Foreword
to
"Criteria for Evaluating Programs that Assess Materials/Products to Determine Impacts on Indoor Air Quality"

Chemical emissions from products and materials can contribute significantly to poor indoor air quality, with potentially serious impacts on the health and productivity of building occupants. Characterizing the sources of these emissions for their potential contribution to indoor air pollution can inform guidance on how to select products and materials that are less polluting, as well as how to modify them to reduce their emissions.

Evaluating emissions is attracting ever more attention currently because of the growth of the green building movement and the emerging consensus that green buildings must provide good indoor air quality. A major element in the assurance of good indoor air is better selection of the products and materials that go into such buildings.

The U.S. Environmental Protection Agency's (EPA's) Office of Research and Development pioneered much of the work to establish basic methods for measuring emissions of products and materials used indoors. The field of emissions testing has advanced greatly in recent years and several private-sector, commercial programs currently provide labels or certification related to products and materials used indoors.

EPA's Indoor Environments Division commissioned the following report under contract with Bruce Tichenor to gain better understanding of these programs and to provide the basis for strategic discussions of product/material emissions testing. Because it is a contractor's report, it presents the findings, recommendations and views of its author, and not necessarily those of EPA, regarding emissions from indoor sources.

Because the report contains so much valuable and timely information, EPA chooses to release this contractor's report in its current form in the belief that other organizations, e.g., industry associations, standard-setting organizations and government agencies, will benefit from the information it offers. EPA believes it will stimulate constructive discussion and promote further progress in this important area.

Foreword prepared by US EPA's Indoor Environments Division

Contractor Report

3/17/06

Final Report

Criteria for Evaluating Programs that Assess Materials/Products to Determine Impacts on Indoor Air Quality

Submitted to:

U.S. Environmental Protection Agency
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Contractor Report

EXECUTIVE SUMMARY

This report describes and defines criteria to be used to evaluate assessment programs or methods that evaluate materials and products to determine their impact on indoor air quality and occupant health, with an emphasis on VOC emissions. Methods are presented showing how the criteria can be used to rate existing and future assessment programs. Emphasis is placed on programs leading to labels or certification. Throughout the report, relevant sources are referenced and where possible, Internet addresses are given for easy access to the cited material. Appendices are used to provide extra information and details.

I. BACKGROUND AND PURPOSE

Title IV of the Superfund Amendments and Reauthorization Act of 1986 (SARA) gives the US EPA broad authority to: a) coordinate research in indoor air quality (IAQ), b) develop and disseminate information on IAQ, and c) coordinate efforts at the federal state and local levels. The main objectives of the EPA's indoor environments program include: 1) the protection of public health by promoting healthy environments; 2) development and implementation of control strategies which would prevent, abate, and mitigate indoor air pollution, including the development and dissemination of guidance on those aspects of building design and construction, operation and maintenance that affect the indoor environment; and 3) development and dissemination of information to educate key audiences about indoor air pollution and its associated health risks, mitigation and control strategies. Using the best science available, the Office of Radiation and Indoor Air develops and disseminates information, guidance, and solution-oriented technologies.

Products (e.g., building materials, cleaning products, office equipment, etc.) used within buildings are potential sources of indoor environmental contamination. There is a growing interest, especially within the green building movement, to purchase and use products that limit negative occupant impacts from exposure to chemical emissions. Because of this interest, manufacturers, governments and third-party organizations have initiated programs to test products and materials used indoors so they can be labeled, certified, and classified regarding their emissions of VOCs and other potential pollutants; such products are often called "green" or "low-emitting". Whether such products are better from a public health standpoint is often hard to determine because the link between exposure to indoor emissions and human health is difficult to accurately evaluate. Thus, the quality and merit of these labeling and certification programs need to be evaluated. Furthermore, claims about improved IAQ and better public health need to be scientifically established. While product testing is increasing, limited objective information is available to assess the validity of the subsequent results.

The US EPA authorized the present study to develop science-based criteria for evaluating methods and practices that are used to measure chemical emissions from products and assess their public health impact. The project was conducted using available information from the technical literature, the Internet, and contact with

appropriate organizations. Assessment programs that do not assess IAQ impacts are beyond the scope of this project. No product testing was conducted.

II. INTRODUCTION

There are many sources of indoor air pollution, including building materials, furnishings, consumer and cleaning products, office equipment, combustion (e.g., tobacco, cooking, heating), and outdoor air. Combustion sources and outdoor air are not considered in the present study. A variety of indoor emissions can occur, including particles, inorganic gases (e.g., CO, NO_x), and volatile organic compounds (VOCs). For this study, the focus is on the emissions of VOCs. For outdoor air pollution concerns, the US EPA defines VOCs as those organic compounds that participate in photochemical reactions that may produce smog. This would exclude some organic vapors such as formaldehyde and many chlorinated organic compounds. For indoor air, all organic vapors are included in the definition of VOCs.

In order to evaluate current and proposed practices used to assess the impact of products on IAQ, an understanding of the fundamental processes involved in assessing the impact of a product or material on IAQ is necessary. For this project, the focus is to develop science-based criteria for evaluating the practices and methods that can be used to determine the impact to IAQ and occupant health from consumer use of a product indoors.

This report describes and defines criteria to be used to evaluate assessment programs or methods that evaluate materials and products to determine their impact on indoor air quality and occupant health, with an emphasis on VOC emissions. To evaluate a product with respect to IAQ and occupant health, three major segments of assessment are considered:

- Product/Material Assessment
- Exposure Assessment
- Health/Risk Assessment

As an introduction to the concepts associated with assessment and testing of indoor material and products, the basic questions and answers have been developed:

1. *Why Assess/Test Indoor Products and Materials?* - The ultimate impact that a material or product has on the indoor environment depends on the compounds emitted and their associated effects on the occupants. Thus, IAQ product assessments must include consideration of their emissions. The specific products assessed for IAQ as well as the type of assessment or testing needed is dependent on either the purpose of the evaluation (e.g., to understand the impact of products widely used in certain building types such as schools) or the needs of the requestor (e.g., industry wants to understand its products; federal, state, or local governments want to develop policies to protect the public; environmental organizations and other interested parties want to promote healthy

products; etc.). Finally, the consumer wants to know if the product's emissions pose a health threat.

2. *How Do Testing and Assessment Differ?* - For the purposes of this report, assessment and testing are defined as follows: *Assessment* - a process that provides information useful to the consumer/user of a material or product with respect to its impact on indoor air quality. *Testing* – a process that subjects the material or product to a specific procedure to obtain information on its emissions to the indoor environment. Examples include: direct analysis, extraction, static headspace, and dynamic chamber testing. Thus, *testing* can be part of an *assessment* program, but all *assessment* programs do not include *testing*.

3. *What Types of Products/Material are Assessed/Tested?* - Any indoor material with measurable emissions is a candidate for assessment, and both dry and wet materials and products are tested to determine their emissions. Dry materials, which include the majority of materials used to construct and furnish residential and commercial environments, have relatively low emission rates that decay slowly. Dry materials include wood products, floor covering (carpet, vinyl, etc.), wall covering (wallpaper, fabric), ceiling materials, insulation, and upholstery. Compared to dry materials, wet materials generally have high initial emission rates (based on the VOC content of their solvents) that decay rapidly. As the materials dry, the emission rates decrease. Wet products include architectural coatings (latex and alkyd paints, stains, varnishes, etc.), adhesives, caulks and sealants, and cleaning/maintenance products.

4. *What is Emitted?* - The first goal of almost any assessment or testing program is to determine what pollutants (VOCs) are or may be emitted from the indoor product or material. Some testing/assessment programs target specific VOCs; others identify a broad range of compounds. The ultimate impact that a material or product has on the indoor environment depends on the compounds emitted and their health effects.

5. *How Much is Emitted and What is the Emission Rate?* - Information on the amount and rate of VOCs emitted from a product or material is needed to calculate the exposure to these compounds by the user or occupant. Emission rates may be constant or they may vary over time. Emission factors are emission rates defined in terms of mass per unit of material per time period (e.g., $\mu g/m^2$-hr). Information on emission rates is needed to determine the concentration of a given VOC in an indoor space where the product or material is used.

6. *What Affects the Emission Rates?* - Many factors affect the emission rates of VOCs from indoor materials. Some of the factors are related to the source, others are dependent on the environment where the source is used or tested. The factors fall into three categories: *Physical and chemical processes* - evaporation, sorption, diffusion, convection; *Environmental factors* – temperature, humidity, air change rate (ventilation), air velocity and turbulence; *Product characteristics* – number and types of chemical in product, chemical properties, product complexity, and manufacturing processes.

7. *What Emission Assessment/Testing Methods are Used?* - Many methods are available for determining emissions from indoor materials: *Use of available Information; Source emission models; Benchtop laboratory studies; and Dynamic chamber tests.*

8. *How are Emission Rates Calculated?* - Dynamic chamber test results are used to determine emission rates of individual VOCs and TVOC. Three types of emission rate calculations are generally used: *Constant emission rates, First order decay, and ASTM direct calculation method*. Mathematical equations are available for each method.

9. *What is the Occupant Exposure?* - Source emissions information is used in IAQ models to calculate the indoor concentrations of specific pollutants. The models may be simple one-compartment models with constant emission and ventilation rates, or they may be more complex models that account for variable emissions and ventilation parameters and include "sink effects". The modeled concentrations are coupled with occupant location and exposure time to predict occupant exposures. Exposures may be calculated for both maximum concentration and time weighted average concentrations. The occupant age, weight, body area and breath volume and frequency are used to determine inhalation and dermal exposure doses.

10. *What is the Occupant Health Risk?* - A variety of health effects can be related to pollutant exposure, including acute and chronic toxicity, cancer, reproductive effects, and odor/irritation. The calculated exposures are compared to available health effects information including dose-response data. Many organizations have published extensive information on the health impact of exposure the air pollutants, including: US Environmental Protection Agency, International Agency for Research on Cancer), National Institute for Occupational Safety and Health, American Conference of Governmental and Industrial Hygienists, and California Office of Environmental Health Hazard Assessment. Most of the available data on health effects of air pollutants were developed for outdoor air pollutants. The application of these criteria to indoor air pollutants must be done with caution. It is also noted that many pollutants emitted from indoor sources are not represented on the various lists referenced above.

III. EVALUATION CRITERIA

Criteria for evaluating assessment/testing programs are recommended for categories within the three major assessment segments: A) Product/Material Assessment, B) Exposure Assessment, and C) Health/Risk Assessment. Within each segment, numerous categories are identified and criteria developed. The evaluation criteria are presented in the form of tables. "Pros and Cons" of various methods and procedures are presented.

A. Product/Material Assessment

The first step in the overall IAQ evaluation process is to assess the emission potential of the materials and products used indoors, including the following parameters: *what is emitted* (i.e., the composition of the emissions), *how much is emitted* (i.e., the mass emitted) and *how fast are the emissions* (i.e., the emission rate). Product/material assessments to obtain this information can range from a limited evaluation of product content to full-blown product testing in dynamic chambers. There are four basic

techniques for assessing products to determine their potential impact on indoor air quality: *use of available information, source emission models, benchtop laboratory methods, and dynamic chamber testing.* In each case, information is presented on how the techniques are used to determine the emissions.

B. Exposure Assessment

After conducting the Material/Product Assessment to determine the potential emissions of indoor pollutants, the next step in assessing the potential health risk is to conduct an Exposure Assessment. The levels (concentrations) of indoor pollutants to which occupants are exposed are determined by many factors, including: source emission characteristics (i.e., chemical composition, emission rate, decay rate), the interaction of the emissions with interior surfaces (i.e., sink adsorption/desorption), dilution and flushing by outdoor air exchange, and processes designed to remove pollutants (i.e., air cleaners and local ventilation). Occupant exposures to indoor pollutants are a function of the spatial and temporal distribution of the pollutants and the activity patterns of the occupants.

C. Health/Risk Assessment

While exposure assessment provides information on the amount (concentration or dose) of a particular pollutant that can affect individuals in specific indoor environments, a Health/Risk Assessment requires the identification and quantification of the health hazard associated with this exposure.

Health Hazard Identification - A variety of health effects can be related to pollutant exposure, including acute toxicity (e.g., respiratory irritation), chronic toxicity (e.g., cancer), and reproductive effects. Odor is also of interest from an indoor air quality perspective, because individuals often subjectively associate odors with health impacts, even though the presence of an odor from a chemical is not indicative of its toxicity. For a given indoor source, multiple compounds can be emitted resulting in a variety of health effects endpoints. A comprehensive treatment of health effects is beyond the scope of this project, so only a cursory treatment is provided. A wide variety of information is available on specific health effects of chemical compounds based on dose-response studies.

TVOC vs. Individual Compounds - Indoor source emissions are often reported for both TVOC and individual VOCs. While data linking exposure to individual VOCs are available, the link between TVOC and health is more tenuous. Early studies by Molhave demonstrated a correlation between health/comfort and TVOC (Molhave, 1986). More recently, Molhave (2003) has indicated that the "TVOC concept is based on several assumptions and its usefulness for prediction of health effects of mixtures in undocumented." Furthermore, he states "TVOC cannot be used for normal regulatory risk assessment. There is just too little scientific basis for this and no Dose-Response relations have been established." The fact remains that TVOC is still widely used to

certify products for indoor emissions, especially as an indication of a "low emitting product".

Qualitative or Quantitative Assessment? - Two types of health/risk assessments are possible depending on the type of information developed on indoor sources. A *qualitative assessment* is conducted when specific exposure information is not available, but information on the compounds emitted from the indoor sources is accessible. A *quantitative assessment* is performed by comparing the predicted exposure parameter (concentration or dose) to published limits based on dose-response studies. Even though the databases contain literally thousands of compounds, in many cases, health effects data on a specific compound will not be found. In such cases, a qualified toxicologist or other professional can be consulted to determine if analogous compounds can be used to make the assessment.

D. Overall Evaluation Criteria

The report contains details on many aspects of the assessment categories discussed above, including numerous tables that summarize the relevant technical information. Table 1 is presented here to provide an overall summary of the criteria used to evaluate various assessment programs:

Table 1 - Overall Evaluation Criteria for IAQ Impact of Product/Material Emissions

Evaluation Criteria	Yes	No
Product/Material Assessment		
Use existing information		
MSDS		
VOC content		
Source emission models available		
Samples collected for evaluation		
Benchtop laboratory methods		
Direct analysis		
Static headspace analysis		
Dynamic chamber testing		
Chamber characteristics adequate		
Test sample properly conditioned and prepared		
Test conditions specified		
Chemical measurements described		
Emission rates determined		
Exposure Assessment		
Scenario developed		
IAQ/exposure model used		
Exposure concentration/dose determined		

Health/Risk Assessment		
Health hazards identified		
Qualitative assessment conducted		
Quantitative assessment conducted		
Numerical limit established		

IV. CURRENT ASSESSMENT/CERTIFICATION PROGRAMS

Several organizations in the US and abroad have developed and implemented programs to label or certify products and materials as "low emitting" based on emissions testing.

A. U.S. Assessment Programs

A number of programs in the U.S. provide labels or certificates relating to indoor air emissions. Some of the programs promote "green" products, and IAQ issues are only a small part of their criteria. Others emphasize IAQ issues.

Indoor Air Emissions Label/Certification Programs - Several of the U.S, assessment programs deal exclusively with indoor emissions and provide product labels and certifications: Greenguard Certification Standards for Low Emitting Products, California 01350 and CHPS (Collaborative for High Performance Schools) Assessment Program, CRI (Carpet and Rug Institute) – Green Label and Green Label Plus, RFCI (Resilient Floor Covering Institute) – FloorScore, SCS (Scientific Certification Systems) – Indoor Advantage and Indoor Advantage Gold, HPVA (Hardwood Plywood and Veneer Association), and BIFMA (Business and Institutional Furniture Manufacturing Association).

"Green Product" Assessment Programs – A number of "green product" assessment programs are active in the U.S. They deal with a wide variety of issues, such as: recycle/reuse; energy efficiency; air, water, and solid waste emissions; land use; renewable resources; etc. Several of these programs, also deal with IAQ issues, including consideration of indoor emissions: Green Seal, USGBC (US Green Building Council) – LEED (Leadership in Energy and Environmental Design), Green Guide for Health Care, Building Green Inc. – GreenSpec, NIST (National Institute of Standards and Technology) – BEES (Building for Environmental and Economic Sustainability), US EPA – EPP (Environmentally Preferred Purchasing), and US EPA – Energy Star Indoor Air Package.

B. Foreign Assessment Programs

There are a multitude of programs throughout the world that certify/label products and materials. The large majority of these programs certify the products to be environmentally "green" based on life-cycle parameters such as: energy use, recycle content, air/water emissions from manufacture, disposal, and use. While many of the programs have criteria for

VOC and hazardous chemical content limits, only a few of the programs (especially in Scandinavia) explicitly deal with indoor air emissions. Many foreign assessment programs are in the *Global Ecolabelling Network*, a multinational organization with 29 members. The US Green Seal program is part of this network. European programs that certify and/or label products include: the European Union (EU) Eco-label – *The Flower*, the Nordic Ecolabel - *The Swan*, Germany's – *Blue Angel Label*, Denmark's - *Indoor Climate Label*, and Finland's - *Emission Classification of Building Materials*.

V. US EMISSIONS TESTING LABORATORIES

At the present time, there are four laboratories in the U.S. that conduct emissions tests for indoor materials and products – Air Quality Sciences (AQS), Berkeley Analytical Associates (BAA), Material Analytical Services (MAS), and Georgia Tech Research Institute (GTRI). (Note that GTRI is primarily a research lab.) One question is often raised - *Which laboratories are qualified and approved for each certification program?* Table 2 links each certification program to "approved" testing laboratories:

Table 2 - "Approved" Testing Laboratories

Certification Program	Testing Laboratory
Greenguard	AQS
California 01350/CHPS	BAA, AQS, MAS
Green Label/Green Label Plus	AQS
FloorScore	BAA, AQS, MAS
Indoor Advantage/Indoor Advantage Gold	BAA, AQS, MAS

VI. EVALUATION PROTOCOLS FOR RATING/RANKING PRODUCT ASSESSMENT PROGRAMS

Evaluation criteria are recommended for categories within the three major assessment segments: A) Product/Material Assessment, B) Exposure Assessment, and C) Health/Risk Assessment. (See Table A). The evaluation criteria are presented in the form of tables. These tables can be used to evaluate any assessment program and provide guidance to determine the program's overall quality and completeness. If a rating or ranking of the assessment programs is desired, both quantitative and qualitative protocols are possible for evaluating the assessment programs:

- A *quantitative method* assigns maximum point values to various criteria so that a total point value for any program could be established. This allows various programs to be compared based on their "score".

- A *qualitative method* assigns a letter grade (e.g., A, B, C, D, F) to various criteria. This allows various programs to be compared based on the grades received for the same criteria.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The following conclusions are presented to highlight a few of the significant findings of the study. This list is not all-inclusive, but is intended to focus attention on some important issues.

1. Product/Material Assessment

"Green product" assessments rely on available information and cover a wide range of energy, environmental and life-cycle issues. Such programs generally do inadequate assessments of indoor emissions due to a lack of emissions information.

Product testing programs assign labels or certificates to products based on pass/fail criteria tied to emission limits determined by dynamic chamber testing. *Pass/fail emission limit criteria* include three types:

a. *Low emission limits* based on TVOC and a limited number of VOCs (e.g., Green Label, Indoor Advantage, Nordic Swan, Finland Emission Classification)

b. *Health effect limits* based on extensive lists of toxic compounds (e.g., California 01350/CHPS, FloorScore, Indoor Advantage Gold, CEN prEN 15052)

c. *Combination low emission and health effects limits* based on TVOC and individual VOCs with health based limits and product specific emissions (e.g., Greenguard and Green Label Plus)

2. Exposure Assessment

Existing programs use *simple one compartment, no sink, steady state IAQ models* to determine occupant exposure based on emission factors derived from dynamic chamber testing. Different *exposure scenarios* are used by the existing programs, so a direct comparison of emission factor limits between programs is difficult.

3. Health/Risk Assessment

There is little consistency among the existing certification programs. Various programs use *different health effects limits* for toxic air contaminants (e.g., ½ CREL, 1/10 TLV, 1/100 TLV) and *different lists of compounds* are used (California - CREL, ACGIH – TLV). Numerical limits are not assigned for *carcinogens or reproductive toxicants*.

4. Current Assessment/Certification Programs

Seven U.S. organizations have developed *product label/certification programs* that require emissions testing to validate emissions limits. At least seven additional programs provide limited indoor emissions assessments as part of *"green building" evaluations*. A large number of foreign assessment programs exist, including five European product/label certification programs.

5. Emissions Testing Laboratories

Only four U.S. laboratories provide *commercial indoor material emissions testing* services. While *accreditation programs* are available for analytical chemistry labs, no such programs exist for material emissions testing labs.

6. Evaluation Protocols for Rating Assessment Programs

Evaluation criteria for various aspects of assessment and testing programs have been developed and presented in tabular form. *Quantitative and qualitative schemes* have also been developed.

B. Recommendations

The following recommendations are intended to provide guidance for improving existing and future indoor emissions assessment programs:

1. *Assessments relying on available information, including "green building" programs, must inform the user of the limitations of the IAQ portion of the program*. These limitations include: no direct measurement of VOC emissions, no occupant exposure determination, and no quantitative health risk calculations.

2. For *material/product testing programs*, several improvements are needed:

a. *Testing laboratory accreditation standards should be developed*. Such standards should apply to all indoor product emission testing programs.

b. All program emission criteria should *include both emission factor and indoor concentration limits*. Indoor concentration limits should be expressed in units of $\mu g/m^3$. If ppm units are used, the equivalent $\mu g/m^3$ value must be provided.

c. All programs should *use the same occupant exposure scenarios* for equivalent products/materials to allow direct comparison of chamber test results.

d. *The use of TVOC emission limits should be minimized.* It is recognized that TVOC levels are not good predictors of health effects, but TVOC levels can be used as indications of "low-emitting" products. To the extent that TVOC limits are used, the definition should be standardized based on the total area of the chromatogram

between C5 to C17 (or C6 to C16) assuming an FID or GC/MS response to toluene.

e. *Product specific emission limits should be developed*. Emission levels tailored to specific products can compare emissions to published health effects data (e.g., the Green Label Plus program specifies limits for known carpet emissions based on California CREL limits). This approach reduces the number of compounds to be measured. Even with a reduced number of compounds, VOC spikes not on the target list require evaluation.

