69	<QL - 14.6
School 3	26	73	4.76	8.11 ± 11.6	<QL - 57.1
School 6	3	100	2.07	2.92 ± 2.50	0.96 - 5.73

[a] Reported as total PCBs from Aroclor measurements.

[b] One-half the quantitation limit was substituted for values less than the quantitation.

[c] QL = quantitation limit; sample size dependent, typically ≤ 1 ppm.

Appendix C.
Congener Measurement Results by Sample Type

Table C-1. Air sample PCB congener concentrations at School 6

	Indoor Air N = 7 ng/m^3		Outddoor Air N = 1 ng/m^3	
PCB Congener #	Mean	SD	Mean	SD
4	0.3	0.5	<QL	---
8	1.5	0.9	<QL	---
17	2.1	1.3	<QL	---
18	3.8	2.0	<QL	---
28	3.8	2.1	<QL	---
31	3.7	1.9	<QL	---
44	19.2	5.1	0.24	---
47	4.8	1.3	0.06	---
49	14.8	4.7	0.17	---
52	44.7	14.6	0.45	---
56	2.6	0.8	0.08	---
64	5.5	1.7	0.04	---
66	6.9	1.9	0.09	---
70	25.3	7.2	0.39	---
74	11.9	3.4	0.18	---
82	3.9	1.6	0.11	---
84	13.9	3.4	0.24	---
85	5.3	2.0	0.11	---
87	17.6	6.7	0.34	---
91	5.8	2.0	0.15	---
92	10.5	3.3	0.15	---
95	50.0	14.6	0.72	---
97	11.2	4.0	0.22	---
99	15.1	4.7	0.24	---
101	53.8	19.1	0.86	---
105	5.5	3.1	0.11	---
110	39.0	21.5	0.49	---
118	18.6	9.3	0.52	---
128	1.4	0.9	<QL	---
130	0.8	0.5	<QL	---
132	6.6	3.2	0.23	---

Table C-1. Air sample PCB congener concentrations at School 6 (continued)

PCB Congener #	Indoor Air N = 7 ng/m³ Mean	SD	Outdoor Air N = 1 ng/m³ Mean	SD
138	8.3	4.9	0.23	---
141	2.2	1.1	0.07	---
146	1.2	0.7	0.03	---
149	12.6	5.6	0.24	---
151	5.8	2.4	0.12	---
153	9.6	5.0	0.23	---
156	0.5	0.3	<QL	---
158	1.2	0.7	0.03	---
163	1.4	0.9	0.04	---
170	0.2	0.1	<QL	---
174	0.7	0.4	<QL	---
180	0.8	0.6	<QL	---
187	0.8	0.6	<QL	---
206	0.2	0.0	<QL	---
Σ 209 Cong.[a]	500	154	7.7	---
Σ 45 Cong.[b]	456	143	7.20	---
Σ DLC Cong.[c]	26	13	0.64	---
DLC TEQ[d]	7.88E-04	4.07E-04	1.91E-05	---
% 45 Cong.[e]	91.0	1.5	93.2	---
% DLC Cong.[f]	5.0	1.6	8.2	---

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the12 dioxin-like congeners.

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table C-2. Surface wipe PCB congener concentrations at School 6

PCB Congener #	Surface Wipe – High Contact Surfaces N = 3 µg/100 cm² Mean	SD	Surface Wipe – Low Contact Surfaces N = 7 µg/100 cm² Mean	SD
4	<QL	---	<QL	---
8	<QL	---	<QL	---
17	<QL	---	<QL	---
18	<QL	---	<QL	---
28	0.0014	0.0024	0.0008	0.0015
31	0.0010	0.0017	0.0006	0.0014
44	0.0083	0.0112	0.0060	0.0091
47	0.0020	0.0029	0.0013	0.0024
49	0.0055	0.0075	0.0038	0.0053
52	0.0179	0.0248	0.0114	0.0174
56	0.0024	0.0033	0.0017	0.0032
64	0.0019	0.0033	0.0013	0.0029
66	0.0042	0.0050	0.0035	0.0053
70	0.0126	0.0129	0.0101	0.0129
74	0.0059	0.0061	0.0047	0.0061
82	0.0047	0.0040	0.0030	0.0048
84	0.0080	0.0076	0.0069	0.0086
85	0.0052	0.0038	0.0041	0.0049
87	0.0170	0.0123	0.0134	0.0146
91	0.0040	0.0039	0.0028	0.0035
92	0.0062	0.0045	0.0055	0.0068
95	0.0206	0.0216	0.0168	0.0216
97	0.0098	0.0078	0.0080	0.0086
99	0.0154	0.0133	0.0129	0.0149
101	0.0377	0.0314	0.0319	0.0354
105	0.0165	0.0113	0.0084	0.0087
110	0.0334	0.0247	0.0243	0.0269
118	0.0351	0.0249	0.0194	0.0202
128	0.0076	0.0066	0.0029	0.0029

Table C-2. Surface wipe PCB congener concentrations at School 6 (continued)