3. The improvement most needed in the health/risk assessment portion of the programs is the *development of consistent criteria for indoor VOCs*. Comparison of existing programs shows wide disparity between the limiting concentrations (e.g., ½ CREL, 1/10 TLV, 1/100 TLV, CEN's LCI). In addition, the VOCs on the various lists are different. Also, the exposed population (children, elderly, healthy adult, etc.) should be considered. Finally, the limits on carcinogens and reproductive toxicants are not consistent between the programs.

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I. BACKGROUND AND PURPOSE

Title IV of the Superfund Amendments and Reauthorization Act of 1986 (SARA) gives the US EPA broad authority to: a) coordinate research in indoor air quality (IAQ), b) develop and disseminate information on IAQ, and c) coordinate efforts at the federal state and local levels. The main objectives of the EPA's indoor environments program include: 1) the protection of public health by promoting healthy environments; 2) development and implementation of control strategies which would prevent, abate, and mitigate indoor air pollution, including the development and dissemination of guidance on those aspects of building design and construction, operation and maintenance that affect the indoor environment; and 3) development and dissemination of information to educate key audiences about indoor air pollution and its associated health risks, mitigation and control strategies. Using the best science available, the Office of Radiation and Indoor Air develops and disseminates information, guidance, and solution-oriented technologies.

Products (e.g., building materials, cleaning products, office equipment, etc.) used within buildings are potential sources of indoor environmental contamination. There is a growing interest, especially within the green building movement, to purchase and use products that limit negative occupant impacts from exposure to chemical emissions. Because of this interest, manufacturers, governments and third-party organizations have initiated programs to test products and materials used indoors so they can be labeled, certified, and classified regarding their emissions of VOCs and other potential pollutants; such products are often called "green" or "low-emitting". Whether such products are better from a public health standpoint is often hard to determine because the link between exposure to indoor emissions and human health is difficult to accurately evaluate. Thus, the quality and merit of these labeling and certification programs need to be evaluated. Furthermore, claims about improved IAQ and better public health need to be scientifically established. While product testing is increasing, limited objective information is available to assess the validity of the subsequent results.

In order to improve the flow of knowledge and information vis-à-vis indoor product emissions testing, labeling and certification, the US EPA authorized the present study to develop science-based criteria for evaluating methods and practices that are used to measure chemical emissions from products and assess their public health impact. EPA needs this information to develop guidance useful to manufacturers, green product standards developers, certification program directors, and those who make product purchasing decisions. The project was conducted using available information from the technical literature, the Internet, and contact with appropriate organizations. No product testing was conducted.

II. INTRODUCTION

A. Scope of the Project

There are many sources of indoor air pollution, including building materials, furnishings, consumer and cleaning products, office equipment, combustion (e.g., tobacco, cooking, heating), and outdoor air. Combustion sources and outdoor air are not considered in the present study. A variety of indoor emissions can occur, including particles, inorganic gases (e.g., CO, NO_x), and volatile organic compounds (VOCs). For this study, the focus is on the emissions of VOCs. For outdoor air pollution concerns, the US EPA defines VOCs as those organic compounds that participate in photochemical reactions that may produce smog. This would exclude some organic vapors such as formaldehyde and many chlorinated organic compounds. [See 40CFR 51.100(s)] For indoor air, all organic vapors are included in the definition of VOCs.

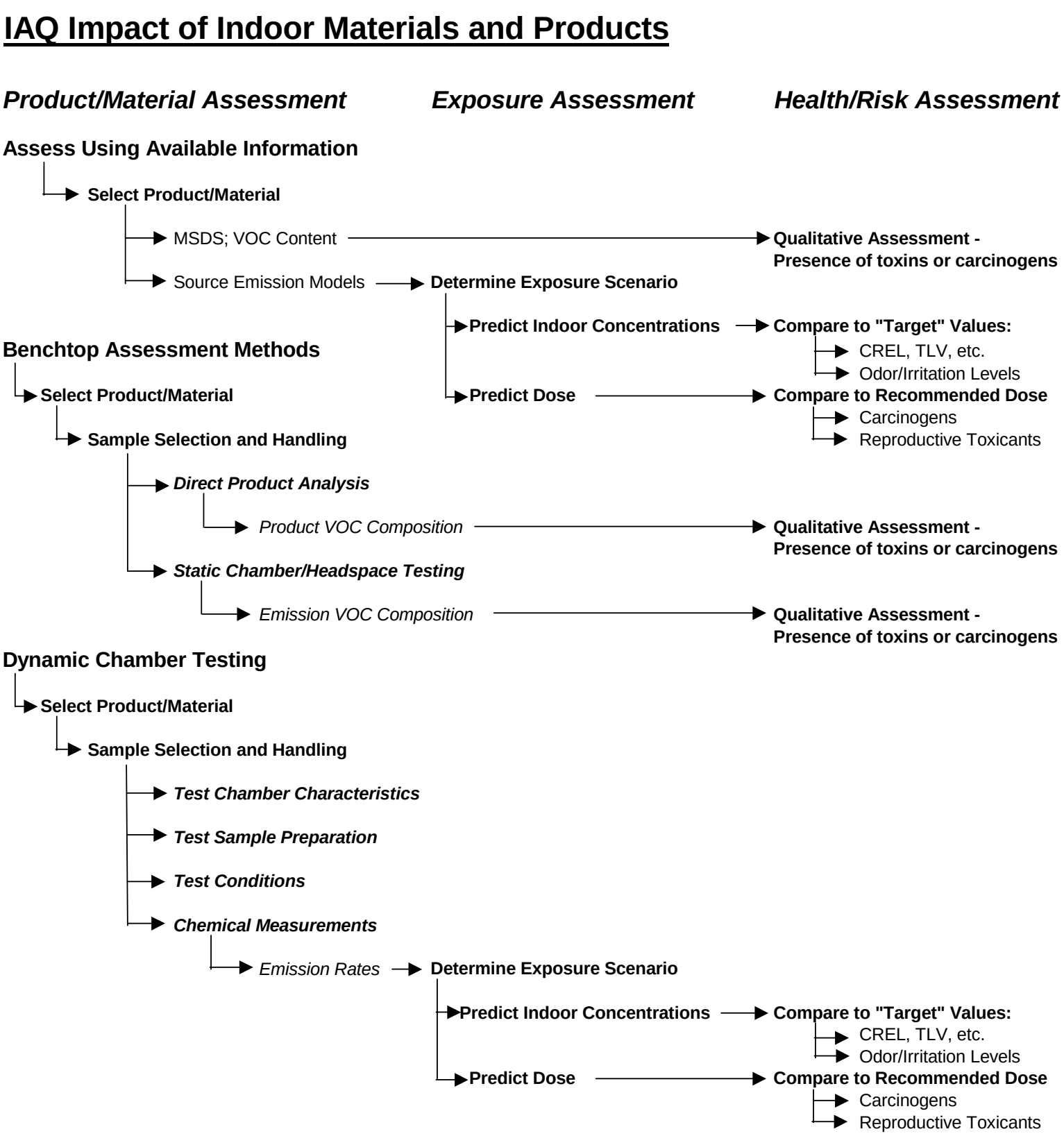
In order to evaluate current and proposed practices used to assess the impact of products on IAQ, an understanding of the fundamental processes involved in assessing the impact of a product or material on IAQ is necessary. For this project, the focus is to develop science-based criteria for evaluating the practices and methods that can be used to determine the impact to IAQ and occupant health from consumer use of a product indoors. Assessment programs that do not assess IAQ impacts are beyond the scope of this project.

This report describes and defines criteria to be used to evaluate assessment programs or methods that evaluate materials and products to determine their impact on indoor air quality and occupant health, with an emphasis on VOC emissions. To evaluate a product with respect to IAQ and occupant health, three major segments of assessment are considered:

- Product/Material Assessment
- Exposure Assessment
- Health/Risk Assessment

Within these three major segments of assessment, numerous categories have been identified and evaluation criteria developed. The relationships between the various assessment segments and categories are presented in Figure II-1. Detailed diagrams of each segment are provided in Appendix A.

Figure II-1. Overview of IAQ Impact of Indoor Materials and Products



B. Ten Basic Questions

An understanding of the fundamental concepts and processes involved in assessing the impact of a product or material on indoor air quality is necessary in order to evaluate a specific assessment program. The following section provides a brief discussion of emission assessment and testing principles in the form of answers to basic questions. Additional details are provided in Appendices B and C.

1. Why Assess/Test Indoor Products and Materials?

The ultimate impact that a material or product has on the indoor environment depends on the compounds emitted and their associated effects on the occupants. Thus, IAQ product assessments must include consideration of their emissions. The specific products assessed for IAQ as well as the type of assessment or testing needed is dependent on either the purpose of the evaluation (e.g., to understand the impact of products widely used in certain building types such as schools) or the needs of the requestor (e.g., industry wants to understand its products; federal, state, or local governments want to develop policies to protect the public; environmental organizations And other interested parties want to promote healthy products; etc.).

2. How Do Testing and Assessment Differ?

For the purposes of this report, assessment and testing are defined as follows:

Assessment - a process that provides information useful to the consumer/user of a material or product with respect to its impact on indoor air quality.

Testing – a process that subjects the material or product to a specific procedure to obtain information on its emissions to the indoor environment. Examples include: direct analysis, extraction, static headspace, and dynamic chamber testing.

Thus, *testing* can be part of an *assessment* program, but all *assessment* programs do not include *testing*.

It is important to understand the purpose of the testing/assessment program. *Assessment programs* can range from a reliance on available information to determine the potential for VOC emissions to a complex risk assessment program involving extensive testing. *Testing programs* can range from those requiring few samples to programs needing large numbers of tests. For example, a product labeling program might be developed to determine if the emissions from a given product category fall within a predetermined range. In this case, a single sample covering a limited number of chemicals might be sufficient. On the other hand, a comprehensive risk assessment covering chronic and acute health effects, as well as sensory impacts, over the "life of the product" would require long-term, multiple sample testing covering a myriad of potential chemical emissions. This would be coupled

with sophisticated exposure modeling followed by risk assessments covering numerous health effects end points. These two examples point out the wide differences that exist in the spectrum of indoor air product testing programs.

3. What Types of Products/Material are Assessed/Tested?

Any indoor material with measurable emissions is a candidate for assessment, and both dry and wet materials and products are tested to determine their emissions. Dry materials, which include the majority of materials used to construct and furnish residential and commercial environments, have relatively low emission rates that decay slowly. Dry materials include wood products, floor covering (carpet, vinyl, etc.), wall covering (wallpaper, fabric), ceiling materials, insulation, and upholstery. Compared to dry materials, wet materials generally have high initial emission rates (based on the VOC content of their solvents) that decay rapidly. As the materials dry, the emission rates decrease. Wet products include architectural coatings (latex and alkyd paints, stains, varnishes, etc.), adhesives, caulks and sealants, and cleaning/maintenance products.

4. What is Emitted?

The first goal of almost any assessment or testing program is to determine what pollutants (VOCs) are or may be emitted from the indoor product or material. Some testing/assessment programs target specific VOCs; others identify a broad range of compounds. The ultimate impact that a material or product has on the indoor environment depends on the compounds emitted and their health effects.

5. How Much is Emitted and What is the Emission Rate?

Information on the amount and rate of VOCs emitted from a product or material is needed to calculate the exposure to these compounds by the user or occupant. Emission rates may be constant or they may vary over time. Emission factors are defined in terms of mass per unit of material per time period (e.g., $\mu g/m^2$-hr). As noted below, information on emission rates is needed to determine the concentration of a given VOC in an indoor space where the product or material is used.

6. What Affects the Emission Rates?

Many factors affect the emission rates of VOCs from indoor materials. Some of the factors are related to the source, others are dependent on the environment where the source is used or tested. The factors fall into three categories:

Mass Transfer Processes - evaporation, sorption, diffusion, convection
Environmental Variables – temperature, humidity, air change rate (ventilation), air velocity and turbulence
Product Characteristics and Composition – number and types of chemical in product, chemical properties, product complexity, and manufacturing processes.

(See Appendix B - Processes and Factors Affecting Emission Rates for additional details.)

7. What Emission Assessment/Testing Methods are Used?

Many methods are available for determining emissions from indoor materials, ranging from use of available information to full-scale testing in dynamic test chambers:

Use Available Information – MSDS, VOC content
Source Emission Models
Benchtop Laboratory Studies – direct product analysis, static headspace
Dynamic Chamber Studies

8. How are Emission Rates Calculated?

Dynamic chamber test results are used to determine emission rates of individual VOCs and TVOC. Three types of emission rate calculations are generally used: *Constant emission rates, First order decay, and ASTM direct calculation method*. Appendix C – Calculating Emission Rates from Dynamic Chamber Data – provides detail on these three techniques.

9. What is the Occupant Exposure?

Source emissions information is used in IAQ models to calculate the indoor concentrations of specific pollutants. The models may be simple one-compartment models with constant emission and ventilation rates, or they may be more complex models that account for variable emissions and ventilation parameters and include "sink effects" (USEPA, 2001b; Sparks, 2005; Dols and Walton, 2002: Walton and Dols, 2003). The modeled concentrations are coupled with occupant location and exposure time to predict occupant exposures.

Based on the emission characteristics of the indoor sources, the exposures are calculated for the VOCs emitted. Exposures are reported for both maximum concentration and time weighted average concentrations. The occupant age, weight, body area and breath volume and frequency are used to determine inhalation and dermal exposure doses.

10. What is the Occupant Health Risk?

A variety of health effects can be related to pollutant exposure, including acute and chronic toxicity, cancer, reproductive effects, and odor/irritation. The calculated exposures are compared to available health effects information including dose-response data. Many organizations have published extensive information on the health impact of exposure the air pollutants, including: US Environmental Protection Agency (USEPA, 2005c), International Agency for Research on Cancer (IARC, 2004), National Institute for Occupational Safety and Health (NIOSH, 2004), American Conference of Governmental and Industrial Hygienists

(ACGIH, 2005), and California Office of Environmental Health Hazard Assessment (California OEHHA, 2005a & 2005b).

Most of the available data on health effects of air pollutants were developed for outdoor air pollutants. The application of these criteria to indoor air pollutants must be done with caution. It is also noted that many pollutants emitted from indoor sources are not represented on the various lists referenced above.

C. Report Structure

The structure of the report follows the general flow shown in Figure II-1. For each category within the testing/assessment process, important factors are identified and discussed. Criteria useful for evaluating the merits and completeness of the category are provided and discussed, including appropriate technical justifications.

At appropriate points, tables are used to present the information. The tables provide three functions: 1) they provide a convenient summary of relevant information within a category; 2) they highlight important factors used to evaluate various testing/assessment program components; 3) they provide a mechanism for comparing assessment programs by use of quantitative and qualitative evaluation procedures. Methods are presented (see Section VI) showing how the criteria can be used to rate existing assessment programs.

Throughout the report, relevant sources are referenced and where possible, Internet addresses are given for easy access to the cited material. Appendices are used to provide extra information and details.

III. EVALUATION CRITERIA

This section describes and defines criteria to be used to evaluate programs that assess materials and products to determine their impact on indoor air quality and occupant health, with an emphasis on VOC emissions. As discussed above, the relationships between the various assessment categories are shown in Figure II-1 and Appendix A. Evaluation criteria are recommended for categories within the three major assessment segments: A) Product/Material Assessment, B) Exposure Assessment, and C) Health/Risk Assessment. Within each segment, numerous categories have been identified and criteria developed. The evaluation criteria are presented in the form of tables. "Pros and Cons" of various methods and procedures are presented. The structure of the report follows the order described by the flow charts. The numbers and letters used to separate the various sections of the report are simply organizational tools and are not meant to imply priorities or significance.

A. Product/Material Assessment

As shown in Figure II-1, the first step in the overall IAQ evaluation process is to assess the emission potential of the materials and products used indoors, including the following parameters: *what is emitted* (i.e., the composition of the emissions), *how much is emitted* (i.e., the mass emitted) and *how fast are the emissions* (i.e., the emission rate). Product/material assessments to obtain this information can range from a limited evaluation of product content to full-blown product testing in dynamic chambers. The following material will describe four basic techniques for assessing products to determine their potential impact on indoor air quality: *use of available information, source emission models, benchtop laboratory methods, and dynamic chamber testing*. In each case, information is presented on how the techniques are used to determine the emissions. Criteria for evaluating each technique are provided, as well as the "Pros and Cons" of the various procedures associated with the evaluation methods. First, the selection of products and materials for evaluation is discussed.

1. Selection of Products and Materials

How are product/materials selected for assessment? Any indoor product or material that emits pollutants is a candidate for assessment of its impact on IAQ and health. Although the list of potential candidates would include almost every building material and product used indoors, the specific products assessed for IAQ are usually dependent on either the purpose of the evaluation (e.g., to understand the impact of products widely used in certain building types such as schools) or the needs of the requestor (e.g., industry wants to understand its products; federal, state, or local governments want to develop policies to protect the public; environmental organizations and other interested parties want to promote healthy products; etc.). For example, the carpet industry assesses carpets, the manufactured wood product industry tests particleboard; the State of California has programs focused on materials widely used in permanent and portable classrooms and in State office buildings. In addition, product

labeling and certification organizations can determine which materials are assessed based on emission potential and/or the needs of their clients. Finally, the emission potential of the product or material may be considered.

2. Assessment Techniques Using Available Information on Product

One technique for assessing the emission potential of a material or product is to determine the composition of the product. This information on *product content* can provide insight into the possible composition of the emissions. For example, the solvents used in many products (e.g., paints, cleaners, waxes/polishes) are emitted during product use. Also, the active ingredients in products such as room deodorizers are designed to be emitted to the indoor air. Thus, the product content can be used to determine potential emissions, assuming that the chemicals in the product will be emitted to the indoor environment. The first step in evaluating the composition of a product or material is to determine what information is available. Two commonly used sources of information on product content are available for many products and materials: Material Safety Data Sheets (MSDS) and manufacturer's data on volatile organic compound (VOC) content.

a. Material Safety Data Sheets

OSHA (the Occupational Safety and Health Administration) requires that Material Safety Data Sheets (MSDS) be prepared for materials or products containing known hazardous substances (OSHA, 2005). MSDS are developed both for raw materials used to produce a product (e.g., solvents) and for finished products. The purpose of the MSDS is to provide the product user with information on the hazards associated with the material contained in the product. The use of MSDS for IAQ evaluations centers on the chemical make-up of the product and associated health effects. From the standpoint of IAQ, the presence of hazardous ingredients indicates the potential for emissions and subsequent exposure. MSDS contain a wealth of information (MSDS Online, 2005). While a strict format for MSDS is not required, OSHA expects the following information to be included, if it is available. Note that only some of this information is useful for assessing the potential impact on IAQ. The items noted with an asterisk would be of interest to an IAQ evaluator.

*Chemical-Product Information** – Identity and use of the product. (Useful for determining indoor uses. For example, many paints are designated for exterior use only.)

Manufacturer's Name and Contact Information – Name, address and phone number; MSDS date and preparer.

*Hazardous Ingredients** – List of hazardous components by name and CAS; percentage composition of components; OSHA PEL (permissible exposure limit) and/or other recommended exposure. (This information is critical to assessing emission potential and possible health effects.)

*Health Hazard Data** – Route of entry (skin, eye, inhalation, ingestion); health hazards (toxicity, carcinogenic, reproductive effects); symptoms; emergency and first aid procedures. (This information is useful in determining the health hazards and exposure mechanisms.)

*Physical/Chemical Characteristics** - Boiling point, vapor pressure, vapor density, specific gravity, melting point, evaporation rate, water solubility, physical appearance and odor. (These data may be useful as input for source emission models – see below.)

Fire and Explosion Hazard Data – Flash point, flammability limits, extinguishing media, firefighting procedures, fire and explosion hazards.

*Reactivity Data** – Stability, conditions to avoid, material incompatibility, hazardous decomposition and/or polymerization. (This information may be useful in evaluating the potential for secondary emissions due to product breakdown and reactions.)

Precautions for Safe Handling and Use – Spill mitigation procedures, waste disposal methods, storage and handling precautions.

Control Measures – Respiratory protection; ventilation requirements; protective gloves, eyewear, clothing, equipment; work/hygiene practices.

Other information, such as ecological effects, other toxic effects, and regulatory control may also be available. Appendix D provides a sample MSDS form with complete information needs (Environmental Health and Safety Online, 2005). MSDS for a multitude of products and materials are available on the Internet. Several sites provide access to MSDS by links to the manufacturers (Vermont SIRI, 2005; Cornell University, 2005). The Household Products Database, by NIH, provides the capability to search for MSDS data by product categories (NIH, 2005a). This database also provides a link to TOXNET, which provides a wealth of health effects information (NIH, 2005b; see below).

Information from MSDS to evaluate potential emissions from indoor material and products should be used with caution. While MSDS information is supposed to be complete, accurate, and up-to-date, only limited reviews of submitted MSDS are conducted. MSDS for many products are incomplete. Also, changes in manufacturing processes and chemicals can occur before MSDS are corrected. In addition, MSDS may not reflect changes in the designated hazardous material list or the most current health hazard information. In summary, users of MSDS should carefully review the information and use it with care.

b. Product VOC Content

Limits on the VOC content of a variety of materials and products have been established by various regulatory bodies under the Clean Air Act in response to the need to alleviate smog formation through photochemical reactions. However it should be noted that many organic compounds have been specifically exempt from these regulations because of low volatility or low reactivity in the formation of smog, including methane, ethane and a number of chlorinated and fluorinated compounds (USEPA, 2004c).Because these exempt chemicals may still may cause adverse health impacts, products designated as low VOC may have hazardous emissions and the labeling of products as low- or no-VOC may be misleading from an indoor air quality perspective.

Under the Clean Air Act, the "VOC content" of certain products must be reported. Paints and coatings VOC limits have been established by EPA, state regulators, and local/regional air pollution control districts. The VOC content of paints and coatings is reported as grams of VOC per liter of product (or lbs/gal) and can be determined by EPA Method 24 (USEPA, 2000). EPA has also set VOC limits on a number of consumer products used indoors, including: air fresheners, bathroom and tile cleaners, cooking sprays, dusting aids, fabric protectants, floor polishes/waxes, furniture maintenance products, general purpose cleaners, glass cleaners, hair care products, adhesives, insecticides, laundry pre-wash, nail polish remover, oven cleaners, shaving creams, and deodorant/antiperspirants (USEPA, 1998a). For these products, the VOC content is reported as weight-percent VOC and is determined by the manufacturer based on the chemicals used to make the product.

Product content may also be available from the manufacturer, although such information is generally considered proprietary. Product labels are usually void of product content information unless required by regulation. As noted above, EPA's Source Ranking Database can be used to obtain information on VOC constituents (USEPA, 2004a).

c. Cautionary Note

As discussed above, several information sources on the VOC content of products and materials are available, including: MSDS, VOC content regulations, and various databases on the Internet. Thus, evaluation of products using available information is facilitated by a variety of data sources. It must be noted, however, that there are several potential problems with using available information. First, the available information is often incomplete. For example MSDS only deal with known hazards; many VOCs will not be listed. Care must be taken when using available product information to ensure its completeness and accuracy. Second, some pollutants not contained in the product may be in the emissions. For example, paints may emit formaldehyde from biocides, even thought the paint and the biocides do not contain formaldehyde. Third, this method of determining emissions will almost always be incomplete, because identification of emitted compounds will be uncertain, and information on emission rates is lacking. Fourth, VOC content information provides no data on individual compounds, many of

which may be toxic or carcinogenic. Also, VOC limits based on photochemical reactivity do not reduce emissions of many compounds known to be hazardous. Finally, no information on the amount or rate of emissions is provided, making a true exposure assessment impossible.

In the end, the use of available information to assess the IAQ impact of a product or material must be considered a judgment call. The assessor needs to evaluate both the quality and quantity of the available information. The more limited the available information, the weaker the assessment. Table III-1 identifies the major information needed to make an assessment based on available information. If the answers to most questions are "Yes", the assessment can proceed. If little or no information is available, an assessment cannot be performed.

Table III-1 – Evaluation Criteria for Product Assessment Using Available Information

Evaluation Criteria	Yes	No
MSDS available		
Hazardous ingredients listed		
Product composition provided		
Exposure limits given (PEL, TLV, etc.)		
Health hazard information		
Route of entry		
Toxicity		
Carcinogenicity		
Reproductive effects		
VOC content provided		
Paint/coating (gm/liter, lb/gal)		
Consumer product (% VOC by weight)		
Other information provided by manufacturer		

Table III-1 is the first of many tables in this report. It provides a convenient summary of relevant information on product assessment using available information and can be used as checklist for evaluating whether critical information is available. In addition, Section VI and Appendix F provide guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

"Pros and Cons" of Product Assessment Using Available Information.

PROS – *Simple; information is available from the manufacturer or Internet.*
- *Inexpensive; information is usually free.*
- *Fast; no waiting for test results or data analysis*.

CONS – *Only potential emissions identified; no data on actual emissions.*
- *MSDS Information may be inaccurate, incomplete, and out-of-date.*
- *VOC content data does not include many potentially hazardous compounds.*
- *No information is provided on the amount or rate of emissions.*
- *Assessments must be considered approximate and qualitative.*
- *No quantitative exposure assessment possible*

3. Source Emissions Models

As noted above, information from MSDS or VOC content cannot be used to determine source emissions. For many sources, models have been developed for predicting source emissions. Many empirical and theoretical models are available for determining emission rates. Theoretical models use equations describing mass transfer processes (see Appendix B), while empirical models assume a particular behavior that is not related to a specific mass transfer process. These models have parameter estimates that are derived from research studies, mostly using dynamic chamber tests.

a. Canadian Study

Examples of the use of both empirical and mass transfer models are shown in a recent Canadian study that provides emission rate equations, including coefficients, for a variety of common building materials, including: dry materials (particleboard, plywood oriented strand board, solid wood, gypsum wallboard, acoustic ceiling tile, vinyl flooring, carpet and carpet pad) and wet materials (wood stain, polyurethane varnish, adhesive, caulking sealant, floor, and paint) (Won *et al*, 2003). Samples of all of the above materials were tested in small dynamic chambers, and the emissions data were analyzed using three emission rate equations.

Emissions from the dry materials were assumed to follow an empirical *power law decay* model:

$$EF_t = at^{-b} \qquad \text{(III-1)}$$

where a and b are empirical coefficients derived from fitting the chamber data to equation (III-1).

The emissions from the wet materials were segmented into three emission regimes.

From $t = 0$ to $t = t_1$, the emissions were described by a mass transfer model shown in equation (III-2). This model was published in 1993 (Tichenor *et al*, 1993) and later applied to latex paint emissions (Sparks et al, 1999a).

$$EF_t = K_m[(C_v(M_t/M_0) - C_t] \quad \text{(III-2)}$$

where, K_m = mass transfer coefficient (m/h), C_v = initial vapor pressure ($\mu g/m^3$), C_t = concentration at time, ($\mu g/m^3$), M_0 = initial mass at the surface available for evaporation ($\mu g/m^2$), M_t = mass available for evaporation at time, t ($\mu g/m^2$).

From $t = t_1$ to $t = t_2$, the emissions were assumed to follow a first order decay:

$$EF_t = EF_0 e^{-k(t - t1)} \quad \text{(III-3)}$$

For $t > t_2$, the emissions were assumed to follow a power law decay, per equation (III-1).

Two examples are given here to illustrate how the coefficients derived from the chamber study are used to predict emission rates over time. In the first example, plywood emissions of five compounds yielded the following coefficients for the power law decay equation:

Compound	a	b
α-pinene	0.155	0.348
Camphene	0.025	0.530
3-carene	0.019	0.161
p-cymene	0.010	0.329
Limonene	0.021	0.308
TVOC	0.391	0.176

Using these coefficients in equation (III-1) provides the emission factors plotted in Figure III-1.

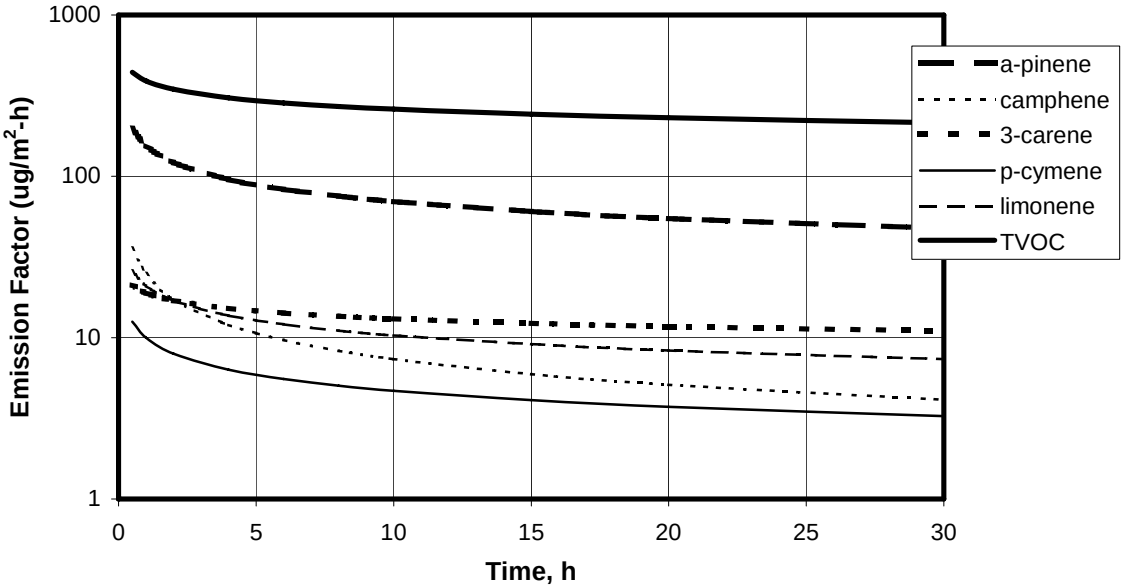


Figure III-1 – Emission Factors for Plywood based on Power Law Decay

The second example uses coefficients derived from testing a wet source, namely an oil based wood stain. The following coefficients were obtained by fitting the chamber data. Note that the units given previously apply, except for mass, which is in mg.

Compound	M_0	K_m	C_v	E_{t1}	E_{t2}	t_1	t_2	k	a	b
Nonane	1615	1.16	1377	43.0	2.13	5	24	0.158	23493	2.93
Decane	6077	1.10	2547	154	16.2	8	24	0.141	8515	1.97
Undecane	3502	1.02	998	134	18.9	8	24	0.122	2689	1.56
Dodecane	223	0.943	48.8	9.68	4.73	8	24	0.0448	649	1.55
TVOC	40794	1.13	18685	888	108	8	24	0.131	18429	1.62

The appropriate coefficients were used in equation (III-2) for $t < t_1$, in equation (III-3) for $t_1 < t < t_2$ (using the solutions in Tichenor *et al*, 1993), and in equation (III-1) for $t > t_2$ to obtain the emission factors plotted in Figure III-2. In addition, the TVOC emission factors from a previous USEPA study of wood stain (Sparks *et al*, 1991) that followed a first order decay (EF_0 = 20,000 mg/m^2-h, k = 0.4 h^{-1}) are shown for comparison purposes.

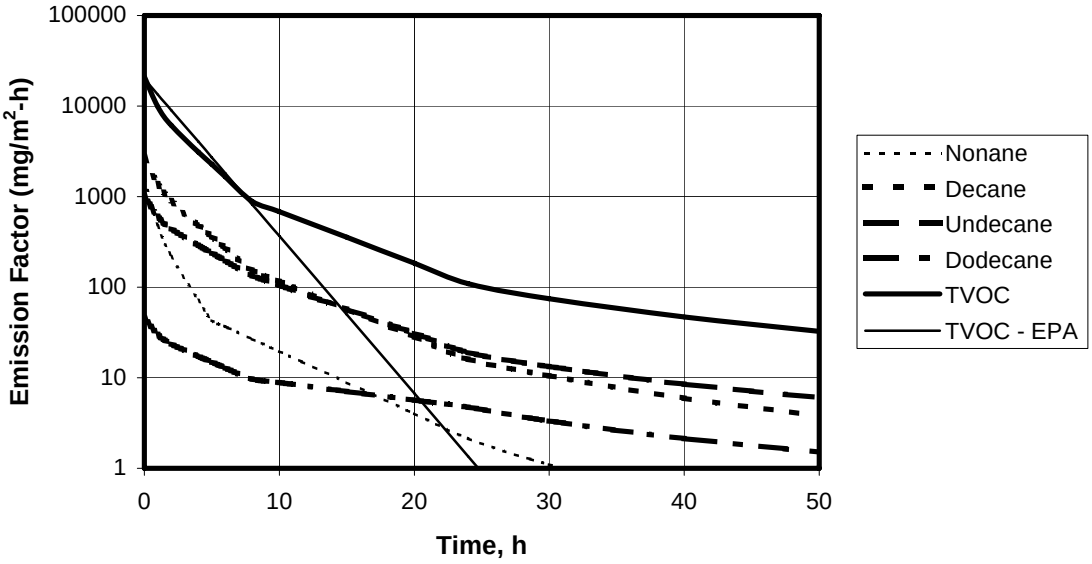


Figure III-2 – Emission Factors for Wood Stain based on Three Emissions Models

These results are presented to illustrate how various emission rate equations can be applied and how emission rates can vary over time. The IAQ literature contains a multitude of studies giving source emission models and test results.

b. Guo Literature Review

Guo presents an excellent summary of emission models found in the IAQ literature, including empirical and theoretical approaches for both wet and dry sources (Guo, 2002a). A total of 52 models are presented:

- 9 empirical multi-purpose models, including constant emission rate, first order decay, second order decay, and power law decay;

- 9 mass transfer and empirical models for paints and coatings, including latex and alkyd paints;

- 4 empirical models for building materials, including formaldehyde from particleboard;

- 9 mass transfer models for building materials, including vinyl flooring and carpets:

- 7 mass transfer models for solvent spills;

- 6 mass transfer models for emissions from household water, including showers, washing machines, and dishwashers;

- 4 mass transfer models for indoor pesticides; and

-4 empirical models for miscellaneous sources, including incense burning and kerosene heaters.

In a companion paper, Guo presents information on how to estimate the many parameters associated with these models (Guo, 2002b). In many cases, numerical estimates of parameters from published studies are provided. Another source of physical and chemical constants needed for solving some of the mass transfer equations is the EPI (Estimation Program Interface) Suite developed by EPA as a tool for exposure assessment (USEPA, 2004b). While a wide variety of source emission models are available, for the most part these models are primarily used by indoor emissions researchers and are not commonly applied to typical product evaluations.

c. Combination Source Models and IAQ Simulators

In some cases, source emission models are combined with IAQ simulation models. For example, EPA's Wall Paint Exposure Model – WPEM (USEPA, 2001a) uses information on paint composition and application parameters to predict occupant and painter exposure to paint emissions. Specific emissions models are used depending on the type of paint (i.e., alkyd or latex). The emission model parameters are based on chemical properties and emissions test results. The WPEM results are presented in terms of exposure; emission rates and concentrations are not reported. Another example of combination source models and IAQ simulators is the USEPA Indoor Environment Management Branch group of models called IAQX, which stands for Simulation Tool Kit for Indoor Air Quality and Inhalation Exposure (USEPA, 2001c). The package contains five stand-alone simulation programs that cover a number of different emission sources. IAQX output is expressed in concentration, but emission rates are not shown. More details on WPEM and IAQX, as well as other IAQ and exposure models, are provided later in the Exposure Assessment section.

d. Cautionary Note

While *source emission models* are useful tools to estimate indoor exposures, care must be taken in their use. The user must ensure that the model is applicable to the particular source of interest. For example, both the amount and rate of emissions from wet sources can vary widely depending on the chemical composition. Therefore, using an empirical model (e.g., 1^{st} order decay) based on tests of similar products may lead to erroneous results. As shown above, emission rates can vary over time, requiring the use of several source models to capture the time history of the emissions. However, in most cases, only a single source emission model is used. As will be discussed later, the most commonly used emission model assumes a constant emission rate. For some sources, this simple model is adequate, but in many cases more realistic models are needed. The most reliable source emissions models have been validated with appropriate tests. Care must be taken, however, if the test conditions (e.g., temperature, ventilation rate) are different from the scenario being modeled. As with any model, faulty input data will

yield erroneous results. Care must be taken to ensure reliable input parameters. Finally, experience in evaluating model outputs is useful. The user should be able to recognize unreasonable model results. In practice, source emission models are not widely used as part of a source assessment program due to the lack of experience and expertise in using them. Table III-2 provides a convenient summary of relevant information on source emission models and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-2 – Evaluation Criteria for Source Emission Models

Evaluation Criteria	Yes	No
Source information available		
Chemical composition		
Application rate (e.g., kg/m^2 for paint)		
Empirical models		
Parameters available		
Model validated		
Theoretical models		
Coefficients available		
Model validated		
All model inputs available		
Model results are "reasonable"		

"Pros and Cons" of Product Assessment Using Source Emission Models

PROS – *Inexpensive; information is usually free.*
- Fast; no waiting for test results or data analysis.
- Provides results useful for exposure assessments

CONS – *Expertise in applying source emissions models is needed*
- Experience in assessing model outputs is necessary (i.e., must be able to recognize unreasonable results)
- Potential errors due to faulty input data
- Models should be validated for specific source of interest
- Calculation methods not widely used

4. Sample Selection and Handling

If available information and/or source emission modeling are insufficient to assess the potential product emissions, then further data on emissions and subsequent IAQ

impacts must be obtained. This involves analysis and testing of samples of the material or product of interest. As discussed in detail below, there are two types of testing possible: *benchtop laboratory methods* and *dynamic chamber testing*. For both of these methods, proper selection and handling of the product sample is required. The following section describes the information needed to insure suitable samples for evaluation.

a. Location of Sample Collection

A variety of locations for collecting samples are possible – point of manufacture, distribution facility, retail outlet, end-user. The location of the sample collection point depends on the nature of the material and on the purpose of the assessment.

If the purpose of the assessment is to determine product emissions and compare them to similar products, then the sample should be taken from the manufacturing facility to avoid any changes in emissions due to product handling or storage. On the other hand, if the purpose of the assessment is to determine the impact on the end-user, the sample should be obtained from a retail outlet or directly from the user.

In general, the nearer in space and time the sample is to the point of manufacture, the less the opportunity for contamination and change in emission characteristics. This is especially true for large surface area products (e.g., carpet) and less true for wet samples in closed containers (e.g., paint). The manufacturing facility should be considered the default sampling location.

b. Type of Sample

The type of sample depends on the product or material being assessed, on the purpose of the assessment, and on the testing procedure to be used.

For wet products (e.g., paint, cleaners, adhesives), full containers are generally collected. The material in the container is applied to the test substrate in an appropriate manner (see below) prior to testing.

For flooring products (e.g., carpet and carpet pads, vinyl, linoleum, etc.) specified sizes (e.g., 2 ft. by 2 ft.) are designated. These samples may be cut into smaller sizes to accommodate the chamber used in the testing program.

For office furniture or workstations, complete assemblages are used in large chambers if the purpose of the testing is to obtain a complete emission profile or to compare emissions between comparable units. In addition, specifications are needed to define comparable units. For example, workstations would be comprised of specific areas of desktop, open shelving, drawers, etc. (Levin *et al*, 2000). On the other hand, sub-samples of the furniture or workstation components can be tested in small chambers to evaluate how different materials can affect overall emissions.

Office machines are tested in large chambers under simulated operating conditions. Thus, the "sample" to be tested includes the machine (e.g., copier, printer, computer) and required supplies (e.g., paper, toner, ink). In addition, a standardized operating sequence is designated (e.g., x copies/hour of a specific set of characters).

c. Sample Size

Sample size can mean two different things: a) the *number* of samples and b) the *physical size* of the sample (i.e., area, volume, weight).

The *number of samples* collected depends on the demands of the testing program. For some products (e.g., office furniture/workstations and office equipment), a single sample per manufacturer may be sufficient. For products to be tested in small chambers, multiple samples may be collected to allow variations in product emissions to be evaluated. Usually, however, products tested for compliance with emissions limits (i.e., for product labels) require only a single sample per product type per manufacturer.

The physical size of the sample depends on testing requirements and on the need to collect a representative sample. For products with large surface areas (e.g., carpet, wood products), spatial variations in emissions can exist. Such variations can cause differences in emissions between two sub-samples of the same material. The larger the sample area, the smaller the variations between samples of a given material. Multiple sub-samples can be tested to evaluate the within material variation in emissions. For materials tested in small chambers, a small sub-sample is generally obtained from the original sample; the size of the sub-sample is established by the size of the chamber and the required loading ratio (see below).

d. Sample Collection Frequency

Emissions from a given product or material can change due to variations in product content, design, component suppliers, and/or manufacturing equipment or process. In order to ensure that emissions are not changing over time, periodic sampling is required. For example, quarterly or annual samples are often required for labeling programs (CRI, 2005; GEI, 2005). In addition, most labeling programs require additional samples be tested when changes are made in the product's composition or construction or in the manufacturing process.

e. Sample Collection Personnel

Several options are available – manufacturer, testing laboratory, end user/consumer – depending on the location of the sampling and the type of sample:

i) If the sample is collected at the manufacturing facility, there are two options: i) a representative of the manufacturer can obtain the sample if it is packaged to prevent contamination (e.g., a can of paint) or if the representative is properly trained to handle

and package the sample (see below) on a routine basis (e.g., periodic carpet samples), ii) if special handling is required or if the sampling is non-routine, personnel from the testing laboratory should collect the sample.

ii) If the sample is collected at other locations, personnel from the testing laboratory should collect the sample.

iii) The end user or consumer should not collect samples for testing. Often consumers want samples tested because of IAQ problems the user attributes to a specific product or material. Usually, however, the product or material has been contaminated or altered by use so that any emissions testing results would not reflect emissions of a new product. If testing is conducted due to a consumer complaint, the testing lab should collect an appropriate sample of the "suspect" material or product.

f. Sample Preservation, Packaging, Transportation, and Conditioning

For many products, emissions can change over time due to "normal" decay in the emission rate, re-emissions of contaminants, or changes in environmental conditions. (See Appendix B for discussions of the effect of environmental variables on emission rates). Thus, it is important to collect and handle the sample in a manner that minimizes changes in its emission characteristics. For products in containers (e.g., paint) little or no product preservation is required.

For many materials, however, the challenge is to preserve the sample from time it's collected to the time it's tested. This normally involves packaging the sample in a non-emitting, non-adsorbing material. Since the emission rates of many materials decay over time, transportation time from the sampling location to the testing laboratory should be minimized.

g. Sample History

The product history should be documented, including the manufacturer and the location and date of production. Product information such as product ID, model number, material composition, MSDS, VOC content, etc. should also be obtained. Sample history would include date and location of sample acquisition and transportation dates.

Table III-3 summarizes the factors and criteria for proper sample selection, collection, and handling. It can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-3 – Evaluation Criteria for Sample Selection and Handling

Evaluation Criteria	Yes	No
Product/material manufacturer		
Identification		
Location		
Manufacture date		
Sample collection		
Location		
Location consistent with project objectives		
Collection date		
Sample size (area, weight, volume, etc.)		
Number of samples		
Collection frequency		
Collection personnel		
Name		
Contact information		
Sample handling specified		
Sample preservation		
Sample packaging		
Sample transportation requirements		
Transportation dates		

5. Benchtop Laboratory Test Methods

Relatively simple benchtop laboratory methods are available to evaluate potential emissions from indoor materials and products. Some methods use *direct product analysis* to determine the chemical make-up of the material. As discussed above, the chemical constituents in a product can be potential emissions. Also, static *headspace analysis* can be used to measure the chemical composition of emissions, but not the emission rate. The benchtop methods discussed below use various analytical methods to identify and measure the various chemicals in the products or associated headspace. References for some of these methods are given; details on the other sampling and analysis techniques are presented later in this report.

a. Direct Product Analysis

When the available information on the content of the product is insufficient to allow an assessment, *direct product analysis* may be conducted. Direct product analysis involves subjecting the product to an appropriate analytical procedure. For example, wet products can be diluted and injected into a gas chromatograph (GC) to determine the

chemical make-up of the product. Test methods for such procedures for various products and materials are available from ASTM (2005) and the USEPA. Methods for determining VOCs in paints, inks, and related coatings have been published by ASTM (ATSM, 1989). EPA Method 24 (EPA, 2000) provides techniques for determining the VOC content of surface coatings and Method 311 (EPA, 1996) tells how to analyze paints and coatings for hazardous air pollutants (HAP) by direct GC injection. VOCs in dry or semi-solid materials can be solvent extracted prior to examination by GC methods. Test methods developed for solid waste analysis can be used (USEPA, 2005a). Information obtained by direct product analysis does not provide specific information on emissions, but it can be used for *product content* assessments or in *source emission models*, as discussed above. Data from direct product analysis should be more complete than from MSDS, if the full spectrum of chemicals in the product is determined.