	Surface Wipe – High Contact Surfaces N = 3 µg/100 cm²		Surface Wipe – Low Contact Surfaces N = 7 µg/100 cm²	
PCB Congener #	Mean	SD	Mean	SD
130	0.0028	0.0019	0.0014	0.0014
132	0.0171	0.0133	0.0087	0.0085
138	0.0330	0.0240	0.0182	0.0151
141	0.0074	0.0047	0.0050	0.0040
146	0.0036	0.0025	0.0018	0.0020
149	0.0221	0.0143	0.0174	0.0151
151	0.0076	0.0054	0.0067	0.0059
153	0.0282	0.0178	0.0201	0.0170
156	0.0050	0.0051	0.0018	0.0016
158	0.0051	0.0033	0.0025	0.0025
163	0.0058	0.0042	0.0031	0.0027
170	0.0031	0.0035	0.0030	0.0031
174	0.0028	0.0031	0.0050	0.0061
180	0.0061	0.0068	0.0102	0.0127
187	0.0039	0.0035	0.0057	0.0071
206	0.0064	0.0055	0.0070	0.0049
Σ 209 Cong.[a]	0.491	0.430	0.371	0.385
Σ 45 Cong.[b]	0.444	0.375	0.323	0.335
Σ DLC Cong.[c]	0.059	0.044	0.031	0.032
DLC TEQ[d]	1.78E-06	1.33E-06	9.39E-07	9.86E-07
% 45 Cong.[e]	92.2	3.0	89.7	9.0
% DLC Cong.[f]	13.0	1.7	8.4	2.9

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the12 dioxin-like congeners

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table C-3. Dust sample PCB congener concentrations at School 6

PCB Congener #	Indoor Dust N = 4 ppm	
	Mean	SD
4	<QL	---
8	<QL	---
17	0.001	0.002
18	0.003	0.005
28	0.018	0.014
31	0.018	0.013
44	0.29	0.112
47	0.073	0.028
49	0.15	0.054
52	0.59	0.246
56	0.13	0.059
64	0.087	0.029
66	0.23	0.088
70	0.73	0.338
74	0.34	0.159
82	0.40	0.275
84	0.51	0.236
85	0.42	0.276
87	1.4	0.875
91	0.19	0.084
92	0.46	0.239
95	1.3	0.568
97	0.74	0.462
99	1.1	0.653
101	2.6	1.408
105	1.2	1.026
110	2.7	1.872
118	2.6	2.056
128	0.51	0.431
130	0.19	0.150
132	1.0	0.771
138	2.1	1.661
141	0.44	0.305
146	0.26	0.225
149	1.5	0.940
151	0.49	0.292
153	1.7	1.224
156	0.28	0.232
158	0.30	0.238
163	0.36	0.290
170	0.15	0.091
174	0.18	0.093
180	0.28	0.131
187	0.14	0.050
206	0.008	0.009
Σ 209 Cong.[a]	30.9	18.6
Σ 45 Cong.[b]	28.1	17.5
Σ DLC Cong.[c]	4.3	3.5
DLC TEQ[d]	1.29E-04	1.04E-04
% 45 Cong.[e]	89.5	3.7
% DLC Cong.[f]	12.2	3.9

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the12 dioxin-like congeners.

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table C-4. Soil sample PCB congener concentrations at School 6

PCB Congener #	Soil Collected 0.15 m From Building N = 2 ppm		Soil Collected 2.44 m From Building N = 1 ppm	
	Mean	SD	Mean	SD
4	<QL	---	<QL	---
8	<QL	---	<QL	---
17	<QL	---	<QL	---
18	<QL	---	<QL	---
28	<QL	---	<QL	---
31	<QL	---	<QL	---
44	0.0040	0.0010	<QL	---
47	0.0004	0.0006	<QL	---
49	0.0037	0.0009	0.0003	---
52	0.0130	0.0043	0.0003	---
56	0.0125	0.0009	0.0077	---
64	0.0007	0.0010	0.0008	---
66	0.0064	0.0024	<QL	---
70	0.0168	0.0066	0.0004	---
74	0.0079	0.0031	<QL	---
82	0.0151	0.0056	0.0006	---
84	0.0117	0.0042	<QL	---
85	0.0183	0.0072	0.0005	---
87	0.0458	0.0179	0.0010	---
91	0.0049	0.0016	<QL	---
92	0.0164	0.0057	0.0004	---
95	0.0301	0.0099	0.0008	---
97	0.0258	0.0096	0.0007	---
99	0.0464	0.0165	0.0013	---
101	0.0952	0.0323	0.0022	---
105	0.0787	0.0241	0.0013	---
110	0.1024	0.0334	0.0022	---
118	0.1415	0.0488	0.0026	---
128	0.0502	0.0149	0.0010	---
130	0.0158	0.0043	0.0005	---
132	0.0553	0.0221	0.0027	---
138	0.1645	0.0488	0.0049	---
141	0.0302	0.0100	0.0046	---
146	0.0173	0.0053	0.0003	---
149	0.0733	0.0211	0.0021	---
151	0.0228	0.0064	0.0007	---