"Pros and Cons" for Direct Product Analysis

PROS – *Relatively simple analysis*
- *Relatively inexpensive (assuming laboratory equipment is available)*
- *More complete information than MSDS*

CONS – *Only potential emissions identified; no data on true emissions.*
- *VOC content analysis may not include many potentially hazardous compounds*
- *No information is provided on the amount or rate of emissions.*
- *Assessments must be considered approximate and qualitative.*
- *No quantitative exposure assessment possible*
- *Expertise in chemical analysis is required*

b. Headspace Analysis

Headspace analysis is used to determine the emission potential of products and materials. Static headspace testing is conducted by measuring the VOC content in the vapor overlying a liquid (e.g., in the space between the lid and the paint in a paint can) or solid (e.g., in a closed container containing a sample of material). Static headspace testing is conducted on closed containers and provides information on the equilibrium concentration of VOCs in the vapor, for example - EPA Method 3810 (USEPA, 2005b). Generally, headspace analyses are conducted at ambient temperatures (e.g., 23^{o}C), however they may be conducted at elevated temperatures to increase the VOC concentration. When evaluating the emission composition of headspace analyses conducted at elevated temperatures, it should be noted that the relative magnitude of various components could change due to differences in vapor pressures. The headspace data provides information on the composition of the VOC emissions of the material or product (i.e., what's in the emissions). Thus, headspace analysis can be used to assess the emission potential of a given product directly, without the uncertainty associated with product content data. Unfortunately, static headspace testing does not provide information on emission amounts or rates and cannot be used to make estimates of occupant or user exposure to the emissions.

"Pros and Cons" for Static Headspace Testing

PROS – *Provides information on emission composition*
– *Relatively simple analysis*
- *Relatively inexpensive (assuming laboratory equipment is available)*

CONS - *No information is provided on the amount or rate of emissions.*
- *Assessments must be considered qualitative.*
- *No quantitative exposure assessment possible*
- *Expertise in chemical analysis is required*

Table III-4 summarizes the criteria for evaluating direct product analysis and static headspace tests to determine IAQ emissions from indoor material and products. It can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-4 – Evaluation Criteria for Direct Product Analysis and Static Headspace Testing

Evaluation Criteria	Yes	No
Direct product analysis		
Test method specified (e.g., EPA Method 311)		
Analytical equipment identified		
VOC content reported		
Individual compounds identified		
Static headspace analysis		
Test method specified (e.g., EPA Method 3810)		
Analytical equipment identified		
VOC emissions reported		
Individual compounds identified		

6. Dynamic Chamber Test Methods

Dynamic chamber testing involves the determination of the emissions from indoor materials and products under controlled environmental conditions, and the results can be used to conduct exposure assessments. Dynamic chamber tests are used to determine both the composition of the emissions and the emission rates. (ASTM, 1997; ASTM 2001; CDHS, 2004). Appendix E identifies a number of international standards for evaluating indoor emissions.

a. Dynamic Test Chamber Operation

Dynamic chamber tests are used to determine both the composition of the emissions and the emission rates. A typical dynamic chamber test is conducted as follows:

- The material to be tested is placed in the chamber and the chamber door is closed.

- Clean air flows through the chamber. The chamber air is well mixed.

- The source emits pollutants into the chamber.

- Samples of air are taken at the chamber outlet.

The following schematic (Figure III-3) illustrates a typical emission test using a dynamic chamber:

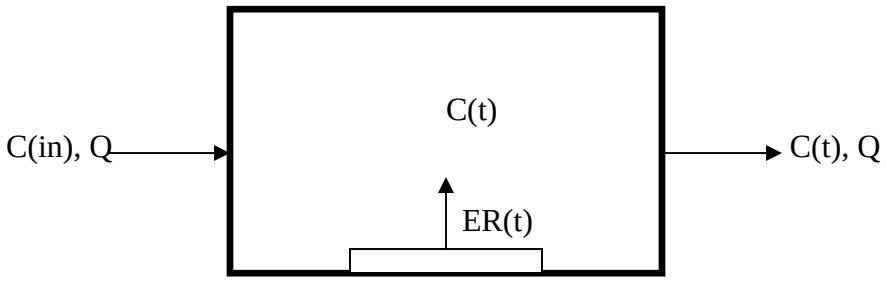


Figure III-3 – Dynamic Test Chamber Schematic

The relationship between the concentration, C, and the emission rate, E, is described by the following mass balance equation:

$$V[dC(t)/dt] = ER(t) - Q[C(t) - C(in)] \qquad \text{(III-4)}$$

where, using typical units, V is the chamber volume (m^3), C(in) is the VOC concentration in the inlet air ($\mu g/m^3$), C(t) is the VOC concentration in the chamber at time t ($\mu g/m^3$), Q is the flow through the chamber (m^3/h), and ER(t) is the VOC emission rate ($\mu g/h$). (See Appendix C – Calculating Emission Rates from Dynamic Chamber Data - for more details.)

Small dynamic chambers (0.05 – 1 m^3) are used to test samples of products and material, while larger chambers (up to 50 m^3) can test full sized assemblages (e.g., office workstations) or equipment (e.g., copy machines). Dynamic chamber testing is the most common method used to determine emission rates of indoor materials and products. When compared to the methods discussed above, dynamic chamber testing is likely to

provide more accurate and complete emissions profile data. Also, compared to the above methods, it is more complex, time consuming and costly. Additional details on factors concerning dynamic chamber testing are given below. Note that many of the details associated with testing specific indoor materials and products are not presented (e.g., sample sizes, sampling times, target lists of chemicals). The reader is encouraged to consult the references if a more comprehensive treatment is required.

b. Dynamic Test Chamber Characteristics

Dynamic test chambers systems designed and operated to evaluate emissions from indoor materials and products must possess certain characteristics as described in the appropriate ASTM standards (ASTM, 1997; ASTM 2001).

i) Construction materials - Adsorption to and desorption from chamber surfaces ("sink" effects) can modify the concentration vs. time measurements of product emissions and cause the calculated emission rates to be in error (Dunn and Tichenor, 1988; Tichenor, 2004). These errors would adversely affect the accuracy of subsequent exposure predictions and health/risk assessments. Therefore, all interior surfaces, including door seals, shall be non-adsorptive, and non-reactive vis-à-vis any chemical emissions to be measured. Stainless steel is the most common chamber construction material. Glass chambers are also used, although glass may irreversibly adsorb some polar compounds.

ii) Environmental controls - The chamber system must be capable of operating with in specified limits of temperature, humidity, and airflow rate. (See Table III-7 for recommended values.) As discussed in Appendix A, each of these parameters can affect the emission rate depending on the mass transfer mechanism.

iii) Air supply - The chamber air must meet specific limits of VOC content. Typical VOC limits for the chamber air supply are: $< 2\ \mu g/m^3$ for individual VOCs and $< 25\ \mu g/m^3$ for total VOCs. Clean air is important so that material emissions can be determined. Many materials have low emission rates that would be difficult to evaluate if the VOC content of the chamber air was high. Air purification systems are used to supply the required clean air. Such systems include activated carbon filters and/or catalytic oxidizers. HEPA filters can be used to provide particulate control.

iv) Air tightness - Chambers should be operated under slight positive pressure to prevent infiltration of outside air. Contamination from outside air would distort the emissions measurements. A positive pressure of 10 Pa is sufficient.

v) Sampling locations - In small chambers, air samples are taken at the chamber outlet. For large chambers, multiple sampling ports can be used depending on the test conditions. For example, if an emission rate were required for a complete office workstation, a single sampling location in a well-mixed chamber would be sufficient. On the other hand, if the chamber air were not well mixed, several sampling locations would be needed to determine the concentration variations within the chamber.

vi) Well-mixed air - For small chambers, the air should be well-mixed. This is usually accomplished by using diffusers at the inlet and outlet to provide turbulence. Well-mixed air is required to ensure that the air sample taken at the outlet represents the average concentration in the chamber (see above). The emission rate calculation procedure (see Appendix C) assumes a well-mixed chamber. For large chambers, well-mixed air is used for most tests. If, however, the effect of different ventilation strategies (e.g., displacement ventilation) is being investigated, the air will not be well-mixed.

vii) Air velocity and turbulence levels - The air velocity and turbulence in the chamber can affect the emission rate (see Appendix B). For wet sources with evaporative mass transfer, higher velocities and turbulence levels can increase emission rates. In these cases, low speed fans can be used to obtain appropriate velocities (i.e., < 0.2 m/s). When emissions are limited by diffusion (i.e., most solid material, dried paint, etc.), velocity is not a critical parameter. Many chamber tests are conducted without velocity measurements, although simple measurements with hot-film or hot-wire anemometers are possible.

Table III-5 provides a convenient summary of relevant information on dynamic test chamber characteristics and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-5 – Evaluation Criteria for Dynamic Test Chamber Characteristics

Evaluation Criteria	Yes	No
Construction		
Non- adsorptive, non-reactive interior surfaces		
Stainless steel		
Glass		
Non-adsorptive, non-reactive seals		
Air tight construction		
Well-mixed air		
Fan		
Inlet/outlet diffusers		
Environmental controls		
Temperature control		
Humidity control		
Flow control		
Air supply		
VOC control – activated carbon		

VOC control – catalytic oxidation		
VOC control - other		
Particulate control – HEPA filters		
Sampling locations		
Small chamber – at outlet		
Large chamber – multiple locations		

c. Test Sample Conditioning and Preparation

The conditioning and preparation of the sample can affect its emission characteristics.

i) Sample conditioning - Once delivered to the testing laboratory, the sample should be maintained in environmentally conditioned space until it is tested. This involves maintaining acceptable levels of temperature (23°C +/- 2°C), humidity (50% +/- 10%), ventilation rate ($\geq$ 2 ACH), and ambient VOC concentrations ($\leq$ 5 $\mu g/m^3$ for individual VOCs and formaldehyde; $\leq$ 25 $\mu g/m^3$ for TVOC). These values are provided for guidance and may be varied if sample contamination can be shown to be prevented with less stringent controls. Environmental control criteria (air flow, temperature, relative humidity) should be measured and recorded continuously; VOC and formaldehyde content should be measured on a weekly basis. The sample should be kept in its packaging until testing to prevent contamination.

ii) Sample preparation - Prior to testing in dynamic chambers, samples may require additional preparation:

Avoid edge effects - Some products (e.g., particleboard, gypsumboard) may have higher emissions from the edges (ASTM, 1997). When samples of such materials are tested in small chambers, the edges are sealed with a non-adsorbent material (e.g., sodium silicate) to ensure that the emissions are limited to the exposed surface. Carpet samples can also have edge effects, so they are generally placed in trays with edges the same height as the carpet thickness. In some cases (e.g., when testing complete assemblages such as workstations), exposed edges may contribute to emissions in actual usage. In these instances, treatment of the edges consistent with use is required.

Use appropriate application method - When testing wet materials, the method of applying the materials to the test substrate can affect the emission rate. In general, the testing lab should use the method most commonly employed when the product is used in the "real world." For paint, several methods are available including, brush, roller, spray, or slit applicator. Each method will give slightly different emission rates due to mass of material applied per unit area and paint film thickness. For adhesives, specialized devices are employed depending on the use of the product. Both saw tooth and square tooth applicators are commonly used. For caulk, a caulking "gun" is used to spread a bead. In all cases, the mass of material applied is determined by weighing the sample substrate before and after the material is applied.

Use appropriate test substrate - Emissions from wet material are affected by the substrate they're applied to. For example, paint applied to a non-porous material (e.g., glass, stainless steel) will have much different emission characteristics than if it were applied to gypsumboard or wood (Sparks et al, 1999a). Thus, the testing laboratory should select a test substrate consistent with the product's use in the "real world." In addition, emissions from a sample of bare substrate should be determined to ensure that any substrate emissions are accounted for.

Table III-6 provides a convenient summary of relevant information on test sample preparation and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-6 – Evaluation Criteria for Test Sample Preparation

Evaluation Criteria	Yes	No
Edge effects avoided or treated consistent with use		
Edges sealed or treated consistently		
Sample tray used		
Application method defined		
Paint – brush, roller, spray, slit applicator		
Adhesive – saw tooth or square tooth applicator		
Caulk – bead applicator (caulking "gun")		
Test substrate specified		

d. Testing Conditions

Chamber testing is conducted under strict protocols that require adherence to specific parameters. Prior to testing, a test plan is developed that specifies the test parameters, the sampling times, and the QA/QC requirements. Table III-8 provides numerical recommendations for many of the parameters discussed below.

i) Environmental variables - Three variables - temperature, humidity, air change rate – are controlled within specified limits.

ii) Inlet air conditions - The VOC level in the inlet air must be maintained within specified limits. The limits may be established for specific individual VOCs and for total VOCs.

iii) Chamber pressure - A positive chamber pressure must be maintained at or above a specified limit.

iv) Sample size and loading factor - The sample area is usually determined by the loading factor (sample area/test chamber volume) achieved in practice. For example, a wall-to-wall carpet in a 3 m by 4 m room with a 2.5 m ceiling has a loading factor of 12/30 = 0.4 m^2/m^3. Thus, for a 100 liter (0.1 m^3) chamber, the sample size would equal (0.4 m^2/m^3) x (0.1 m^3) = 0.04 m^2. This would be equivalent to a 20 cm by 20 cm square. If wet samples are tested, the weight of the sample is also determined (see above).

v) Sampling times - Chamber air samples are taken at times prescribed in the test plan. For materials with slowly changing or constant emission rates, a single sample may be collected at a specified time (e.g., 96 hours). For wet material with rapidly decaying emission rates, multiple samples may be required (e.g., 1, 2, 4, 8, 16, 32 hours). Note that the sampling time is measured from the start of the test and is considered the mid-point of the sample collection period. For example, a sorbent sample (see below) collected by drawing chamber air through a sampler starting at 5.5 hours from the start of the test and ending at 6.5 hours would be considered the 6-hour sample. Note that duplicate samples are often required for quality control purposes.

vi) Quality Assurance/Quality Control (QA/QC) - Accuracy and precision of testing conditions will be defined in the test plan and measured periodically during the test. The following parameters will have QA/QC limits established and reported: temperature, humidity, chamber air flow, chamber pressure, and sampling air flow.

Table III-7 provides a convenient summary of relevant information on dynamic chamber testing conditions and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-7 – Evaluation Criteria for Dynamic Chamber Testing Conditions

Evaluation Criteria	Target Value	QA/QC Limits Accuracy / Precision
Environmental variables		
Air flow	1.0 ACH*	±0.03ACH / ±0.05ACH
Temperature	23°C	±0.5°C / ±1°C
Relative humidity	50%	±5% / ±5%
Velocity over sample surface	0 – 0.2 m/s	Based on method used
Inlet air quality		
Specified individual VOCs	< 2 μg/m^3	±2 μg/m^3 / ±15% RSD
Formaldehyde	< 5 μg/m^3	±2 μg/m^3 / ±15% RSD
Total VOCs (as toluene)	< 25 μg/m^3	±10 μg/m^3 / ±15% RSD

Chamber pressure	10 – 30 Pa	±5 Pa / ±5 Pa
Sample size		
Area	Based on loading	±1% / ±1%
Mass (weight)	-	±1% / ±1%
Sampling times	Mid-point of sampling interval specified	±1% / ±1%

* An air change rate of 1 ACH is a default value. Testing conditions (chamber size, sample loading, and testing goals) may justify different values.

e. Chemical Emissions Measurements

Indoor products and materials can be comprised of and emit a wide variety of pollutants, including a vast array of organic vapors. Products, headspace and chamber air samples are analyzed to determine the identity and quantity of the chemicals emitted. The following material provides limited details on the sampling and analytical methods to evaluate indoor emissions, with an emphasis on dynamic chamber test methods. As discussed above, many of these techniques are also applicable to direct product analysis and static headspace testing. It is emphasized that the information on sampling and analysis techniques is limited and is provided here to highlight categories of methods applicable to emissions testing. References are provided to assist the reader in gaining more complete information.

i) Compounds to be measured - Each indoor material/product has a different set of VOCs and other compounds in its emissions. The challenge for the testing program is to select the appropriate compounds for measurement. For certification or labeling programs, a limited number of compounds are generally targeted for quantification. This "target list" is obtained from preliminary testing conducted to develop the certification program. Some testing programs focus on lists of chemicals with known health effects. The measurement program is designed to identify and quantify all compounds on the "target list." In addition, compounds not on the list that appear as large emission "spikes" may require measurement - for example, any compound that accounts for a given percent (e.g., 10%) of the total chromatogram. Also, the total VOC (TVOC) content of the emissions is often determined.

ii) Sampling methods - A variety of sampling methods are available for collecting chamber air samples, depending on the chemicals of interest and the concentrations. For some VOCs at high concentrations, GC (gas chromatograph) sampling loops can be used to capture chamber air samples. Other "whole air samplers" include syringes and canisters. Usually, however, low chamber concentrations require larger volume samples, and sorbent samplers are employed. Chamber air is drawn through the samplers and the VOCs are adsorbed on the sorbents. The total sample volume is equal to the sampling flow rate times the sampling time. For example, sampling at 300 cc/min for one hour yields a sample volume of 18 liters (0.018 m^3). A variety of sorbents are available for use depending on the VOCs to be measured (USEPA, 1999).

iii) Analytical methods - A variety of analytical methods are available to measure indoor emissions. The following material is a brief overview; the reader is encouraged to consult the technical literature for more details (Winberry et al, 1990; USEPA, 1999).

The *basic instruments* used to measure the organic compounds emitted from indoor materials and products can be place in three broad categories:

Gas chromatograph with flame ionization detector (GC/FID) is used to quantify individual and total VOCs (TVOC). For individual VOCs, response time and peak areas are determined. For TVOC emissions, the value is based on the total area of the chromatogram between specified limits (e.g., C5 to C17; C6 to C16) assuming an FID or GS/MS response to a specific compound (e.g., toluene). While TVOC emissions are generally not associated with specific health effects, they allow comparison between products and are required in several certification programs.

Gas chromatograph with mass spectrometer (GC/MS) measures individual VOCs. GC/MS is the most widely used method for identifying and quantifying individual VOCs emitted from indoor products.

High performance liquid chromatograph (HPLC) is needed to measure formaldehyde and other low molecular weight carbonyl compounds. Samples are collected on DNPH sorbent cartridges. Aldehydes are often of concern in indoor emissions, so HPLC measurements are often required.

For each of these instruments and methods, specified operating conditions are required including temperature programs, GC flow rates, and parameters associated with the sorbent desorption.

iv) QA/QC data - Each method requires QA/QC limits (accuracy and precision) for the following parameters: GC flow rate, sample volume, and mass detected.

Table III-8 provides a convenient summary of relevant information on chemical emissions measurements and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-8 – Evaluation Criteria for Chemical Emissions Measurements

Evaluation Criteria	Yes	No
Compounds to be measured		
Target compounds		
Large “spike” compounds		
TVOC		

Chamber air sampling methods		
Closed loop sampling		
Whole air samples – canisters, syringes		
Sorbent samples		
Analytical methods		
GC/FID – for TVOC		
GC/MS – for individual VOCs		
HPLD – for aldehydes		
Sample volume		
Sampling flow rate (e.g., 300 cc/min)		
Sampling durations (e.g., 1 hour)		

f. Emission Rate Determinations

The main purpose of measuring VOC emissions in dynamic chambers is to determine the emission rates. As shown in Appendix C, a mass balance equation is used to relate the chamber concentration to the emission rate. Several types of emission rate equations are available. The following three methods are the most common models used by testing laboratories to determine emission rates from dynamic chamber tests:

i) Constant emission rate - The most common method used to calculate the emission rate assumes a constant rate over time:

$$ER = (C - C_b)Q \qquad \text{(III-5)}$$

where, using typical units, ER is the emission rate (μg/hr), C is the chamber concentration (μg/m^3), C_b (μg/m^3) is the chamber background concentration, and Q is the air flow rate (m^3/h). The emission rate is often expressed as an emission factor:

$$EF = (C - C_b)(N/L) \qquad \text{(III-6)}$$

where, EF is the emission factor (μg/m^2-hr), N is the air change rate (1/h), and L is the ratio of the sample area to the chamber volume (m^2/m^3).

ii) First order decay rate - For wet sources (and other fast decaying sources) where multiple chamber measurements are made over time, a common way to express the emission factor is via a *first order decay* model:

$$EF_t = EF_0 e^{-kt} \qquad \text{(III-7)}$$

where, EF_t is the emission factor at time t, EF_0 is the emission factor at time 0, and k is the first order decay constant. Values of EF_0 and k are obtained by a least-square curve

fit of the C vs. t chamber data using the mass balance equation (ASTM, 1997). (See Appendix C for calculation procedures.)

iii) Direct calculation - Both the constant emission rate and first order decay methods require and assumption regarding the time behavior of the emission rate. The ASTM small chamber guide (ASTM, 1997) provides a method for calculating the emission rate directly from the chamber data. (See Appendix C for calculation procedures.)

iv) Other calculation methods - As discussed previously in the section on Source Emission Models, a variety of empirical and theoretical mass transfer models are available for describing the emissions from many indoor sources (Guo, 2002a). The parameters and coefficients for many for these models can be determined from dynamic chamber test results. For example, the Canadian study presented earlier used chamber data to obtain the model parameters for two empirical and one mass transfer model for a number of common building materials (Won *et al*, 2003).

Table III-9 provides a convenient summary of relevant information on emission rate determinations and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-9 – Evaluation Criteria for Emission Rate Determinations

Evaluation Criteria	Yes	No
Constant emission rate		
C_b = chamber background concentration ($\mu g/m^3$)		
C = chamber concentration ($\mu g/m^3$)		
N = air change rate (hr^{-1})		
L = chamber loading (m^2/m^3)		
EF = C(N/L) = emission factor ($\mu g/m^2$-hr)		
First order emission rate decay ($EF = EF_0e^{-kt}$)		
Chamber concentration vs. time data provided		
Curve fit program specified		
EF_0 and k determined		
Direct calculation per ASTM method		
Chamber concentration vs. time data provided		
EF provided at all sampling times		
Other calculation method		

"Pros and Cons" for Emission Rate Determination Methods

Constant Emission Rate:

PROS – *Simple to calculate*
- Limited data needed (only 1 data point)
- Most widely used method

CONS - *Large errors can occur if emission rate is rapidly changing*
- Only useful for slowly changing emission rates
- Cannot be used for initial emissions from wet materials

First Order Decay:

PROS - *Widely used method for initial emissions of wet materials*
- Computer programs available to calculate parameters

CONS - *Need multiple data points (6 or more points are recommended)*
- Large errors can occur if emission rate doesn't follow a first order decay

Direct Calculation Method:

PROS - *Does not assume any specific emission rate behavior*
- Calculations possible with electronic spreadsheet

CONS - *Need multiple data points (5 or more points are recommended)*
- Method not as widely used as constant rate and first order decay

Other Calculation Methods:

PROS - *Mass transfer models describe true emission rate behavior*
- Literature contains values for some model parameters

CONS - *Many model parameters not available*
- Calculation methods not widely available
- Usually need multiple data points
- Methods not widely used

g. Recap of Dynamic Chamber Test Method

Since dynamic chamber testing encompasses many categories, a short summary may be useful before presenting the PROS and CONS. The categories presented above are: *test chamber characteristics* (materials of construction, environmental controls, air supply, air tightness, sampling locations, well-mixed air, and air velocity/turbulence); *test sample conditioning and preparation* (edge effects, application methods, test substrate); *testing conditions* (environmental variables, inlet air, chamber pressure, sample

size/loading factor, sampling times, QA/QC*); chemical emissions measurements* (compounds to be measured, sampling methods, analytical methods, QA/QC); and *emission rate determinations* (constant emission rate, first order decay direct calculation, other methods). Each of these categories is discussed above and evaluation criteria are presented. Following are the overall PROS and CONS for dynamic chamber testing:

"Pros and Cons" for Dynamic Chamber Test Methods

PROS – *Provides data on chemical compounds emitted*
- *Provides emission rate data for use in exposure assessment*
- *Data enables quantitative risk assessments*
- *Provides controlled environment for testing*
- *Variable and constant emission rates can be measured*

CONS - *Testing is costly and time consuming*
- *Specialized equipment (chambers, environmental controls) is required*
- *Expertise in chemical analysis is required*

7. Other Chamber Methods

The *CLIMPAC*, a European innovation, is a special dynamic test chamber that couples the chemical determination of the emissions with a sensory output. This chamber is designed to allow human subjects to evaluate the emissions and provide a sensory (e.g., odor) assessment (Gunnarsen *et al*, 1993).

The Field and Laboratory Emission Cell (*FLEC*), also developed in Europe, is a dynamic, micro-chamber (0.000035 m^3) that can be used in the field to determine emissions from flat surfaces (Wolkoff, 1991). Because of the nature of the FLEC's operating characteristics (e.g., very high ventilation rate) it cannot be used for testing wet, evaporative sources (i.e., wet paint), but it is useful for determining diffusion controlled emissions (i.e., dried paint) (Tichenor, 2001). Both the CLIMPAC and the FLEC provide data comparable to "standard" dynamic chamber tests. An ASTM standard has been developed for the FLEC - D7143-05 Standard Practice for Emission Cells for the Determination of Volatile Organic Emissions from Indoor Materials/Products.

Test houses are used as research tools to validate emissions studies conducted in dynamic chambers (Sparks *et al*, 1991). They are instrumented to allow measurement of VOC concentration and air change rates. Test house studies provide data used to validate and refine IAQ models (Sparks *et al*, 1999b). Test houses are quite expensive to maintain and operate and are not generally used to routinely assess the IAQ impact of material and products.

"Pros and Cons" for Alternative Chamber Systems

PROS – ***CLIMPAC*** *– Supplements emission rate data with sensory assessment*
- ***FLEC*** *– Able to provide on-site emission rate data in the field*

- ***Test House*** *- Provides validation data for dynamic chamber tests under "real world" conditions*

CONS - *Systems are not widely used in United States*
- *Testing is costly and time consuming*
- *Specialized equipment (chambers, environmental controls) is required*
- *Expertise in chemical analysis is required*

B. Exposure Assessment

After conducting the Material/Product Assessment to determine the potential emissions of indoor pollutants, the next step in assessing the potential health risk is to conduct an Exposure Assessment. The levels (concentrations) of indoor pollutants to which occupants are exposed are determined by many factors, including: source emission characteristics (i.e., chemical composition, emission rate, decay rate), the interaction of the emissions with interior surfaces (i.e., sink adsorption/desorption), dilution and flushing by outdoor air exchange, and processes designed to remove pollutants (i.e., air cleaners and local ventilation). Occupant exposures to indoor pollutants are a function of the spatial and temporal distribution of the pollutants and the activity patterns of the occupants (Tichenor and Sparks, 1996).

1. Develop Exposure Scenarios

Once the source characteristics are determined, a critical step in exposure assessment is establishing the exposure scenario, including: the volume of the space, the ventilation rate, and the source area (or other measure). For a given material or product, the indoor concentration is a function of room volume, product area and ventilation rate. A change in any of these parameters will result in a change in the concentration. For example, a product with a given emission factor might be used in an office and a school with different volumes, areas, and air change rates giving different concentrations of indoor pollutants. Many factors can affect the scenario parameters. For example, furniture can reduce the effective volume of a room; doors and windows can change the wall areas; ventilation rates can change over time (nighttime ventilation rates are often a small fraction of the daytime rates). Occupant activities have a major impact on exposure – a painter will be exposed to much higher concentrations of paint emissions than someone who enters the space after the paint has dried. Likewise, the time and location of the occupant affects his/her exposure. Finally, sorption to and from indoor sinks can affect concentrations over time and impact occupant exposures. In multi-room environments, HVAC systems can alter indoor concentrations by transferring air and pollutants between rooms.

Table III-10 provides a convenient summary of relevant information on exposure scenarios and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-10 – Evaluation Criteria for Exposure Scenarios

Evaluation Criteria	Yes	No
Source emissions model		
Area (amount) of source given		
Emission rate available		
Spatial dimensions established		
Length		
Width		
Height		
Single compartment		
Ventilation parameters provided		
Constant ventilation (ACH)		
Variable ventilation		
HVAC system operation		
Other factors		
Furniture volume deducted		
Doors and windows accounted for		
Sink effects considered		
Occupant activity patterns		
Location		
Time History		

2. Select IAQ Model

The basic tool used to evaluate occupant exposure to indoor air pollution is the indoor air quality (IAQ) simulation model. IAQ models couple source emissions with ventilation parameters to predict indoor concentrations. Additional calculations are performed to predict occupant exposures in terms of concentration and/or dose (see below). IAQ models range from simple one-compartment, no-sink models to those encompassing multiple rooms, variable emission and ventilation rates, and sink interactions.

a. Constant Emission Rate, Single Compartment, No-sink Model

The simplest and most commonly used IAQ model assumes a single room without sink effects and a constant VOC emission rate. For this model, the indoor concentration of a given pollutant *i* is:

$$C_i = EF_i(A/NV) = EF_i(L/N) \quad \text{(III-8)}$$

where, C_i is the indoor concentration of pollutant *i* ($\mu g/m^3$), EF_i is the source emission factor for pollutant *i* ($\mu g/m^2$-hr), A is the area of the source (m^2), N is the air change rate (1/hr), V is the volume of the space (m^3), and L is the product loading (A/V, m^{-1}). The model is often rearranged as:

$$EF_i = C_i(NV/A) = C_i(N/L) \quad \text{(III-9)}$$

to determine the emission factor that corresponds to a given concentration for a given pollutant. Many assessment program limits are based on a maximum allowable indoor concentration for a specified pollutant, and this equation shows the limiting emission factor.

The following graphs illustrate the effect of various factors on predicted indoor concentrations due to sources in a single room without sink effects and with constant emission rates. Figures III-4 and III-5 show the effect of air change rate (N) on the predicted concentration for various emission factors assuming constant emission rates and a product loading of 0.365 m^2/m^3 (based on flooring in a room with 9 foot ceilings). Figure III-5 uses logarithmic scales to show more detail at the low concentrations.

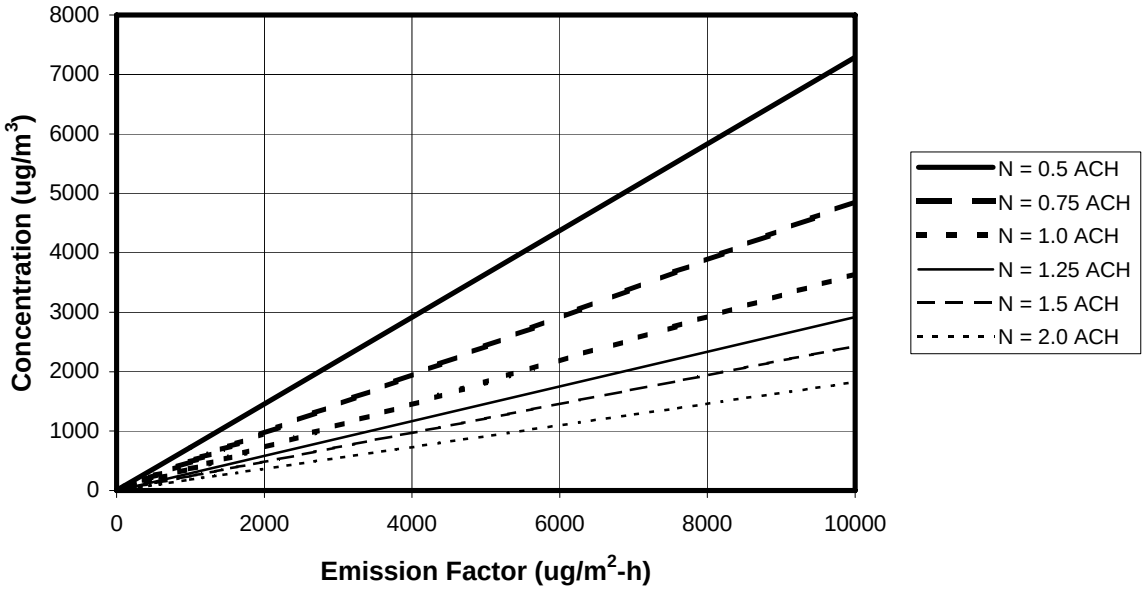


Figure III-4 – Effect of Air Change Rate on Indoor Concentration (Constant Emission Rate) - (Linear Scales)

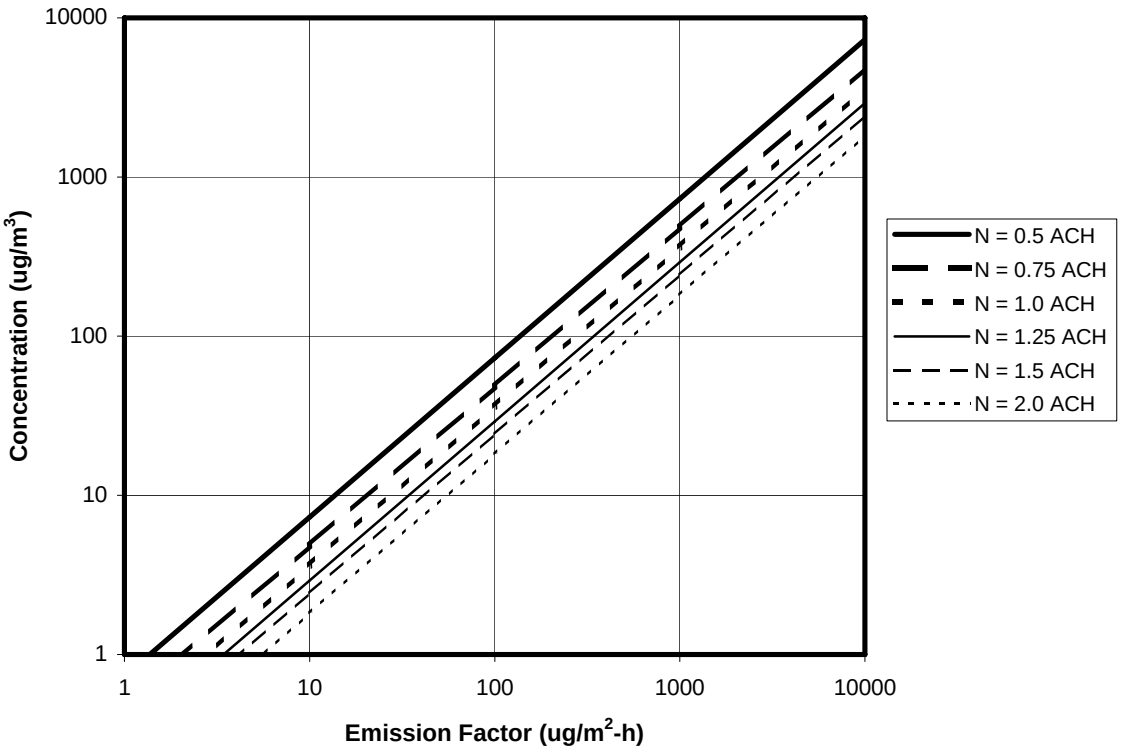


Figure III-5 – Effect of Air Change Rate on Indoor Concentration (Constant Emission Rate) - (Logarithmic Scales)

Figures III-6 and III-7 show the effect of product loading (L) and on the predicted concentration for various emission factors assuming constant emission rates and an air change rate of 1.0 ACH. Figure III-7 uses logarithmic scales to show more detail at the low concentrations.

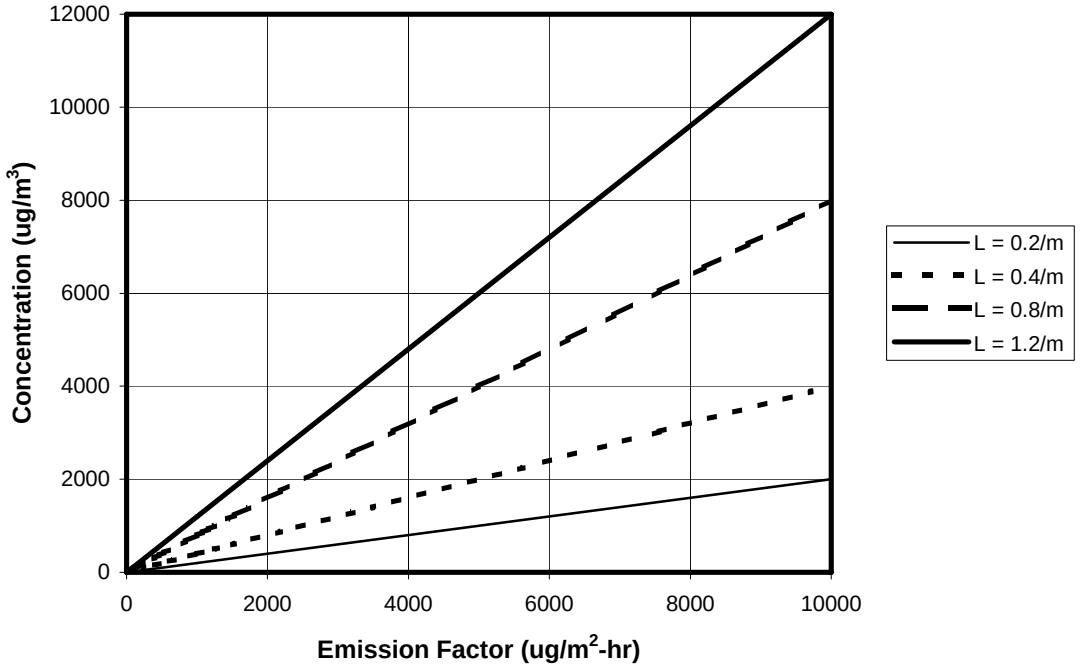


Figure III-6 – Effect of Product Loading on Indoor Concentration (Constant Emission Rate) - (Linear Scales)

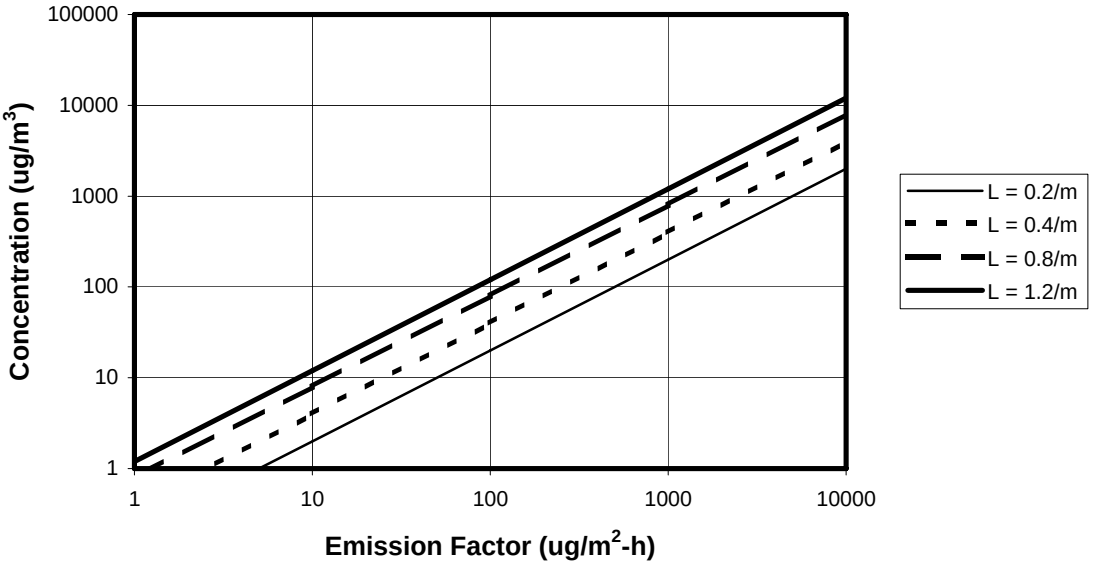


Figure III-7 – Effect of Product Loading on Indoor Concentration (Constant Emission Rate) - (Logarithmic Scales)

b. Variable Ventilation and Emission Rate, Multiple Compartment Models with Sink Effects

Sophisticated and complex IAQ models are available, including: RISK (Sparks, 2005), and CONTAM (Dols and Walton, 2002: Walton and Dols, 2003). These models account for multiple rooms, multiple sources, time varying emission rates, variable ventilation rates, and sink effects. They can be used to analyze complex IAQ scenarios and predict indoor concentrations and occupant exposures to indoor pollutants. The RISK model focuses on sources and sinks and provides the user with multiple source models and recommended model parameters. CONTAM is a sophisticated airflow model that predicts ventilation parameters based on HVAC characteristics, structure geometry and meteorological conditions. Both models predict both concentration profiles. While developed to be "user friendly" via the use of "Windows" data entry forms, these models require considerable experience in developing input data, careful attention to details, and expertise in evaluating indoor emission sources. CONTAM is especially challenging for the novice IAQ modeler.

c. IAQX Models

In order to bridge the gap between the simple one compartment, no-sink model and the complex IAQ models described above, Dr. Zhishi Guo of the USEPA Indoor Environment Management Branch in Research Triangle Park, NC has developed a suite of models called IAQX, which stands for Simulation Tool Kit for Indoor Air Quality and Inhalation Exposure (USEPA, 2001c). The package contains five stand-alone simulation programs:

i) GPS.EXE is a general purpose IAQ simulation program with a library of 25 indoor source and 5 sink models; it also handles chemical reactions.

ii) VBX.EXE implements three models for VOC emissions from solvent-based indoor coating materials; it includes a built-in VOC property database.

iii) SPILL.EXE contains three models for small-scale solvent spills in the indoor environment.

iv) SLAB.EXE implements a mass transfer model (Little *et al,* 1994) for VOC emissions from building materials.

v) PM.EXE predicts indoor particulate matter concentrations; it considers such factors as penetration of outdoor PM, emissions from indoor sources, deposition, ventilation, and filtration.

Each of these models is relatively user friendly and guidance is given to the user to assist in running the model simulations. All the models predict both concentration and cumulative inhalation exposure over time. Many of the models and coefficient estimates

in the IAQX software are from the papers by Guo discussed previously (Guo, 2002a: Guo, 2002b). Table III-11 summarizes some of the models' parameters:

Table III-11 - IAQX Model Parameters

Model	No. of Zones	No. of Sources	No. of Sinks	Ventilation
GPS	10	Multiple	3 per zone	Variable
VBX	3	1	2 per zone	Constant
SPILL	3	1	2 per zone	Constant
SLAB	1	1	No Sinks	Constant
PM	3	Multiple	Deposition	Constant

To illustrate the application of the GPS model, the coefficients from the EPA wood stain study (EF_0 = 20,000 mg/m^2-h, k = 0.4 h^{-1}) presented earlier (Figure III-3) were used in a simple model simulation assuming a first order decay (Equation III-6). Two model runs were conducted assuming two zones. The source was placed in zone 1, and air was exchanged between the two zones and with the outside at 0.5ACH. In one run, a strong reversible sink was used (k_a = 0.5, k_d = 0.3 – see Equation A-2 in Appendix A); in the other run, no sink was assumed. Figure III-8 presents the results of this simulation, showing the difference in concentration between the two zones and the effect of the sink on the concentrations. Note the higher concentrations in zone 1 where the source is located. Also note the initially higher concentrations for the "no-sink" case, but the re-emissions from the sinks cause the concentrations to be higher for the "sink" case later in the simulation.