Table C-4. Soil sample PCB congener concentrations at School 6 (continued)

PCB Congener #	Soil Collected 0.15 m From Building N = 2 ppm		Soil Collected 2.44 m From Building N = 1 ppm	
	Mean	SD	Mean	SD
153	0.1113	0.0293	0.0038	---
156	0.0341	0.0098	0.0005	---
158	0.0212	0.0062	0.0005	---
163	0.0288	0.0086	0.0009	---
170	0.0237	0.0064	0.0009	---
174	0.0159	0.0044	0.0007	---
180	0.0294	0.0074	0.0016	---
187	0.0177	0.0027	0.0013	---
206	0.0027	0.0011	0.0019	---
Σ 209 Cong.[a]	1.60	0.49	0.071	---
Σ 45 Cong.[b]	1.41	0.44	0.052	---
Σ DLC Cong.[c]	0.27	0.09	0.005	---
DLC TEQ[d]	8.22E-06	2.58E-06	1.52E-07	---
% 45 Cong.[e]	87.8	1.0	72.9	---
% DLC Cong.[f]	17.0	0.3	7.1	---

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the12 dioxin-like congeners.

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table C-5. Caulk sample PCB congener concentrations at School 6

PCB Congener #	Interior Caulk Samples N = 5 ppm Mean	SD	Exterior Caulk Samples N = 3 ppm Mean	SD
4	<QL	---	<QL	---
8	0.01	0.01	<QL	---
17	0.01	0.01	11	19
18	0.03	0.04	11	19
28	0.05	0.04	46	80
31	0.05	0.04	52	89
44	0.31	0.15	1350	506
47	0.08	0.04	336	127
49	0.19	0.10	769	380
52	0.70	0.33	3140	1360
56	0.06	0.03	351	50
64	0.09	0.04	382	143
66	0.14	0.06	771	141
70	0.42	0.17	2650	379
74	0.20	0.08	1250	177
82	0.12	0.06	1240	34
84	0.29	0.12	1820	192
85	0.15	0.07	1310	45
87	0.48	0.21	2950	2550
91	0.11	0.05	773	85
92	0.22	0.10	1760	90
95	0.77	0.36	5160	673
97	0.28	0.13	2520	59
99	0.48	0.21	3940	194
101	1.15	0.53	9590	457
105	0.27	0.16	3920	274
110	0.87	0.40	8920	173
118	0.64	0.34	8300	511
128	0.10	0.09	2180	262
130	0.04	0.03	728	55
132	0.25	0.14	3610	413
138	0.45	0.32	8200	889
141	0.10	0.07	1620	133
146	0.06	0.03	861	60
149	0.42	0.24	5140	267
151	0.16	0.09	174	58

Table C-5. Caulk sample PCB congener concentrations at School 6 (continued)

PCB Congener #	Interior Caulk Samples N = 5 ppm Mean	Interior Caulk Samples N = 5 ppm SD	Exterior Caulk Samples N = 3 ppm Mean	Exterior Caulk Samples N = 3 ppm SD
153	0.40	0.26	6150	556
156	0.06	0.06	1490	178
158	0.07	0.05	1250	128
163	0.08	0.06	1440	158
170	0.03	0.04	970	123
174	0.04	0.04	721	75
180	0.06	0.06	1410	177
187	0.03	0.03	504	28
206	0.01	0.01	<QL	---
Σ 209 Cong.[a]	11.5	5.88	114000	2250
Σ 45 Cong.[b]	10.5	5.28	101000	2070
Σ DLC Cong.[c]	1.02	0.59	14500	1000
DLC TEQ[d]	3.08E-05	1.80E-05	0.436	0.029
% 45 Cong.[e]	91.7	1.9	89.2	3.2
% DLC Cong.[f]	8.7	1.2	12.8	1.1

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the12 dioxin-like congeners.

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table C-6. Other building material sample PCB congener concentrations at School 6