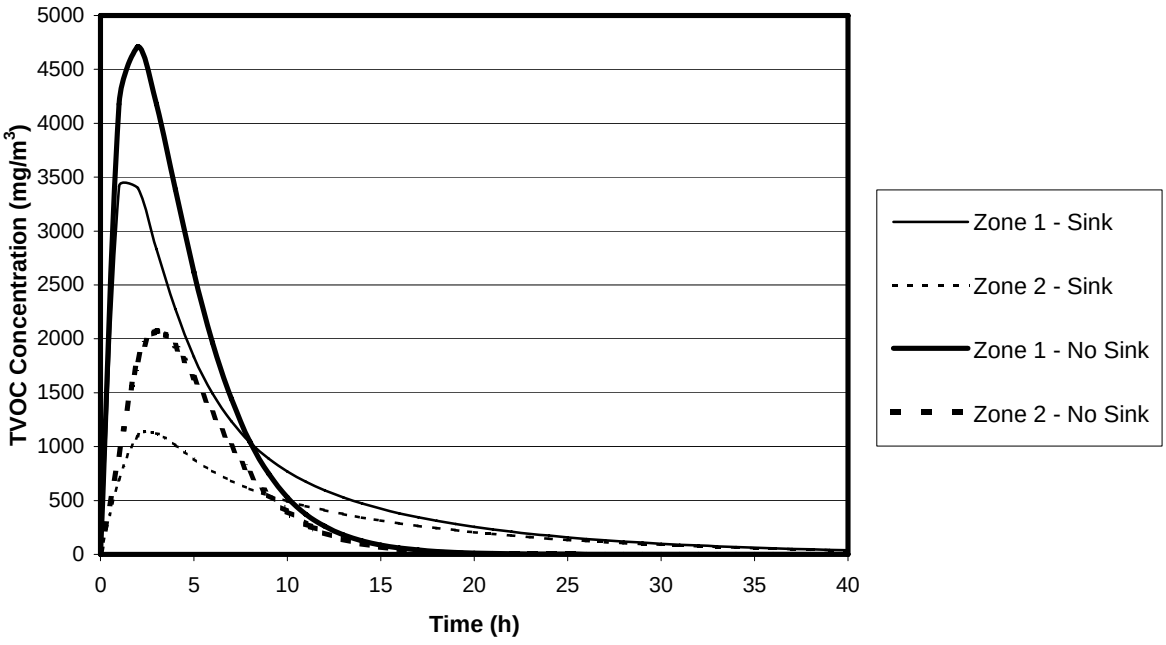


Figure III-8 - GPS Model Results for Emissions from Wood Stain

Table III-12 provides a convenient summary of relevant information on IAQ model selection and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-12 – Evaluation Criteria for IAQ Model Selection

Evaluation Criteria	Yes	No
Source emission model		
Constant emission rate		
Variable emission rate		
Empirical model parameters available		
Mass transfer model coefficients available		
Ventilation rates		
Constant		
Variable		
Compartments/Zones/Rooms		
Single		
Multiple		
Sink effects		
No sinks		
Sink model parameters available		

"Pros and Cons" for IAQ Models

Simple one-compartment, no-sink model:

PROS – *Simple to use*
- *Most widely used method*

CONS - *Large errors can occur for variable emission and/or ventilation rates*
- *Only useful for slowly changing emission rates*
- *Cannot be used for initial emissions from wet materials*
- *Ignores sink effects*

Complex simulation models (RISK & CONTAM):

PROS - *Comprehensive models that account for all important factors*
- *Programs available on Internet*

CONS - *Extensive IAQ modeling experience required*

- *Complex input requirements*
- *Source/sink model parameters may be difficult to determine*
- *Not widely used for exposure assessments*

IAQX Models:

PROS - *Models account for most important factors*
- *Relatively simple to use*
- *Programs available on Internet*

CONS - *Some IAQ modeling experience required*
- *Source/sink model parameters may be difficult to determine*
- *Not widely used for exposure assessments*

3. Occupant Exposure Calculations

Once the concentration of an indoor pollutant is determined, the exposure of a given occupant or user to indoor emissions is predicted as a function of time and location. Both *exposure concentration* and *dose* can be calculated for each pollutant. The following exposure concentrations are routinely calculated: average lifetime exposure, average daily exposure, maximum concentration, average 8 hour exposure, average 15 minute exposure. When concentrations vary with time, each of these exposures may have a different value; for the constant concentration case, only a single value is reported. For IAQ, dose is calculated as inhalation exposure, based on such factors as age, breathing rate and volume, and body weight. Dose is reported as the inhaled mass of pollutant (e.g., total mg or mg/kg body weight) for lifetime exposure, daily exposure, or maximum exposure rate. These parameters are calculated by available IAQ or exposure models.

a. USEPA Exposure Models

USEPA's Office of Pollution Prevention and Toxics (OPPTP) has developed two models that predict occupant exposure to indoor pollutant sources:

i) The Wall Paint Exposure Model (WPEM) uses paint composition information to predict occupant and user exposures for various painting scenarios. (USEPA, 2001a) The model uses the chemical properties (molecular weight, vapor pressure) of the paint components; empirical coefficients for emission rates decay and sink effects (adsorption and desorption rates); building characteristics (volume, ventilation parameters, painted area); and paint application parameters to predict exposures (dose and concentration) to specific VOCs.

ii) The Multi-Chamber Concentration and Exposure Model (MCCEM) predicts exposure to emissions from indoor sources used in residences (USEPA, 2001b). It is limited to four zones per residence. Outdoor air change rates and airflows between zones are specified based on the type of residence and the geographic area of the country (US),

although the user can change the rates. Emission sources are defined by simple emission models (constant emission rate, 1st order emission rate decay, and user defined emission rates), and the user supplies the appropriate model coefficients. Either reversible or irreversible sinks can be used in each zone. A unique feature of MCCEM is the application of Monte Carlo simulations (assuming one of four statistical distributions - normal, triangular, uniform, log-normal) to allow multiple predictions to be made for various values of emission rates, air change rates, and/or sink rates.

b. Model Exposure Calculations

Each of the IAQ and exposure models discussed above calculate specific exposure and/or dose parameters as shown below with typical units:

i) IAQX Models - Each of the IAQX models predicts *instantaneous exposure* (mg/m^3) and *cumulative inhalation dose* (mg). For example, Figure III-8 shows *instantaneous exposure,* and Figure III-9 shows *dose* for the wood stain GPS model runs described above. The dose is based on the occupant being in the space from time zero to the end of the simulation. A breathing rate of 14 liters/min was assumed. Note the higher dose in zone 1 where the stain was applied. Also note the initially higher dose when sinks are ignored, but over time the re-emissions from the sinks equalize the exposure.

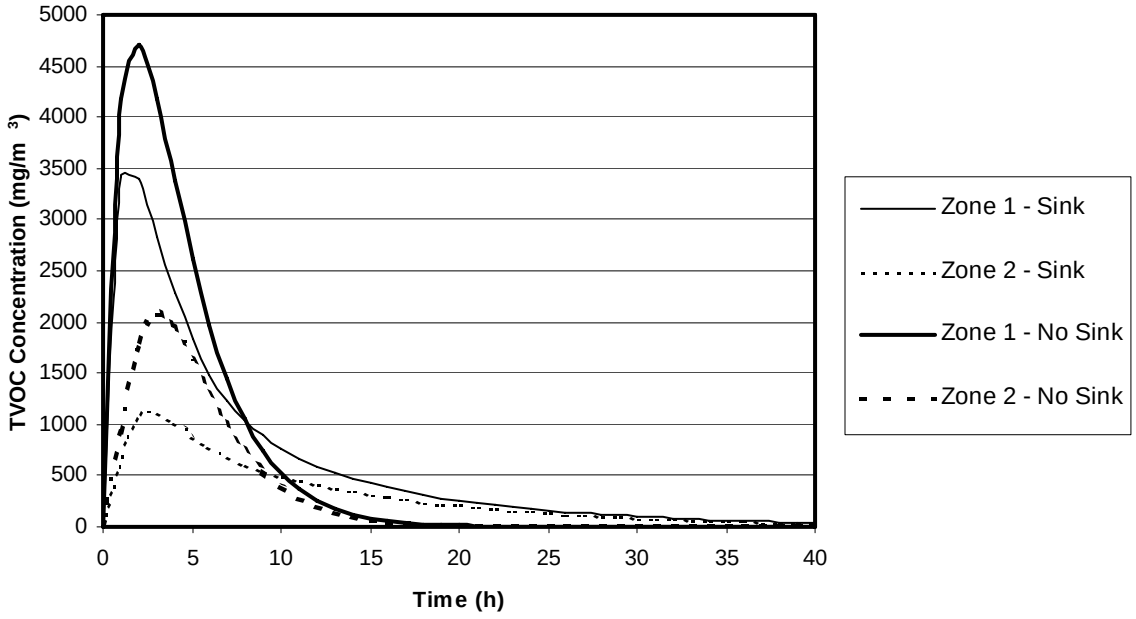


Figure III-9 - GPS Model Prediction of TVOC Dose from Wood Stain Emissions

ii) RISK Model - The RISK model provides predictions of several exposure parameters:

- *Peak concentration* (mg/m^3)
- *Instantaneous exposure* at any time (mg/m^3)
- *Average exposure* for specified (e.g., 8 hours) time period (mg/m^3)

Each of these concentrations is converted to *inhalation dose* (mg) by multiplying by the exposure time (h) and breathing rate (m^3/h). RISK also calculates the exposure time (h) above a specific concentration (e.g., irritation limit). This parameter is used in Denmark's building material labeling program (Wolkoff and Nielsen, 1993).

iii) CONTAM Model - The CONTAM model calculates the following exposure parameters:

- *Peak concentration* (mg/m^3)
- *Instantaneous exposure* (mg/m^3)
- *Cumulative exposure* (mg/m^3-hr)

CONTAM does not calculate dose; the user can use the cumulative exposure results to determine dose.

iv) WPEM Model - The Wall Paint Exposure Model calculates several exposure parameters:

- *Lifetime average daily dose (LADD)* (mg/kg-days)
- *Average daily dose (ADD)* (mg/kg-days)
- *Acute potential dose rate (APDR)* (mg/kg-days) – Highest 24 hour dose rate
- *Time of APDR* (days from start of exposure)
- *Single event dose* (mg)
- *Lifetime average daily concentration (LADC)* (mg/m^3)
- *Average daily concentration (ADC)* (mg/m^3)
- C_{Peak} *(highest instantaneous concentration)* (mg/m^3)
- $C_{15\text{-}min}$ *(highest 15-minute average concentration)* (mg/m^3)
- $C_{8\text{-}hour}$ *(highest 8-hour average concentration)* (mg/m^3)

v) MCCEM Model - The Multi-Chamber Concentration and Exposure Model calculates many of the same parameters as the WPEM model: *LADD, ADD, APDR, time of APDR, single event dose, LADC, ADC, and* C_{peak}. In addition, when Monte Carlo simulations are conducted, the predictions for each of these parameters include the mean, standard deviation, and maximum value.

"Pros and Cons" for Exposure Models

IAQX Models

PROS –*Instantaneous exposure concentrations provided*
- Relatively user friendly

CONS - *Limited number of exposure parameters calculated*

RISK and CONTAM

PROS – *Instantaneous exposure concentrations provided*

CONS - *Limited number of exposure parameters calculated*
- Not user friendly

WPEM and MCCEM

PROS – *Comprehensive set of exposure parameters*
- Specifically designed for exposure calculations
- Relatively user friendly
- MCCEM provides distribution based on Monte Carlo simulations

CONS - *Instantaneous concentration exposures not provided*
- Limited source emission models available

Table III-13 provides a convenient summary of relevant information on occupant exposure and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-13 – Evaluation Criteria for Determining Occupant Exposure

Evaluation Criteria	Yes	No
Exposure model available		
Exposure concentrations determined		
Instantaneous concentrations		
C_{Peak} (highest instantaneous concentration)		
$C_{15\text{-min}}$ (highest 15-minute average concentration)		
$C_{8\text{-hour}}$ (highest 8-hour average concentration)		
Lifetime average daily concentration (LADC)		
Average daily concentration (ADC)		
Inhalation doses determined		

Lifetime average daily dose (LADD)		
Average daily dose (ADD)		
Acute potential dose rate (APDR)		
Single event dose		
Time parameters		
Time of APDR		
Time of peak concentration		
Time of exposure above a specific concentration		

c. Cautionary Note

As discussed above, models can be useful tools in assessing indoor sources, including source emission models, IAQ models and exposure models. All models must be used with care. Attention must be paid to the selection of input parameters, since faulty input data will yield erroneous results. Experience and expertise in developing input data and in evaluating model outputs is essential. The user must be able to recognize unreasonable model results. In practice, only the simplest source emission, IAQ and exposure models are used due to the lack of experience and expertise in employing more realistic, comprehensive and complex models.

C. Health/Risk Assessment

Exposure assessment provides information on the amount (concentration or dose) of a particular pollutant that can affect individuals in specific indoor environments. A *health/risk assessment* requires the identification and quantification of the health hazard associated with this exposure.

1. Health Hazard Identification

A variety of health effects can be related to pollutant exposure, including acute toxicity (e.g., respiratory irritation), chronic toxicity (e.g., cancer), and reproductive effects. Odor is also of interest from an indoor air quality perspective, because individuals often subjectively associate odors with health impacts, even though the presence of an odor from a chemical is not indicative of its toxicity. For a given indoor source, multiple compounds can be emitted resulting in a variety of health effects endpoints. A comprehensive treatment of health effects is beyond the scope of this project, so only a cursory treatment is provided here. A wide variety of information is available on specific health effects of chemical compounds based on dose-response studies. Much of this information is compiled in databases accessible via the Internet.

a. Sources of Health Effects Data

The following provides various sources containing data linking exposure (concentration and/or dose) to specific health effects. As noted previously, most of the available data on health effects of air pollutants were developed for outdoor air pollutants. The application of these criteria to indoor air pollutants must be done with caution. It is also noted that many pollutants emitted from indoor sources are not represented on the various lists referenced below.

i) US Environmental Protection Agency

Integrated Risk Information System (IRIS)

The IRIS database, available on-line, contains dose-response information on over 500 chemical compounds (USEPA, 2005c). Oral reference doses (RfD, mg/kg-day) and inhalation reference concentrations (RfC, mg/m^3) are provided for chronic non-cancer health effects. Oral and inhalation unit risk factors are given for cancer.

Health Effects Assessment Summary Tables (HEAST)

The data in the HEAST documents are often used when IRIS values are not available (USEPA, 1998b).

ii) U.S. National Toxicology Program (NTP) - NTP (2005) evaluates the carcinogenic and reproductive toxicity of chemicals to which US citizens could be exposed. NTP publishes a "Report on Carcinogens" (available on-line) that lists chemicals: i) Known to be Human Carcinogens and ii) Reasonably Anticipated to be Human Carcinogens. NTP's Center for Evaluation of Risks to Human Reproduction (CERHR) provides information on the reproductive effects of chemicals.

iii) The International Agency for Research on Cancer (IARC) - IARC (2004) has evaluated and classified 900 chemicals and mixtures and placed them into 5 groups:

- Group 1 – Known human carcinogen (95 chemicals or mixtures)
- Group 2A – Probable human carcinogen (66)
- Group 2B – Possible human carcinogen (241)
- Group 3 – Not classifiable as a human carcinogen (497)
- Group 4 – Probably not a human carcinogen (1)

iv) National Institute for Occupational Safety and Health (NIOSH) - NIOSH (2005a) is responsible for several databases on hazards associated with airborne pollutants. The NIOSH Pocket Guide (NIOSH, 2004) is a comprehensive reference that contains the following information on 677 chemicals or chemical groups:

- Chemical name, synonyms, trade names, conversion factors
- NIOSH Recommended Exposure Limits (REL, mg/m^3)

- OSHA Permissible Exposure Limits (PEL, mg/m^3)
- NIOSH Immediate Dangerous to Life and Health Values (IDLH, mg/m^3)
- Physical description with chemical and physical properties
- Measurement methods
- Information on health hazards – route, symptoms, first aid and target organs.

Note that both RELs and PELs can be expressed as:

- Time Weighted Average (TWA) values for an 8-hour day, 5 day work week
- Short Term Exposure Limit (STEL) values for a 15-minute exposure.

NIOSH is also responsible for maintaining the Registry of Toxic Effects of Chemical Substances (RTECS). This database is available for a fee from a private contractor (NIOSH, 2005b).

v) American Conference of Governmental and Industrial Hygienists (ACGIH) - ACGIH annually publishes data on TLV (Threshold Limit Values), in terms of TWA and STEL, exposure guidelines for a variety of chemicals and mixtures that are known workplace hazards (ACGIH, 2005).

vi) California Office of Environmental Health Hazard Assessment (OEHHA) - California OEHHA has developed three lists relevant to the assessment of indoor air pollutants:

- The Safe Drinking Water and Toxic Enforcement Act of 1986 (commonly known as Prop 65) requires the state to annually list all "Chemicals Known to the State to Cause Cancer or Reproductive Toxicity" (California OEHHA, 2005a). The latest list has over 600 chemicals listed.

- A list of Chronic Exposure Levels (CREL, $\mu g/m^3$) for 79 chemicals presented as non-binding guidelines for new office buildings (California OEHHA, 2005b).

- A list of odor thresholds (ppm) and irritation characteristics for 60 VOCs known or suspected of being emitted from building materials and cleaning products (Alevantis, 1999).
- In addition, California OEHHA publishes a list of acute exposure levels (California OEHHA, 2005c).

vii) National Institutes of Health/National Library of Medicine (NIH/NLM) - NIH's National Library of Medicine operates TOXNET, an integrated system of toxicology and environmental health databases that are available on the web (NIH, 2005b). The following databases are available for searching via TOXNET:

- HSDB (Hazardous Substances Data Bank) contains information on over 4,800 toxic or potentially toxic chemicals in such areas as toxicity, environmental fate, human

exposure, chemical safety, waste disposal, emergency handling, and regulatory requirements.

- TOXLINE is a bibliographic database covering the biochemical, pharmacological, physiological, and toxicological effects of drugs and other chemicals. It contains over 3 million citations, almost all with abstracts and/or index terms and CAS Registry Numbers.

- ChemID*plus* provides access to structure and nomenclature information for over 368,000 chemical records, of which over 235,000 include chemical structures.

- IRIS by USEPA, described above.

- ITER contains data in support of human health risk assessments. It contains over 600 chemical records and provides a comparison of international risk assessment information in a side-by-side format and explains differences in risk values derived by different organizations. ITER data, focusing on hazard identification and dose-response assessment, contains links to the source documentation.

-CCRIS (Chemical Carcinogenesis Research Information System) is a data bank sponsored by the National Cancer Institute. It contains data and information related to carcinogens, mutagens, tumor promoters, cocarcinogens, metabolites and inhibitors of carcinogens on over 8,900 chemicals.

- GENE-TOX is a data bank created by the Environmental Protection Agency (EPA) with genetic toxicology test results on over 3,000 chemicals.

- DART/ETIC (Developmental and Reproductive Toxicology/Environmental Teratology Information Center) is a bibliographic database covering teratology and developmental toxicology literature published since 1950.

Links to each of these databases are found on the TOXNET web page. In addition, the TOXNET "Multiple Databases" option allows for simultaneous searching of HSDB, IRIS, CCRIS, and GENE-TOX.

viii) Agency for Toxic Substances and Disease Registry – ATSDR provides Minimum Risk Levels (MRLs) for acute and chronic effects of inhalation exposure for a large number of hazardous substances (ATSDR, 2005).

ix) American Industrial Hygiene Association (AIHA) – AIHA publishes Emergency Response Planning Guidelines (ERPG) levels for a variety of potential indoor air pollutants (AIHA, 2005).

b) TVOC vs. Individual Compounds

Indoor source emissions are often reported for both TVOC and individual VOCs. While data linking exposure to individual VOCs are available, the link between TVOC and health is more tenuous. Early studies by Molhave demonstrated a correlation between health/comfort and TVOC (Molhave, 1986). More recently, Molhave (2003) has indicated that the "TVOC concept is based on several assumptions and its usefulness for prediction of health effects of mixtures in undocumented." Furthermore, he states "TVOC cannot be used for normal regulatory risk assessment. There is just too little scientific basis for this and no Dose-Response relations have been established." The fact remains that TVOC is still widely used to certify products for indoor emissions, especially as an indication of a "low emitting product".

Table III-14 provides a convenient summary of relevant information on health hazard identification and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-14 – Evaluation Criteria for Health Hazard Identification

Evaluation Criteria	**Yes**	**No**
Specific health effects		
Toxicity		
Acute		
Chronic		
Cancer		
Reproductive effects		
Odor/Irritation		

2. Qualitative or Quantitative Assessment?

Two types of health/risk assessments are possible depending on the type of information developed on indoor sources. A *qualitative assessment* is conducted when specific exposure information is not available, but information on the compounds emitted from the indoor sources is accessible. A *quantitative assessment* is performed by comparing the predicted exposure parameter (concentration or dose) to published limits based on dose-response studies. Even though the databases contain literally thousands of compounds, in many cases, health effects data on a specific compound will not be found. In such cases, a qualified toxicologist or other professional can be consulted to determine if analogous compounds can be used to make the assessment.

a. Qualitative Assessment

Three types of product/material assessments result in qualitative information on emissions: *use of available information*, *direct product analysis*, and *static headspace analysis*. These assessments indicate specific compounds that could occur in the emissions from a given product, but do not provide predictions on the emission mass or rate. Thus, only qualitative health/risk assessments are possible. Qualitative health/risk assessments are conducted by determining if the potential compounds emitted are found on specific lists of toxic or hazardous pollutants. This is accomplished by searching the relevant databases for each potential compound and noting the specific health effect. Since no quantitative exposure data is available, no further evaluation is possible.

Table III-15 provides a convenient summary of relevant information on qualitative health assessment and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-15 – Evaluation Criteria for Qualitative Health Assessment

Evaluation Criteria	Yes	No
Potential source emissions identified		
Compounds found in database		
Specific health effect noted		
Toxicity		
Acute		
Chronic		
Cancer		
Reproductive effects		
Odor/Irritation		
Compound not found in database		
Analogous compound identified/found in database		

b. Quantitative Assessment

Product/material assessments leading to quantitative emissions estimates include: *source emission models*, *dynamic chamber tests*, and *other chamber methods*. The information on emission rates is used in IAQ and exposure models to calculate various exposure parameters. These parameters are compared to the limits published in the various health/risk assessment databases. Thus, it is possible to determine if the indoor exposure to a specific compound exceeds a known health effects limit.

Table III-16 provides a convenient summary of relevant information on quantitative health assessment and can be used as checklist for evaluating whether critical information is available. See Section VI and Appendix F for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-16 – Evaluation Criteria for Quantitative Health Assessment

Evaluation Criteria	Yes	No
Exposure parameters (concentration/dose) quantified		
Compounds found in database		
Specific health effect limit established		
Toxicity		
Acute		
Chronic		
Cancer		
Reproductive effects		
Odor/Irritation		
Compound not found in database		
Analogous compound identified/found in database		

D. Summary of IAQ Impact of Product/Material Emissions

The above material highlights the important factors to be considered in assessing indoor materials and products relative to their impact on occupant health. The first order of business is to determine the potential indoor emissions from the material/product. Sometimes available information is sufficient to make qualitative judgments on risk. If quantitative assessments are required, source emission models may be available. If necessary, additional product testing can be conducted to determine the emission characteristics. When emission rate information is available, exposure scenarios can be developed for use in IAQ or exposure models to predict occupant exposure parameters – concentration or dose. This information is then compared to published health effects limits to complete the quantitative health/risk assessment.

Table III-17 provides a convenient summary of relevant information on the overall assessment of IAQ impacts of product/material assessments. See Section VI for guidance on how the table can be used to compare and rate assessment programs using quantitative or qualitative criteria.

Table III-17 – Overall Evaluation Criteria for IAQ Impact of Product/Material Emissions

Evaluation Criteria	Yes	No
Product/Material Assessment		
Use existing information		
MSDS		
VOC content		
Source emission models available		
Samples collected for evaluation		
Benchtop laboratory methods		
Direct analysis		
Static headspace analysis		
Dynamic chamber testing		
Chamber characteristics adequate		
Test sample properly conditioned and prepared		
Test conditions specified		
Chemical measurements described		
Emission rates determined		
Exposure Assessment		
Scenario developed		
IAQ/exposure model used		
Exposure concentration/dose determined		
Health/Risk Assessment		
Health hazards identified		
Qualitative assessment conducted		
Quantitative assessment conducted		
Numerical limit established		

IV. CURRENT ASSESSMENT/CERTIFICATION PROGRAMS

Several organizations in the US and abroad have developed and implemented programs to label or certify products and materials as "low emitting" based on emissions testing. In the early 1990's, the state of Washington required emissions tests on materials and furnishings used in new state office buildings to limit indoor VOC emissions. Since 1992, the Carpet and Rug Institute (CRI) has had a Green Label program to ensure low emitting carpet products. More recently, Greenguard has developed programs to certify compliance with specified emission limits. California and the US EPA have procurement programs that limit indoor emissions for new construction. The US Green Building Council's LEED program recognizes low emitting furniture and other indoor products as part of an environmental rating system for new buildings. European countries, such as Sweden, Norway, Denmark, and Germany, have emission limits on various indoor products and materials. The following material describes many of these programs:

A. U.S. Assessment Programs

A number of programs in the U.S. provide labels or certificates relating to indoor air emissions. Some of the programs promote "green" products, and IAQ issues are only a small part of their criteria. Others emphasize IAQ issues. The following material describes many of the current US programs.