PCB Congener #	Paints and Floor Varnish N = 12 ppm		Chair Cushion Foam and Pin Board N = 2 ppm		Cove Molding and Floor Underlayment N = 2 ppm		Floor Tile and Ceiling Tile N = 2 ppm	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
4	<QL	---	0.07	0.05	0.01	0.02	<QL	---
8	<QL	---	0.09	0.10	0.06	0.06	<QL	---
17	0.02	0.03	0.10	0.06	0.15	0.15	<QL	---
18	0.05	0.06	0.17	0.07	0.24	0.22	<QL	---
28	0.13	0.09	0.37	0.20	0.53	0.52	0.002	0.002
31	0.11	0.09	0.31	0.15	0.43	0.40	0.000	0.000
44	0.92	0.45	1.30	0.13	0.79	0.09	0.008	0.012
47	0.23	0.11	0.33	0.03	0.20	0.02	0.002	0.003
49	0.45	0.31	0.78	0.06	0.59	0.08	0.01	0.002
52	1.72	0.86	2.23	0.10	1.29	0.007	0.04	0.015
56	0.29	0.14	0.40	0.16	0.25	0.17	0.01	0.001
64	0.27	0.14	0.40	0.07	0.28	0.06	0.01	0.001
66	0.56	0.28	0.73	0.32	0.49	0.26	0.01	0.003
70	1.47	0.53	1.41	0.17	0.76	0.07	0.04	0.002
74	0.69	0.25	0.66	0.08	0.36	0.03	0.02	0.001
82	0.59	0.21	0.31	0.05	0.15	0.07	0.02	0.007
84	1.01	0.35	1.01	0.23	0.53	0.04	0.02	0.000
85	0.59	0.20	0.41	0.06	0.18	0.12	0.02	0.006
87	1.97	0.67	1.31	0.14	0.53	0.37	0.05	0.024
91	0.37	0.11	0.37	0.03	0.17	0.10	0.01	0.002
92	0.70	0.22	0.65	0.07	0.29	0.20	0.02	0.002
95	2.50	0.81	2.32	0.01	0.86	0.26	0.03	0.047
97	1.08	0.35	0.81	0.11	0.34	0.23	0.03	0.013
99	1.59	0.52	1.46	0.20	0.65	0.44	0.05	0.012
101	3.80	1.27	3.02	0.36	1.32	0.80	0.12	0.028
105	1.29	0.60	0.50	0.02	0.25	0.14	0.04	0.034
110	3.62	1.31	2.18	0.20	0.81	0.49	0.10	0.057
118	2.87	1.25	1.33	0.11	0.59	0.41	0.07	0.095
128	0.49	0.26	0.15	0.03	0.08	0.06	0.02	0.014
130	0.20	0.09	0.06	0.01	0.04	0.02	0.01	0.003
132	1.33	0.51	0.54	0.01	0.26	0.13	0.04	0.059
138	2.21	1.01	0.73	0.08	0.39	0.27	0.07	0.073
141	0.54	0.22	0.41	0.22	0.12	0.06	0.02	0.015
146	0.28	0.13	0.11	0.00	0.05	0.03	0.01	0.008
149	1.97	0.69	1.02	0.05	0.50	0.32	0.06	0.049
151	0.71	0.24	0.45	0.04	0.24	0.09	0.02	0.016

Table C-6. Other building material sample PCB congener concentrations at School 6 (continued)

PCB Congener #	Paints and Floor Varnish N = 12 ppm		Chair Cushion Foam and Pin Board N = 2 ppm		Cove Molding and Floor Underlayment N = 2 ppm		Floor Tile and Ceiling Tile N = 2 ppm	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
153	1.95	0.80	0.78	0.03	0.42	0.24	0.08	0.045
156	0.24	0.13	0.07	0.02	0.04	0.04	0.01	0.006
158	0.32	0.15	0.10	0.01	0.06	0.04	0.01	0.013
163	0.39	0.18	0.13	0.01	0.07	0.05	0.01	0.013
170	0.17	0.10	0.09	0.09	0.04	0.003	0.004	0.006
174	0.33	0.25	0.11	0.04	0.07	0.007	0.01	0.014
180	0.47	0.40	0.21	0.19	0.10	0.01	0.02	0.017
187	0.34	0.33	0.11	0.04	0.08	0.001	0.01	0.016
206	0.06	0.07	0.04	0.02	0.02	0.002	0.01	0.011
Σ 209 Cong.[a]	45.8	15.5	36.1	1.2	19.8	0.2	1.26	0.76
Σ 45 Cong.[b]	40.9	13.6	30.1	2.6	15.7	3.0	1.14	0.69
Σ DLC Cong.[c]	4.65	2.07	2.02	0.09	0.940	0.631	0.118	0.141
DLC TEQ[d]	1.41E-04	6.25E-05	6.19E-05	2.89E-06	2.86E-05	1.96E-05	3.55E-06	4.24E-06
% 45 Cong.[e]	89.2	2.5	83.4	4.6	78.9	14.4	90.2	0.9
% DLC Cong.[f]	10.0	2.7	5.6	0.1	4.7	3.1	7.3	6.8

[a] Sum of all 209 congeners, including those not shown in this table.

[b] Sum of the 45 congeners shown in this table.

[c] Sum of the 12 dioxin-like congeners (77, 81,105, 114, 118, 123, 126, 156, 157, 167, 169, 189).

[d] TCDD toxic equivalence for the sum of the12 dioxin-like congeners.

[e] Percent of the total concentration of all 209 congeners for the sum of the 45 congeners in this table.

[f] Percent of the total concentration of all 209 congeners for the sum of the 12 dioxin-like congeners.

Table C-7. Air sample PCB homolog weight percents at School 6[a]

	Indoor Air N = 7		Outdoor N = 1	
PCB Homolog	Mean	SD	Mean	SD
1-Chlorine	0.02	0.1	<QL	---
2-Chlorine	0.6	0.7	<QL	---
3-Chlorine	4.3	2.1	<QL	---
4-Chlorine	31.1	6.0	26.4	---
5-Chlorine	51.1	5.4	56.6	---
6-Chlorine	11.9	3.5	17.0	---
7-Chlorine	0.8	0.5	<QL	---
8-Chlorine	0.1	0.1	<QL	---
9-Chlorine	0.04	0.0	<QL	---
10-Chlorine	<QL	---	<QL	---
	ng/m^3	ng/m^3	ng/m^3	ng/m^3
Σ 209 Cong.[b]	500	154	7.7	---

[a] Each chlorine-number homolog’s percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

Table C-8. Surface wipe sample PCB homolog weight percents at School 6[a]

	Surface Wipe – High Contact Surfaces N = 3		Surface Wipe – Low Contact Surfaces N = 7	
PCB Homolog	Mean	SD	Mean	SD
1-Chlorine	<QL	---	<QL	---
2-Chlorine	<QL	---	<QL	---
3-Chlorine	0.4	0.7	1.4	1.0
4-Chlorine	10.5	6.8	12.1	5.1
5-Chlorine	46.6	3.3	44.0	14.4
6-Chlorine	36.4	5.1	27.8	5.5
7-Chlorine	4.4	0.8	8.3	11.6
8-Chlorine	0.2	0.3	2.3	4.4
9-Chlorine	1.4	1.6	4.1	7.2
10-Chlorine	<QL	---	<QL	---
	µg/100 cm^2	µg/100 cm^2	µg/100 cm^2	µg/100 cm^2
Σ 209 Cong.[b]	0.491	0.430	0.371	0.385

[a] Each chlorine-number homolog’s percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

Table C-9. Dust sample PCB homolog weight percents at School 6[a]

	Interior Dust N = 4	
PCB Homolog	**Mean**	**SD**
1-Chlorine	<QL	---
2-Chlorine	<QL	---
3-Chlorine	0.4	0.5
4-Chlorine	11.3	5.3
5-Chlorine	50.8	3.1
6-Chlorine	31.6	7.1
7-Chlorine	5.4	3.4
8-Chlorine	0.5	0.6
9-Chlorine	0.1	0.1
10-Chlorine	<QL	---
	ppm	ppm
Σ 209 Cong.[b]	30.9	18.6

[a] Each chlorine-number homolog’s percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

Table C-10. Soil sample PCB homolog weight percents at School 6[a]

	Soil Collected 0.15 m From Building N = 2		Soil Collected 2.44 m From Building N = 1	
PCB Homolog	**Mean**	**SD**	**Mean**	**SD**
1-Chlorine	<QL	---	<QL	---
2-Chlorine	<QL	---	<QL	---
3-Chlorine	<QL	---	<QL	---
4-Chlorine	5.3	0.6	32.7	---
5-Chlorine	40.8	1.7	22.1	---
6-Chlorine	44.3	0.3	33.1	---
7-Chlorine	8.6	0.8	7.5	---
8-Chlorine	0.8	0.1	1.4	---
9-Chlorine	0.2	0.02	2.7	---
10-Chlorine	<QL	---	<QL	---
	ppm	ppm	ppm	ppm
Σ 209 Cong.[b]	1.60	0.49	0.071	---

[a] Each chlorine-number homolog’s percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

Table C-11. Caulk sample PCB homolog weight percents at School 6[a]

	Interior Caulk Samples N = 5		Exterior Caulk Samples N = 3	
PCB Homolog	Mean	SD	Mean	SD
1-Chlorine	0.0	0.0	0.0	0.0
2-Chlorine	0.1	0.1	0.0	0.0
3-Chlorine	1.8	1.2	0.1	0.2
4-Chlorine	21.8	2.9	10.5	2.8
5-Chlorine	53.4	4.1	49.6	1.3
6-Chlorine	21.0	3.4	34.8	3.7
7-Chlorine	1.7	1.2	4.8	0.6
8-Chlorine	0.1	0.1	0.2	0.1
9-Chlorine	0.1	0.1	0.0	0.0
10-Chlorine	0.0	0.0	0.0	0.0
	ppm	ppm	ppm	ppm
Σ 209 Cong.[b]	11.5	5.88	114000	2250

[a] Each chlorine-number homolog's percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

Table C-12. Building material PCB homolog weight percents at School 6[a]

	Paints and Floor Varnish N = 12		Chair Cushion Foam and Pin Board N = 2		Cove Molding and Floor Underlayment N = 2		Floor Tile and Ceiling Tile N = 2	
PCB Homolog	Mean	SD	Mean	SD	Mean	SD	Mean	SD
1-Chlorine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2-Chlorine	0.0	0.0	0.5	0.5	0.4	0.5	0.0	0.0
3-Chlorine	1.1	0.8	4.7	2.6	12.4	12.8	0.2	0.3
4-Chlorine	16.9	5.3	27.9	2.9	36.2	13.4	14.0	8.3
5-Chlorine	49.6	4.0	45.1	3.0	34.7	18.7	49.2	3.7
6-Chlorine	26.8	4.9	15.1	1.7	13.5	8.1	31.2	8.6
7-Chlorine	4.8	2.7	6.0	6.8	2.3	0.1	4.6	2.5
8-Chlorine	0.7	1.0	0.6	0.6	0.4	0.2	0.4	0.6
9-Chlorine	0.1	0.2	0.1	0.1	0.1	0.0	0.4	0.6
10-Chlorine	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Σ 209 Cong.[b]	45.8	15.5	36.1	1.2	19.8	0.2	1.26	0.76

[a] Each chlorine-number homolog's percent of the total concentration of all 209 congeners.