1. Indoor Air Emissions Label/Certification Programs

A number of the U.S, assessment programs deal exclusively with indoor emissions and provide product labels and certifications:

a. Greenguard Certification Standards for Low Emitting Products

The Greenguard Environmental Institute (GEI) has developed and conducts certification programs for low emitting products (www.greenguard.org). The program was developed to deal exclusively with indoor air emissions. The Greenguard certification program requires testing in environmental chambers with emission factors developed based on testing at 96 hours. Chamber testing is conducted using ASTM standards for small (ASTM D-5116-97) and large (ASTM D-6670-01) chambers. Greenguard has established "allowable emission levels" for a number of specific VOCs (formaldehyde, total aldehydes, 4-PC, and styrene), TVOCs, and, where applicable, particles for a variety of indoor materials and products, including: adhesives, appliances, ceiling materials, cleaning systems, consumer products, flooring, general construction, insulation, office equipment, office furniture (workstations, seating, desks, wood and metal case goods, tables, vertical and lateral files, storage cabinets, movable walls/partitions, and acoustical panels), paints, textiles, and wall coverings. Greenguard's "allowable emission levels" are presented in concentration units (mg/m^3 or ppm) based on the material/product being used in a room volume of 32 m^3 with an outdoor air change rate of 0.8 ACH. (No information on product loading is specified.) The limits are based on information from the State of Washington, the US EPA, the World Health

Organization, and the German Blue Angel Program. In addition to the allowable limits, Greenguard requires listing of carcinogens and reproductive toxins identified by California Prop. 65, the US National Toxicology Program (NTP), and the International Agency for Research on Cancer (IARC). Finally, if any unlisted compound has a predicted concentration exceeding 1/10 of the ACIGH 8 hour TWA-TLV value, the product sample fails the test; for children and schools the limit is 1/100 of the TLV or ½ of the California CREL, whichever is lower. In this case, the compound exceeding the limit does not have to be identified. Finally, any pollutant exceeding the National Ambient Air Quality Standards (NAAQS) must be noted. (NAAQS are established for the following criteria pollutants: CO, lead, NO_2, PM_{10}, $PM_{2.5}$, ozone and SO_x.) Testing is conducted at specified intervals – quarterly screening and annual testing.

b. California 01350 and CHPS Assessment Program

The State of California has developed environmental specifications for testing building materials entitled "Special Environmental Requirements, Specifications Section 01350" (www.ciwmb.ca.gov/GreenBuilding/Specs/Section01350/). Section 01350 includes testing and selection criteria for indoor air quality as well as requirements for recycled contents and lighting. Section 01350 is used by California to select materials for new state-owned buildings, and since its development in 2000, the 01350 program has been adopted by California's CHPS (Collaborative for High Performance Schools) program for the selection of low emitting materials and products (www.chps.net). Information on the details of the 01350 program and CHPS is available on the Internet. Documents available for download include "Standard Practice For The Testing Of Volatile Organic Emissions From Various Sources Using Small-Scale Environmental Chambers" which spells out the details of the Section 01350 testing procedures, exposure assessment, and health effects criteria. The Section 01350 certification program requires testing in environmental chambers with emission factors developed based on testing at 14 days, with 10 days of conditioning and 4 days of testing. Chamber testing procedures are provided in the "Standard Practice" and apply the ASTM standard for small chambers (ASTM D-5116-97). Section 01350 requires the following chemical emissions to be measured: 1) Compounds on California's list of chemical with non-cancer Chronic Reference Exposure Levels (CREL); 2) Carcinogens and reproductive toxicants on California's Prop. 65 list; 3) Compounds on the California Air Resources Board list of Toxic Air Contaminants (TAC); 4) The 10 most abundant VOCs not included on any of the above lists. (All lists of compounds are available on the Internet). Concentration limits have been established for the compounds on the CREL list as well as selected odorous and irritant compounds. These concentration limits apply to either commercial offices or schools based on specified exposure scenarios. IAQ models calculations are applied using the emission factors developed from the chamber tests.

c. CRI – Green Label and Green Label Plus

The Carpet and Rug Institute (CRI) is a national trade association representing over 90% of all carpet produced in the United States, and suppliers of raw materials and services to the industry (www.carpet-rug.com).

In 1992, after extensive negotiations with the US EPA and other organizations concerning carpet emissions, CRI developed and implemented its *Green Label* program for carpets, carpet adhesives, and carpet cushions. This programs requires environmental chamber emissions testing of carpet, adhesive, or cushion samples for 24 hours and sets emission limits for TVOC and specific compounds:

Carpet – formaldehyde, 4-PC, styrene
Adhesive – formaldehyde, 2-ethyl-1-hexanol
Cushion – formaldehyde, BHT, 4-PC

Products that meet the emission limits are awarded the *Green Label* that signifies that the product is "low-emitting". Annual retesting is conducted to confirm emission limits.

In 2004, CRI worked with the California Department of Health Services to develop the *Green Label Plus* (GLP) program to meet the requirements of California's 01350 and CHPS programs. Program details are contained in "Standard Practice for the Testing of Volatile Organic Emissions from Various Sources Using Small-Scale Environmental Chambers" - Section 9 - Acceptable Emissions Testing For Carpet - Section 01350 / CRI Green Label Plus. The GLP program for carpet sets emissions limits for TVOC and 13 specific VOCs; for adhesives, limits are placed on 15 VOCs. Chamber emission factor limits are calculated using the California concentration limits for commercial offices. Initial testing for GLP is conducted at 1 and 14 days. These data are analyzed to develop correlations between the 1 day and 14 day values. If acceptable correlations are achieved, future testing can be conducted at 1 day. Carpets are tested quarterly; adhesives are tested semi-annually.

d. RFCI – FloorScore

The Resilient Floor Covering Institute (RFCI) is a trade association of resilient floor covering producers in North America who manufacture tile, sheet vinyl, linoleum or rubber products for residential and commercial flooring installation (www.rfci.com). The FloorScore program was developed by the Resilient Floor Covering Institute in collaboration with Scientific Certification Systems - SCS (see below). A flooring product bearing the FloorScore label is certified to meet the requirements of California Section 1350.

As a third-party certifier, SCS ensures the program's integrity and independence. SCS (1) works with the manufacturer to identify the appropriate samples for testing; (2) reviews VOC emission test reports generated by independent testing laboratories for individual candidate products; (3) determines if the test results meet the California Section 1350 requirements for individual VOCs of concern; and (4) periodically inspects manufacturing plants to review product formulas, processing and quality control in order to define the permitted use of the FloorScore seal.

e. SCS – Indoor Advantage and Indoor Advantage Gold

Scientific Certification Systems (SCS) is an independent, third-party organization that certifies products which meet recognized standards. For products with indoor

emissions, SCS has developed two certification programs: *Indoor Advantage* and *Indoor Advantage Gold* (www.scscertified.com/iaq/). The *Indoor Advantage* program certifies that products meet the indoor emissions limits defined by the LEEDs program (see below) for: furniture and seating; paints and coatings; adhesives and sealants. The *Indoor Advantage Gold* program certifies that products meet the indoor emissions limits required by the California 01350 program. *Indoor Advantage Gold* "… applies to any non-flooring product generally used within an enclosed indoor environment such as wall coverings, systems furniture, casework, and insulation." SCS does not perform emission testing, but acts as a facilitator to assist manufacturers in obtaining product certification.

f. HPVA

The Hardwood Plywood and Veneer Association (HPVA) is a trade association whose member companies produce 90% of the hardwood plywood stock panels and hardwood veneer manufactured in North America (www.hpva.org/). HPVA has its own laboratory that evaluates products for formaldehyde emissions using two ASTM test methods: E1333-96, *Standard Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber* and D5582-00, *Standard Test Method for Determining Formaldehyde Levels from Wood Products Using a Desiccator*. The results of this testing are used to determine compliance with US Department of Housing and Urban Development (HUD) limits on formaldehyde emissions as specified in 24 CFR Part 3280.308 and 24 CFR Part 3280.406. These regulations specify a formaldehyde limit of 0.2 ppm when tested in a large chamber according to ASTM E1333-96.

g. BIFMA

The Business and Institutional Furniture Manufacturers Association (BIFMA) is a trade association who's "… membership of over 260 companies represents over 80% of the value of North American shipments of office furniture" (www.bifma.com). In the area of indoor air emissions, BIFMA's Furniture Emissions Subcommittee has developed two documents: 1) an emissions standard meeting LEED requirements (X7.1-2005) and 2) a standard test method (M7.1-2005). The documents were approved by the BIFMA membership in September 2005 for use as BIFMA standards and for release to the ANSI canvas process. The BIFMA International Association (non-ANSI) approved versions of both documents have received unanimous support by the USGBC Environmental Quality Technical Advisory Group as an alternative for demonstrating compliance to the USGBC LEED-CI EQ 4.5 credit for "Low-Emitting Furnishings". Final approval by the USGBC is pending the results of a public comment period extending until March 24, 2006. The State of California Department of General Services 2006 Bid IFB 54800 for Open Office Panel Systems specifies the BIFMA M7.1-2005 test method as an acceptable alternative for demonstrating compliance of office furniture to CA 1350 emission concentration criteria. Both BIFMA M7.1-2005 and BIFMA X7.1-2005 were open to ANSI canvass and public comment from early November 2005 through mid January 2006. Currently BIFMA is working to address the comments received.

2. "Green Product" Assessment Programs

A number of "green product" assessment programs are active in the U.S. They deal with a wide variety of issues, such as: recycle/reuse; energy efficiency; air, water, and solid waste emissions; land use; renewable resources; etc. Some of these programs, also deal with IAQ issues, including consideration of indoor emissions:

a. Green Seal

"Green Seal is an independent, non-profit organization that strives to achieve a healthier and cleaner environment by identifying and promoting products and services that cause less toxic pollution and waste, conserve resources and habitats, and minimize global warming and ozone depletion." (www.greenseal.org). Indoor air quality is only one of many factors considered by Green Seal. Green Seal uses two major mechanisms to identify and recommend "green" products:

Product Standards and Certification – Green Seal establishes environmental standards that products must meet to achieve certification. The standards/certification process uses life cycle analysis techniques to evaluate environmental impacts. The certification process meets ISO 14024 requirements for "Type I Environmental Labeling." Products are submitted to Green Seal by manufacturers for evaluation against the criteria in applicable Green Seal standards. Based on an analysis by Green Seal using data from testing, the literature, and the manufacturer, products are certified if they meet all Green Seal requirements and are then eligible to use the Green Seal Certification Mark on the product label and in advertising The certification process includes inspection by Green Seal of the manufacturing facility. The cost of the certification is borne by the manufacturer. To date, Green Seal has issued 32 environmental certification standards. The following four standards include an IAQ component: Commercial Adhesives (GS-36); Industrial and Institutional Cleaners (GS-37); Industrial and Institutional Floor-Care Products (GS-40); and Paints (GS –11). The IAQ portion of the standards for these products includes:

- limits on VOC content (per the EPA VOC definition in 40 CFR 51.100(s))
- limits on inhalation toxicity
- prohibitions on carcinogens (per IARC and NTP)
- prohibitions on reproductive toxicants (per California's Prop. 65)
- prohibitions on specified compounds

These limits and prohibitions (except for inhalation toxicity) apply to the product composition not the product emissions; no emissions data or testing are generally required. If test data for inhalation toxicity are not supplied, Green Seal will estimate it using the procedure specified in Appendix A of GS-37.

Product Recommendations – As stated in the Green Seal web site, "Recommendations of environmentally preferable products are published as Choose Green Reports giving environmental criteria for the category, rationales for them, the product recommendations, and sources for recommended products." Product

recommendations are based on life cycle analyses similar to those used in Green Seal's environmental standards and certification process. While product recommendations include consideration of the same factors as environmental standards, no Green Seal certificates are issued. In addition, many of the product recommendation propose the use of non-Green Seal criteria (e.g., CRI criteria for carpet; Greenguard criteria for office furniture). Each Choose Green Report contains lists of recommended products and manufacturers. No manufacturer funds are required for inclusion on the recommended product list. To date, Green Seal has published 19 Choose Green Reports, including the following six that deal with IAQ issues: Carpet; Floor Care Products – Finishes and Strippers; Office Furniture; Office Supplies; Particleboard and Medium-Density Fiberboard, Wood Finishes and Stains. Note that Product Recommendations for materials without Green Seal certifications are being phased out.

e. USGBC – LEED

The US Green Building Council (USGBC) is a "… coalition of leaders from across the building industry working to promote buildings that are environmentally responsible, profitable and healthy places to live and work" (www.usgbc.org). "The LEED (Leadership in Energy and Environmental Design) Green Building Rating System® is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings." LEED standards are currently available for:

- New commercial construction and major renovation projects (LEED-NC)
- Existing building operations (LEED-EB)
- Commercial interiors projects (LEED-CI)
- Core and shell projects (LEED-CS)
- Homes (LEED-H)

LEED standards provide numerical credits for meeting specific requirements leading to a "green building." For indoor air emissions, LEED-NC, LEED-CI and LEED-CS provide credits for the following *Low-Emitting Materials*:

- Adhesives and sealants
- Paints and coatings
- Carpet systems
- Composite wood and laminate adhesives
- Systems furniture and seating (only in LEED-CI)

LEED requirements for low-emitting material credits are based on criteria established by other organizations. For example, LEED credits for adhesives, sealants, paints, and coatings are based on Green Seal or SCAQMD (South Coast Air Quality Management District) VOC content limits; for carpet, CRI's Green Label Plus emissions limits are required. LEED credits for systems furniture and seating are based on Greenguard emission limits.

c. Green Guide for Health Care

The Green Guide for Health Care (GGHC) was developed by a consortium of parties involved in the design, construction, and operation of health care facilities (www.gghc.org). GGHC is basically a LEED document that assigns credits to various "green building" factors. For indoor air emissions, GGHC uses the LEED criteria discussed above.

d. Building Green Inc. – GreenSpec

Building Green is "… a subscription-based online resource for environmentally sensitive design and construction" (www.buildinggreen.com). Building Green publishes the GreenSpec Directory listing products based on available information concerning such factors as recycle content, resource conservation, indoor air emissions, etc. The directory's 5th Edition contains over 1,850 "green building products." No quantitative criteria are used to evaluate a product for inclusion on the GreenSpec lists. No product testing is performed. Products are selected for evaluation in one of two ways: a) manufacturers request that their product be evaluated or b) GreenSpec personnel select the product based on products characteristics. GreenSpec personnel conduct the product evaluation, and the decision to assign the GreenSpec designation is based on their best judgment. No funds are accepted from manufacturers for product evaluation or inclusion on the GreenSpec list.

e. NIST – BEES

The National Institute of Standards and Technology's (NIST) Building and Fire Research Laboratory has developed the BEES (**B**uilding for **E**nvironmental and **E**conomic **S**ustainability) software for selecting cost-effective, environmentally-preferable building products (www.bfrl.nist.gov/oae/software/bees.html). "The BEES methodology takes a multidimensional, life-cycle approach. That is, it considers multiple environmental and economic impacts over the entire life of the building product." BEES accounts for indoor air emissions for three products – floor coverings, interior wall finishes, and chairs. The BEES program uses available TVOC emission factor data and assumes that all emissions occur in the first 72 hours after each installation. A specified number of product replacements are assumed over a 50 year period based on the projected useful life of the product. Thus, the total TVOC emissions equal the TVOC's emitted in the first 72 hours times the number of installations. No assessment of individual VOCs is conducted.

f. US EPA – EPP

Executive Order 13101 – *Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition* - signed by President Clinton in September 1998, requires the Federal Government to consider a wide variety of environmental factors in the acquisition of federal property. The US Environmental Protection Agency (US EPA) has developed the Environmentally Preferred Purchasing (EPP) program to meet this goal (www.epa.gov/opptintr/epp/). Indoor air emissions are among the many factors considered in the EPP program. For example, the construction and furnishing of two

major EPA facilities (Federal Triangle, Washington, DC; Office and Research Campus, Research Triangle Park, NC) required consideration of indoor emissions from a wide variety of material and products (USEPA, 1997). The EPP program has developed a "Database of Environmental Information for Products and Services" that includes considerations of indoor air emissions (http://yosemite1.epa.gov/oppt/eppstand2.nsf). In this database, the indoor air emission recommendations are based on existing programs, i.e., Greenguard, CRI/Green Label, etc. The EPP program has joined with the National Institute of Building Sciences to develop the Whole Building Design Guide (WBDG)(www.wbdg.org). The WBDG provides guidance on "green" construction and is developing a DRAFT Federal Guide for Green Construction Specs that will include consideration of indoor air emissions from a variety of material and products. Existing programs (e.g., LEED, CRI/Green Label) will be utilized when appropriate.

g. US EPA– Energy Star Indoor Air

The US EPA's Energy Star program is designed to identify and certify energy efficient appliances, devices, and systems (www.energystar.gov). A major emphasis is placed on new homes. Recently, an *Indoor Air Package* has been developed for Energy Star homes. (At www.energystar.gov under Partner Resources go to *For Home Builders, Lenders, Raters* and click on "Indoor Air Package" in the Quick Links box.) The Indoor Air Package includes consideration of indoor air emissions and recommends adherence to existing emissions limits for specific materials (e.g., CRI-Green Label Plus).

B. Foreign Assessment Programs

An Internet search uncovered a multitude of programs throughout the world that certify/label products and materials. The large majority of these programs certify the products to be environmentally "green" based on life-cycle parameters such as: energy use, recycle content, air/water emissions from manufacture, disposal, and use. While many of the programs have criteria for VOC and hazardous chemical content limits, only a few of the programs (especially in Scandinavia) explicitly deal with indoor air emissions. Following are summaries of the major foreign assessment programs:

1. The Global Ecolabelling Network

The Global Ecolabelling Network (GEN) is a non-profit association of third-party, environmental performance labeling organizations founded in 1994 to improve, promote, and develop the "ecolabelling" of products and services. (http://www.gen.gr.jp/)

The mission of the GEN is to:

- serve its members, other ecolabelling programs, other stakeholders, and the public by improving, promoting and developing the ecolabelling of products, the credibility of ecolabelling programs worldwide, and the availability of information regarding ecolabelling standards from around the world;
- foster co-operation, information exchange and harmonization among its members, associates, and other ecolabelling programs with regard to ecolabelling;
- facilitate access to information regarding ecolabelling standards from around the world;
- participate in certain international organizations in order to promote ecolabelling generally; and
- encourage the demand for, and supply of, more environmentally responsible goods and services.

In support of this mission, GEN members:

- set criteria for and certify products and services with lower environmental burdens and impacts than comparable products/services with the same function;
- provide information, advice and technical assistance to organizations contemplating or developing programs;
- disseminate information to the public; and
- represent the interests of ecolabelling in various international meetings and events.

As of the end of 2001, the GEN included twenty-nine national and multinational member organizations that operate ecolabelling programs around the world. The following table lists each member (and programs from four non-member organizations noted with an asterisk).

Table IV-1 - Global Ecolabelling Network

Country	Program	Organization	Contact
Australia	Australian Ecolabel Program	Australian Environmental Labelling Association Inc.	Mr. Petar Johnson, office@aela.org.au
Austria*	Austrian Eco-Label	Lebensministerium	andreas.tschulik@ lebensministerium.at
Brazil	Brazilian Ecolabelling	Associacao Brasileira de Normas Tecnicas	Mr. Frederico Jose Marques Cabral, fcabral@abnt.org.br

Canada	Environmental ChoiceM Program	TerraChoice Environmental Marketing Inc., Environment Canada	Mr. John C. Polak, jpolak@terrachoice.ca
Croatia	Environmental Label	Ministry of Environmental Protection and Physical Planning, Environmental Protection Division, Department for EU Integration and International Projects	Ms. Mirela Holy, mirela.holy@mzopu.hr
China*	Environmental Labelling	China Environmental United Certification Center	Mrs. Ursula Becker, ubecker@integration.org
Czech Republic	Environmental Choice	Ministry of the Environment	Ms. Andrea Legnerova, andrea_legnerova@env.cz
Denmark	Nordic Swan Label, and EU Eco-label	Ecolabelling Denmark	Ms. Lisbeth Engerl Hansen, leh@ecolabel.dk
European Union (EU)[1]	EU Eco-label	European Commission - DG ENVIRONMENT (G2)	Ms. Nicola Marinucci, nicola.marinucci@cec.eu.int
France*	NF Environment		marque-nf@afor.fr
Germany	The Blue Angel	Federal Environmental Agency	Mr. Wolfgang Lohrer, wolfgang.lohrer@uba.de
Greece	ASAOS	Ministry of the Environment Physical Planning	Ms. Amalia Katsoy, A.katsou@minenv.gr
Hong Kong (GC)	Green Label	Green Council	Ms. Linda Ho, info@greencouncil.org
Hong Kong (HKFEP)	Environment Label Certification	Hong Kong Federation of Environmental Protection (HKFEP) Limited	Ms. Lisa Kwok, hkfep@hkfep.com
India	Ecomark	Central Pollution Control Board (CPCB)	Dr. B. Sengupta, ssmqa@cpcb.delhi.nic.in
Japan	Eco Mark Program	Eco Mark Office, Japan Environment Association (JEA)	Mr. Seiji Taguchi, taguchi@japan.email.ne.jp
Korea	Environmental Labelling	Korea Environmental Labelling Association (KELA)	Mr. Sun-Woo SEOK, ecomark@chollian.net
Luxembourg	EU Eco-label	Attache De Gouvrement, Ministere De L'Environment	Henri Haine,
Netherlands*	Stichting Milieukeur		milieukeur@milieukeur.nl
New Zealand	Environmental Choice	Environmental Choice New Zealand	Robin Taylor, info@enviro-choice.org.nz
Nordic Countries	Nordic Swan Label	Organizations in Denmark, Finland, Iceland, Norway, and Sweden	See Swan Label write-up
Norway	Nordic Swan Label	Norwegian Foundation for Environmental Labelling	Mr. Jan Erik Stokke, jes@ecolabel.no
Philippines	Green Choice Philippines	Clean & Green Foundation, Inc.	Ms. Imerda P. Sarmiento, cgfi@itextron.com
R.O.C. (Taiwan)	Green Mark Program	Environment and Development Foundation	Ning Yu, ningyu@edf.org.tw
Singapore	Singapore Green Label Scheme (SGLS)	Singapore Environment Council	Mr. Yatin Premchand, info@sec.org.sg
Spain	AENOR-Medio Ambiente	AENOR. Asociacion Espanola de Normalizacion y Certificacion	Mr. Andres Blazquez, aeleja@aenor.es
Sweden (SIS)	Nordic Swan Label	SIS Ecolabelling AB	Ragnar Unge, ragnar.unge@sismab.se
Sweden (SSNC)	Good Green Buy	The Swedish Society for Nature Conservation	Ms. Eva Eiderstrom, Eva.Eiderstrom@snf.se
Sweden (TCO)	TCO	TCO Development	Mrs. Helena Nordin,

			helena.nordin@ tcodevelopment.com
Thailand	Green Label - Thailand	Thailand Environment Institute	Dr. Pongvipa Lohsomboon, pongvipa@tei.or.th
Ukraine	Living Planet	The Program for Development of Ecological Marking in Ukraine	Ms. Sveltana V. Berzina, liveplan@gala.net
United Kingdom	EU Eco-label	Department for Environment, Food and Rural Affairs (DEFRA)	Charles Cox, charles_cox@defra.gsi.gov.uk
U.S.A.	Green Seal	Green Seal Inc.	Arthur B. Weissman, aweissman@greenseal.org

[1]The EU is comprised of the following countries: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Slovakia, Slovenia, Spain, Sweden, The Netherlands, and United Kingdom.