[b] Sum of the measured concentrations for all 209 congeners.

Appendix D.

Other School Data for SHEDS PCB Exposure /Dose Modeling

Summary

In 2009, Dr. Peter Egeghy of the National Exposure Research Laboratory assembled PCB measurement data at schools and college buildings from various literature and internet sources (shown below). Distributions for PCB concentrations in air, surface wipe, dust, and soil were used to generate input distributions for SHEDS modeling (FigureD-1). All of the SHEDS absorption and activity model parameters and inputs that were used for modeling absorbed doses in this report were also used for these data.

Data Sources

Indoor Air:

UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)

University of Rhode Island (http://www.uri.edu/news/chafeeclosedfinal.htm)

Coghlan et al., 2002 (http://www.pcbinschools.org/Characterize%20pcb.pdf)

Sullivan et al., 2008 (http://www.trcsolutions.com/Files/File/dioxin2008_Sullivan_Paper.pdf)

Harrad 2007 (http://www.rsc-aamg.org/Documents/Papers/MAA2007/StuartHarrad.pdf)

[Survey of NYC Schools not included because only 1 of 127 samples was above the rather high detection limit of 0.56 µg/m³]

Outdoor Air:

UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)

University of Rhode Island (http://www.uri.edu/news/chafeeclosedfinal.htm)

Harrad 2007 (http://www.rsc-aamg.org/Documents/Papers/MAA2007/StuartHarrad.pdf)

Dust:

UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)

University of Rhode Island (http://www.uri.edu/news/chafeeclosedfinal.htm)

Coghlan et al., 2002 (http://www.pcbinschools.org/Characterize%20pcb.pdf)

Sullivan et al., 2008 (http://www.trcsolutions.com/Files/File/dioxin2008_Sullivan_Paper.pdf)

Soil:

Massachusetts Schools (http://www.pcbinschools.org/Sampling%20Reports.htm)

SUNY Oswego (http://www.pcbinschools.org/Sampling%20Reports.htm)

MIT (http://westgate.mit.edu/node/10)

Herrick et al., 2004 (http://www.ehponline.org/members/2004/6912/6912.pdf)

Wipe:

NYC Schools (http://www.pcbinschools.org/Caulking%20Survey%20FINAL%204.5.08.xls)

French Hill (http://www.pcbinschools.org/Sampling%20Reports.htm)

UMass Amherst (http://www.ehs.umass.edu/PCB-information.htm)

Coghlan et al., 2002 (http://www.pcbinschools.org/Characterize%20pcb.pdf)

PCB Concentration Distributions

Distributions of PCB measurement results for indoor and outdoor air, surface wipe, dust, and soil samples obtained from the source above were plotted and are shown in Figure D-1. Distributional parameters from these data sets were input into the SHEDS model to generate distributions of estimated absorbed doses for comparison with estimates derived from the 2010 NYC school measurement data.

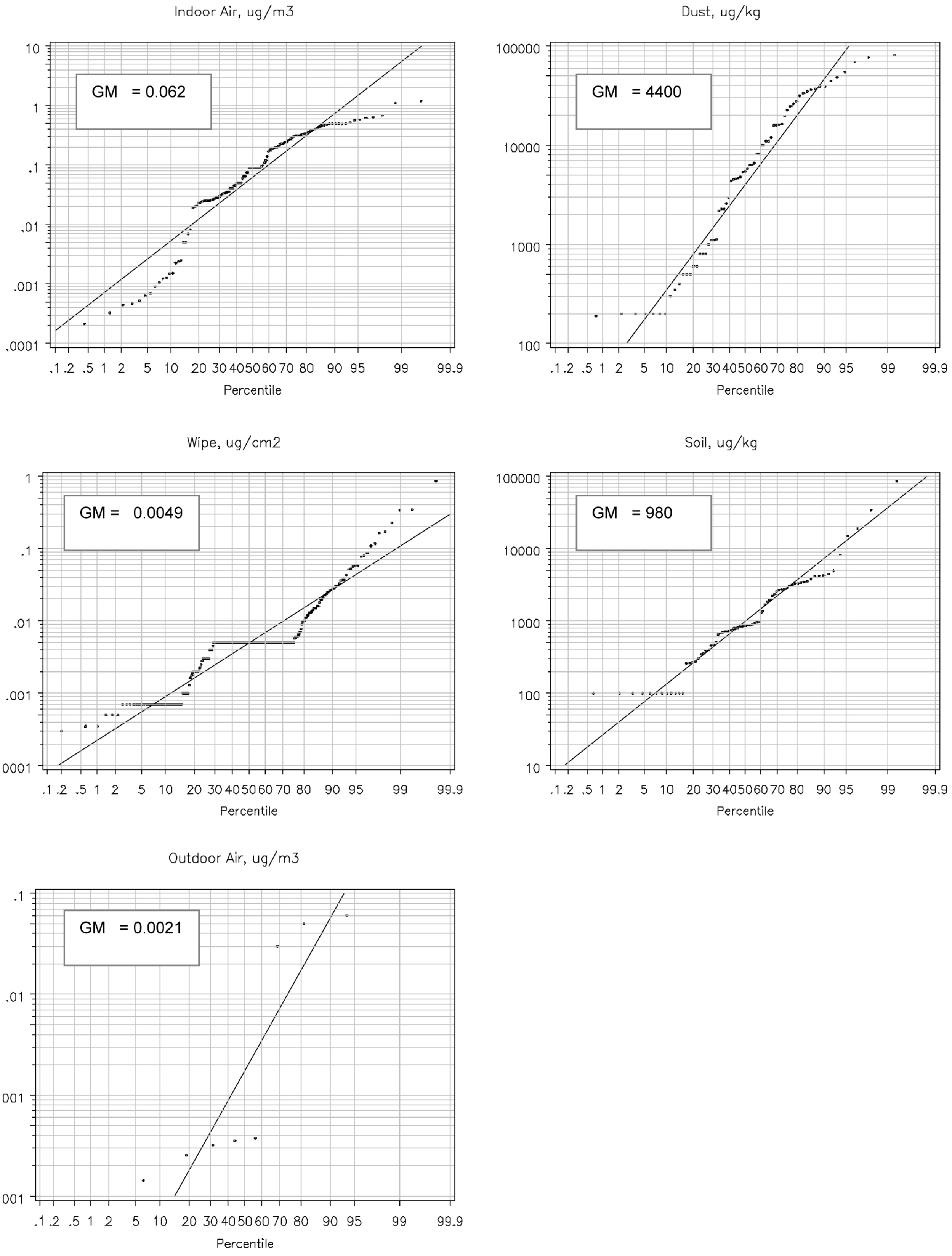

Figure D-1. Distributions of total PCB concentrations in several environmental media collected at school and college buildings (GM is the geometric mean)

Appendix E.
Estimation of PCB Concentrations in Dust

Background

The SHEDS model uses distributions of PCB concentrations measured in multiple environmental media to generate distributions of exposure estimates. Indoor air, surface wipe, and soil concentration measurement results were available to use in SHEDS modeling for the six schools considered for this report. However, interior dust samples were not collected as part of the NYC remedial pilot investigation. Dust samples were collected in several rooms at the other school, but this building had not been routinely cleaned over the previous five weeks, and it is not known if the PCB concentrations would be similar to those in the regularly cleaned building. Dust can be an important source of exposure to children through inhalation, non-dietary ingestion, and dermal contact. Therefore, several approaches for estimating PCB concentrations in dust were considered.

Initial SHEDS modeling runs were performed using the distribution of PCBs in soil samples as a surrogate for the distribution of PCB levels in dust, followed by using 5-times the soil concentrations as the dust surrogate. The latter approach was based on extant information shown in Appendix D, where the ratio between the geometric means of school dust PCB concentrations and school soil concentrations was 4400 µg/kg to 980 µg/kg, or a ratio of 4.5. While track-in of outdoor soil may contribute to dust inside of school buildings, for SVOCs there is likely to be a stronger relationship between levels in indoor air and indoor dust, particularly when there are relatively strong sources of SVOCs in the building. Therefore, estimation based on relationships between indoor air and dust is likely to be more appropriate for estimating concentrations in dust. This approach also has the advantage that air measurements are available from multiple rooms in each school building at each of the time points used for SHEDS modeling. Thus, any change in air concentrations as a result of remedial actions would be reflected in both the air and the dust – a situation likely to occur in school buildings.

We considered two approaches for estimating PCB concentrations on dust using air measurement results, each with strengths and weaknesses. The first was a method published by Weschler and Nazaroff (2010) that uses an approach based on the octanol-air partition coefficient to estimate the partitioning between SVOCs in air and settled dust in indoor environments. Using published data for many SVOCs, the authors found a high correlation between measured and predicted concentrations in dust ($R^2 = 0.76$). But for a few PCB congeners that were included, the approach over-estimated the actual concentrations by a range of 2.6 to 9.9 fold, depending on the congener. This approach also required assumptions about the fraction of organic carbon in dust and for other factors. A second approach was based on a predictive model for material/air partition coefficients that was developed from chamber testing of multiple materials (Guo, 2002).

Using the second approach the estimated geometric mean and geometric standard deviation based on pre-remediation air concentrations in six schools were 7.03 (4.26) ppm. This value and the resulting distribution were similar to those of the extant dust data shown in Appendix D. The geometric mean of 7.03 was somewhat greater than the 4.4 ppm for the extant data, but the air levels in the six schools were also greater, on average, than those in the extant data set. We elected to use the second approach to generate dust PCB concentrations for SHEDS modeling, but there are clearly uncertainties in this estimate, particularly how well the model represents the actual partioning for the different PCB congeners for school dust. In general, in the absence of dust measurements there is no perfect approach for estimating the dust PCB concentration information needed for SHEDS modeling. The air/dust partitioning approach is more appropriate than estimates based on outdoor soil concentrations in this scenario.

Method

Step1: Estimate the congener concentrations in room air assuming an unaged Aroclor 1254 mixture.

Step 2: For each congener, estimate the material/air partition coefficients for dust from Eq.1:

$$\ln K_{i = 8.785} \ln P_i \quad (1) \quad \text{(Guo et al., 2002)}$$

where

K_i = solid/air partition coefficient (dimensionless)
P_i = vapor pressure (torr)

Step 3: Estimate the dust concentration from Eq. 2:

$$C_{di} = 10^{-3} \frac{C_{ai} \, x \, K_i}{\rho} \qquad (2)$$

where

C_{di} = estimated concentration if congener i in dust (µg/kg)

C_{ai} = measured concentration of congener I in room air (µg/m^3)

ρ = density of dust (g/cm3), assumed to be 1.5 g/cm^3

Step 4: Estimate the total PCB concentration in dust by summing up all congeners for the room.

Step 5: Repeat for all school rooms with total PCB measurements.

This approach assumes that equilibrium conditions have been reached between air and dust PCB congener concentrations, that the density of school dust is 1.5 g/cm^3, and that the data used to develop equation 1 applies reasonably well to PCB congeners and school dust.

Distributions of Dust Concentrations

Table E-1 shows selected parameters for the distribution of dust concentrations calculated using the room air total PCB concentrations at each SHEDS modeling time point.

Comparision of SHEDS Results Using Differen Dust Estimation Approaches

Table E-2 shows distributions of estimated total PCB absorbed doses from the SHEDS model based on two different approaches for estimating total PCB concentrations in dust. The first approach is the one described here in Appendix E based on estimates of solid/air partition coefficients for the congeners. The second approach uses 5-times the soil total PCB measured concentrations as a surrogate for dust concentrations. The geometric mean and geometric standard deviations for the solid/air partition approach were 7.03 (4.26) ppm and were 2.68 (3.65) for the 5-times soil concentration surrogate approach. Thus, the solid/air partition coefficient approach generates higher dust concentrations. Even though the estimated dust concentrations from the solid/air partition coefficient estimation approach are higher, SHEDS model estimates of total PCB absorbed dose are close to those estimated from 5-times the soil concentrations from the 5th through about the 75th percentile of the distribution. For the two younger age groups, estimated absorbed doses using the solid/air partition coefficient approach become larger than those from the 5-times soil approach, particularly at the 99th percentile. This difference is not seen for the two older age groups because there are not suitable hand/mouth activity data for dust ingestion for these age groups, and as this component of exposure is considered much smaller for older children, was not included in the SHEDS model.

Table E-1. Distributions of total PCB concentrations on dust estimated from solid/air partition coefficient estimation.

Condition	Geometric Mean	Geometric SD	Percentiles of the Distribution of Dust Estimates (ppm) p5	p25	p50	p75	p95
6 Schools, Pre-remedition	7.03	4.26	0.75	1.82	9.77	22.8	41.9
5 Schools, Pre-remediation	6.24	4.44	0.75	0.78	7.91	23.5	44.9
5 Schools, Post-remediation	2.29	2.87	0.71	0.75	2.23	6.44	8.83
3 Schools, Year 1 Pre-remediation	9.82	3.86	0.75	4.90	15.3	25.8	47.8
3 Schools, Year 1 Post-remediation	2.35	2.87	0.71	0.74	2.33	6.54	8.71
3 Schools, Year 2 Pre-remediation	3.07	3.07	0.75	7.63	3.75	7.91	13.8

Table E-2. Distributions of SHEDS estimates of total PCB absorbed doses using two approaches for estimating indoor dust levels at the six schools

			Percentiles of the Distribution of Dose Estimates (µg/kg/day)					
Child Age Group	**Mean**	**SD**	**p5**	**p25**	**p50**	**p75**	**p95**	**p99**
4 – 5 year olds								
Dust from solid/air K	0.023	0.012	0.012	0.017	0.021	0.026	0.036	0.061
Dust from 5-times soil	0.020	0.006	0.011	0.016	0.019	0.023	0.029	0.037
6 – 10 year olds								
Dust from solid/air K	0.027	0.032	0.015	0.019	0.022	0.027	0.041	0.125
Dust from 5-times soil	0.022	0.008	0.014	0.018	0.021	0.025	0.032	0.050
11 – 13 year olds								
Dust from solid/air K	0.015	0.005	0.009	0.012	0.015	0.018	0.022	0.028
Dust from 5-times soil	0.014	0.004	0.008	0.011	0.014	0.016	0.021	0.026
14 – 18 year olds								
Dust from solid/air K	0.011	0.005	0.004	0.007	0.010	0.014	0.018	0.023
Dust from 5-times soil	0.010	0.004	0.003	0.007	0.010	0.013	0.017	0.020

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