2. European Product Labeling/Certification Programs

The following material provides brief summaries of several European programs that label, certify, and or test products and materials for their impact on indoor air quality:

a. European Union (EU) Eco-label – the Flower

The EU Eco-Label goal is:

"For the Flower to be recognized as Europe's premier award for products which are a genuinely better choice for the environment, helping manufacturers, retailers and service providers to get recognition for good standards, and purchasers to make reliable choices." (www.europa.eu.int/comm/environment/ecolabel/index_en.htm)

Key aims are:

"- to achieve significant environmental improvements by developing, publishing and promoting criteria that push the market forward, in order to minimize the environmental impacts of a wide range of products over their whole life-cycle;

- to ensure the credibility of the award by efficient administration, and through criteria which:
  - are environmentally strong
  - are based on good science, including the precautionary principle
  - take account of consumer health
  - require product performance
  - are developed transparently and cost-effectively, with the participation of stakeholders
  - are reasonably attainable
  - are up to date

- to encourage manufacturers, retailers and service providers to apply for

the award, to publicize their own participation in the scheme, and to promote the availability of ecolabelled products and information about them;

- to encourage purchasers to buy products with the award;

- to improve consumer awareness and behavior regarding the environmentally optimal use of products."

Criteria for obtaining the EU Eco-labels have been developed for the following product groups: cleaning products, appliances, paper products, home and garden (including indoor paints and varnishes), clothing, tourism, and lubricants. A review of the criteria did not uncover specific references to indoor air emissions.

b. Nordic Ecolabel - The Swan

In November 1989, the Nordic Council of Ministers adopted a measure to implement a voluntary, positive ecolabelling scheme in the Nordic countries. The scheme is administered by national boards (see below) that co-operate through the Nordic Ecolabelling Board. The Swan is the official Nordic ecolabel, approved by the Nordic Council of Ministers representing the following countries – Denmark, Finland, Iceland, Norway, and Sweden (www.svanen.nu/Eng/default.asp). The Swan logo is used to demonstrate that a product has been evaluated and is considered environmentally sound. The objective of ecolabelling is to provide information to consumers to enable them to select products that are the least harmful to the environment. Ecolabelling is intended to stimulate environmental concern in product development. The symbol has been applied to around 60 product groups. For example, a variety of products from laundry soap to furniture to hotels carry the Swan label. The label indicates that products satisfy specified criteria using methods such as samples from independent laboratories, certificates and control visits. The label is usually valid for three years, after which the criteria are revised and the company must reapply for a licence. In this way, it is ensured that products better suited to the environment are constantly being developed.

In its work on ecolabelling, Nordic Ecolabelling follows the ISO 14024 standard: "Environmental labels and declarations - Guiding principles". The product groups and environmental and performance requirements selected by Nordic Ecolabelling reflect the objectives, principles, practices and requirements of the standard. ISO 14024 includes the requirements that criteria should be objective, reasonable and verifiable, that interested parties should be given the opportunity to participate and that account should be taken of their comments. The criteria are based on evaluation of the environmental impacts during the actual products' life cycle. Based on a thorough examination the criteria set requirements towards a number of factors considered environmentally harmful. Upon application, all products found to meet the requirements of the criteria are awarded the environmental label.

For many products, the Swan label criteria include consideration of IAQ impacts. Ecolabelling criteria documents dealing with indoor emissions are available for five product groups:

Product Group	Indoor Air Considerations
Adhesives	VOC emissions limits
Building Panels	Formaldehyde emission limits
Flooring	Formaldehyde and VOC emissions
Furniture and Accessories	Formaldehyde and VOC emissions
Office Machines	Dust, ozone, and styrene emissions

For the most part, the test methods recommended for use in the Nordic ecolabelling criteria documents are certified by ISO (International Standards Organization) or CEN (European Committee for Standardization). Swan Label Nordic Web Pages are available for: Denmark (www.ecolabel.dk), Finland (www.sfs.fi/ymparist/), Iceland (www.svanurinn.is), Norway (www.ecolabel.no), and Sweden (www.svanen.nu).

c. Germany – Blue Angel Label

The German Blue Angel environmental label has been used for over 25 years to identify "green" products. At the present time, about 710 companies use the label on over 3800 products (www.blauer-engel.de/englisch/navigation/body_blauer_engel.htm). The label is only issued when published criteria are met. A number of product criteria include requirements for indoor air emission testing or evaluations, including:

- Low-emission composite wood panels (particleboard, fiberboard, plywood)
- Copiers
- Multifunction devices
- Low-emission wood products and wood based products (flooring, residential furniture, office furniture, wood panels)
- Low-emission floor covering adhesives and other installation materials
- Low-pollutant varnishes
- Low-emission upholstery
- Mattresses
- Printers
- Low-emission wall paints

d. Denmark - Indoor Climate Label

The Danish Indoor Climate Labelling (DICL) system is a voluntary scheme for indicating the impact of building materials and products on the indoor climate (http://www.danishtechnology.dk/building/13268). The indoor climate label includes the following:

VOC emissions - All products are tested according to specific criteria and an indoor-relevant time-value (days) is determined. The time-value is based of the time it takes the most slowly emitting individual substances to reach the odor and irritation threshold for the substance. Thus, the lower the time-value, the less time an occupant is exposed to an odorous or irritating pollutant level. This time-value is based on chemical measurements conducted on samples collected from dynamic test chambers as well as human sensory evaluation of the acceptability and odor intensity. The chamber measurements are converted to indoor concentrations for a "standard" room based on specific dimensions and ventilation parameters.

Particle emissions - Ceiling products are evaluated for particle emissions.

Indoor guidelines - The manufacturer prepares guidelines with regard to transport, storage, assembly, cleaning and maintenance, which are to be followed in order not to reduce the indoor-relevant properties of the products in practice in relation to the certificate.

At present, labeling criteria are available for 10 product areas:

- Ceiling and wall systems
- Carpets
- Interior doors and folding partitions
- Resilient Flooring, Wood-Based Floors and Laminated Floors
- Oils for Wood Floors
- Windows and Exterior Doors
- Kitchen, Bath and Wardrobe Cabinets
- Furniture
- Interior paint
- Cable trunking systems

e. Finland - Emission Classification of Building Materials

The Building Information Foundation (RTS) of Finland has developed a system for certifying building materials based on their emission rates. Materials are given one of three classifications (M1, M2, and M3) depending on the emissions of TVOC, formaldehyde, ammonia, and carcinogens (IARC, Category 1). The emission rates are based on dynamic chamber testing (http://www.rts.fi/emission_classification_of_building_materials.htm). In addition, odor limits are established based on sensory panel evaluations. The following table summarizes the classifications:

Criteria	M1	M2	M3
TVOC (mg/m^2-h)	< 0.2	< 0.4	> 0.4
Formaldehyde (mg/m^2-h)	< 0.05	< 0.125	> 0.125
Ammonia (mg/m^2-h)	< 0.03	< 0.06	> 0.06
Carcinogens (mg/m^2-h)	< 0.005	< 0.005	> 0.005
Odor (< 15% dissatisfaction)	No Odors	No Significant Odors	Significant Odors

Emission rates are based on a 4-week test period.

For TVOC, a minimum of 70% of the compounds must be identified. A large number of building materials have been tested and have received the M1 label, including: concrete products, bricks, laminated beams, fiberboard, particleboard, plywood, gypsumboard, decorative panels, insulation materials, sealants, adhesives, flooring material, wallpaper, paints, and varnishes.

V. US EMISSIONS TESTING LABORATORIES

A. U.S. Testing Laboratories

At the present time, there are four laboratories in the U.S. that conduct emissions tests for indoor materials and products – Air Quality Sciences (AQS), Berkeley Analytical Associates (BAA), Material Analytical Services (MAS), and Georgia Tech Research Institute (GTRI). (Note that GTRI is primarily a research laboratory that conducts testing consistent with its research objectives.) The following information was supplied by each of the laboratories:

1. Air Quality Sciences (AQS)

Air Quality Sciences
1337 Capital Circle
Marietta, GA 30067

Phone: 770-933-0638
e-mail: mailto:info@aqs.com
Web page: http://www.aqs.com/

Principal contacts: Dr. Marilyn Black – Chief Scientist
Mr. Anthony Worthan – Chief Operating Officer

Environmental test chambers:

- 34 dynamic, stainless steel chambers ranging in size from 0.05 m^3 to 26 m^3
- Operation and verification processes meet ASTM D5116 and D6670 for small, medium and large chambers.
- Intermediate and large chambers meet EPA-ETV and German Blue Angel requirements

Environmental/clean air systems:

- Temperature, air moisture content, and airflow are controlled among chambers to achieve and precisely maintain required conditions.
- Chambers are process-controlled with thermodynamic and air distribution models that verify accuracy.
- Chambers have centralized air purification systems and construction materials that achieve non-detectable background levels for VOCs, aldehydes, respirable particles, carbon monoxide, nitrogen oxides, and ozone.

Sampling and analysis equipment:

- Mass flow control solid sorbent sampling systems
- GC
- GC/MS; TD-GC/MS
- HPLC

- Continuous on line monitors for VOCs, ozone, particles, carbon monoxide, ammonia, and others.

Certification testing:
- Greenguard
- Green Label/Green Label Plus
- LEED
- California 01350/CHPS
- Germany Blue Angel
- Japan JIS
- CEN Flooring Test Standard - prEN15052 (See Appendix E)
- FloorScore
- Indoor Advantage and Indoor Advantage Gold

2. Berkeley Analytical Associates (BAA)

Berkeley Analytical Associates, LLC
815 Harbour Way South, Unit 6
Richmond, CA 94804-3612

Phone: 510-236-2325
Fax: 510-236-2335
e-mail: berkeleyanalytical@att.net
Web page: NA

Principal contacts: Raja Tannous, Laboratory Director
Al Hodgson, Research Director

Environmental test chamber facilities:

Test specimen conditioning facility
- 48 Conditioning chambers with individual flow controls
- Clean air supply
- Temperature and humidity control systems
- Data acquisition system

Small-scale environmental chamber test facility
- 16 Dynamic, electropolished stainless-steel chambers, 70 L volume
- Two FLECs (Field and Laboratory Emission Cells)
- Temperature and humidity control systems
- Chamber airflow rates regulated with electronic mass flow controllers (MFCs)
- Data acquisition and control system

Mid-scale environmental chamber test facility
- Two dynamic chambers with polished stainless-steel surfaces, 6 m^3 volume
- Clean air generation system

- Temperature and humidity control systems
- Chamber airflow rates regulated with electronic MFCs
- Data acquisition and control system

Large-scale environmental chamber test facility
- Under construction
- 25 m^3 volume

Sampling and analysis equipment:
- Electronic MFC sampling systems for VOCs, carbonyl compounds, and other analytes
- Two thermal desorption gas chromatography/mass spectrometry (TD-GC/MS) systems for analysis of VOCs collected on sorbent tubes
- High performance liquid chromatography (HPLC) system for analysis of carbonyls
- Performance testing program for VOCs and carbonyls by ISO 17025 chemical calibration provider

Certification testing:
- California Specification 01350/CHPS
- FloorScore
- Indoor Advantage and Indoor Advantage Gold
- Furniture testing following BIFMA M7.1-2005 and X7.1-2005, BIFMA® International

3. Material Analytical Services (MAS)

Material Analytical Services
3945 Lakefield Court
Suwanee, Georgia 30024

Phone: 770-866-3200 or 800-421-8451
Fax: 770-866-3259
e-mail: mailto:bpeters@mastest.com
Web page: http://www.mastest.com/

Principal contacts: Ben Peters, Chemist
Martin Bennett, Senior Consultant

Environmental test chambers:
- Eight small and one large dynamic, stainless steel chambers.
- Intermediate ~5m^3 in 2nd quarter 2006 planned.
- One drywall lined large chamber used primarily for asbestos work studies.

Environmental/clean air systems:
- Temperature, humidly and air flow control
- Clean air system to limit VOCs and particles

Sampling and analysis equipment:

- Sorbent and particulate sampling systems
- GC/MS
- GC with FID, TCD, and ECD
- HPLC
- FTIR

Certification testing:

- LEED
- Green Label/Green Label Plus
- California 01350/CHPS
- CEN Flooring Test Standard - prEN15052 (See Appendix E)
- FloorScore
- Indoor Advantage and Indoor Advantage Gold

4.Georgia Tech Research Institute (GTRI)

Environmental Exposures & Analysis Branch
Health and Environmental Systems Laboratory
Georgia Tech Research Institute
925 Dalney Street, MC 0841
Atlanta, GA 30322-0841

Phone: 404-894-5361
e-mail: charlene.bayer@gtri.gatech.edu
Web page: http://www.gtri.gatech.edu/researchers/showcase_bayer.html
User Name: researchguest; Password: gtresearch

Principal Contacts: Dr. Charlene W. Bayer – Principal Research Scientist/Branch Head
Dr. Victor R. De Jesús – Research Scientist

Environmental Test Chambers:

Large-scale environmental facility

- 27.5 m^3 in volume
- Temperature (to within to within $\pm 2^oC$)
- Relative humidity (to within 5% RH)
- Cleanliness (both for particles and gaseous contaminants) of supply air constantly maintained with air purification systems.
- Operable in 100% outside air, recirculated, and static modes (lowest maintainable static mode 0.10 air changes per hour)

Small-scale environmental chamber facility

- 15 (12 operating at any one time) dynamic, electropolished stainless-steel chambers, 0.53 m^3

- Two FLECs (Field Laboratory Emission Cells)
- Temperature and humidity control systems
- Clean air delivery system to maintain air supply cleanliness both for particles and gaseous contaminants
- Chambers airflow regulated with electronic mass flow controllers

Sampling and Analysis Instrumentation and Equipment:

- Extensive mass spectrometry and chromatography (both liquid and gaseous)
- A variety of sample introduction methods are used including thermal desorption, gaseous introduction, HPLC and other methods of introducing wet samples, SPME fibers, etc.

Certification Testing:

GTRI is capable of performing CHPS, Green Label, and other certification testing, but GTRI is a research laboratory and primarily conducts more unique types of testing that meet its research criteria.

B. "Approved" Testing Laboratories for Certification Programs

Section IV.A.1 identifies and describes various labeling and certification programs and Section V.A identifies U.S. laboratories that perform emissions tests on indoor materials and products. A question remains – *Which laboratories are qualified and approved for each certification program?* The following table links each certification program to "approved" testing laboratories:

Table V-1 - "Approved" Testing Laboratories

Certification Program	Testing Laboratory
Greenguard	AQS
California 01350/CHPS	BAA, AQS, MAS
Green Label/Green Label Plus	AQS
FloorScore	BAA, AQS, MAS
Indoor Advantage/Indoor Advantage Gold	BAA, AQS, MAS

1. Greenguard

To date, the only U.S. laboratory approved for Greenguard certification testing is AQS. Greenguard has developed a "Laboratory Qualifications and Proficiency Requirement" and plans to submit it for ANSI approval. Once approved by ANSI, these requirements will be used by the Greenguard Environmental Institute to approve other testing laboratories.

2. California 01350/CHPS

The California 10350/CHPS program lists three testing laboratories - BAA, AQS, and MAS – but does not approve, endorse, or certify them. A manufacturer desiring Cal./CHPS certifications is responsible for selecting a qualified testing laboratory that must be approved by the building owner.

3. Green Label/Green Label Plus

To date, the only laboratory conducting Green Label and Green Label Plus certification testing is AQS, although the other three labs are capable of performing these tests.

4. FloorScore and Indoor Advantage/Indoor Advantage Gold

Both of these program, administered by SCS, list BAA, AQS, and MAS as approved testing laboratories.

C. Laboratory Accreditation

There are at least three national and international standards available for analytical and testing laboratories to become accredited:

- ISO 9000 series - *Quality Management System*- defines the requirements for maintaining high quality laboratory operations

- ISO/IEC 17025 – *General Requirements for the Competence of Testing and Calibration Laboratories*

- AIHA (American Industrial Hygiene Association) – *Industrial Hygiene Laboratory Accreditation Program (IHLAP).* This program requires AIHA review and approval in the following areas:
  - QA programs
  - QC data
  - Qualifications of personnel
  - Equipment and facilities.

AIHA is an ISO member, and IHLAP accreditation also meets ISO/IEC 17025 requirements.

Among the IAQ emissions testing programs discussed in Section IV, three programs recommend ISO 17025 or AIHA-IHLAP – California 01350/CHPS, BIFMA, and Greenguard's *Laboratory Qualifications Proficiency Requirements.* Among the three U.S. testing laboratories, AQS is ISO 9000 certified and BAA is AIHA-IHLAP accredited.

The AIHA and ISO 17025 standards apply to analytical chemistry laboratories. There are no accreditation programs for dynamic chamber testing, even though ASTM standards are

in place and California, Greenguard, and BIFMA have recommended testing procedures. (As noted previously, Greenguard and BIFMA plan to submit their recommendations to ANSI.)

VI. EVALUATION PROTOCOLS FOR RATING/RANKING PRODUCT ASSESSMENT PROGRAMS

The previous material describes and defines criteria to be used to evaluate programs that assess materials and products to determine their impact on indoor air quality and occupant health, with an emphasis on VOC emissions. Evaluation criteria have been recommended for categories within the three major assessment segments: A) Product/Material Assessment, B) Exposure Assessment, and C) Health/Risk Assessment. Within each segment, numerous categories have been identified and criteria developed. The evaluation criteria are presented in the form of tables. These tables can be used to evaluate any assessment program and provide guidance to determine the program's overall quality and completeness. If a rating or ranking of the assessment programs is desired, both quantitative and qualitative protocols are possible for evaluating the assessment programs:

- A *quantitative method* would assign maximum point values to various criteria so that a total point value for any program could be established. This would allow various programs to be compared based on their "score".
- A *qualitative method* would assign letter grades (e.g., A, B, C, D, F) to various criteria. This would allow various programs to be compared based on the grades received for the same criteria.
- A *semi-quantitative method* that would assign a numerical score (e.g., 1 - 10) to various criteria. This would allow various programs to be compared based on the scores received for the same criteria.

Evaluation protocols for these three methods are presented below. All three methods use the Evaluation Criteria Tables presented previously.

A. Quantitative Evaluation Protocol

The quantitative evaluation protocol is based on a maximum total score for any program. A total maximum score of 100 is assumed, with the points distributed as shown below in Table VI-1 (based on the summary Table III-17). The points were assigned based on the author's best judgment regarding the relative importance of each item within the categories.

Table VI-1 - Overall Scoring Criteria for IAQ Impact of Product/Material Emissions

Maximum Points = 100

			Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**See Table**	**I**	**II**	**III**	**IV**	**V**
Product/Material Assessment	***50***						
Use existing information							
MSDS	**10**	F-2					
VOC content/Manufacturer supplied information	**5**	F-2					
Source emission models available	**10**	F-3					
Samples collected for evaluation	**5**	F-4					
Benchtop laboratory methods							
Direct analysis	**10**	F-5					
Static headspace analysis	**10**	F-5					
Dynamic chamber testing							
Chamber characteristics adequate	**10**	F-6					
Test sample properly conditioned	**5**	F-7					
Test sample properly prepared	**5**	F-8					
Test conditions specified	**10**	F-9					
Chemical measurements described	**5**	F-10					
Emission rates determined	**10**	F-11					
Exposure Assessment	***25***						
Scenario developed	**10**	F-12					
IAQ/exposure model used	**5**	F-13					
Exposure concentration/dose determined	**10**	F-14					
Health/Risk Assessment	***25***						
Health hazards identified	**5**	F-15					
Qualitative assessment conducted	**5**	F-16					
Quantitative assessment conducted	**15**	F-17					
TOTAL POINTS =							

Note that the total of the Max. Points column for Product/Material Assessment is greater than 50 due to some mutually exclusive scores. For example, if emission rates are determined by dynamic chamber testing (10 points), the source emissions model (also 10 points) would not be used. The last five columns are used to evaluate programs designated arbitrarily as I, II, III, IV, and V. The third column identifies the tables in Appendix F that provides the criteria for each score. The tables in Appendix F have corresponding tables (III-1 through III-17, excluding Table III-11) earlier in the text and

include maximum point columns and additional columns for evaluating up to five programs (I, II, etc.).

B. Qualitative Evaluation Protocol

While the scoring system described above allows programs to be compared numerically, it may not provide a good measure of the quality of the program. One way to provide a measure of quality is to assign letter grades, similar to educational institutions. In this case, various program segments or categories could be assigned a letter grade (i.e., A, B, C, D, F) based on the reviewer's best judgment. The evaluation tables used above to determine scores can be used to assign letter grades as shown below in Table VI-2. In cases where the program does not address a particular category, no grade would be assigned. This qualitative protocol would allow programs with similar numerical scores to be also judged based on the grades assigned to the same program categories.

Table VI-2 - Overall Grades for IAQ Impact of Product/Material Emissions

			Program Evaluation Grade				
Evaluation Criteria	**Letter Grade**	**See Table**	**I**	**II**	**III**	**IV**	**V**
Product/Material Assessment							
Use existing information							
MSDS	**A - F**	F-2					
VOC content/Manufacturer supplied information	**A - F**	F-2					
Source emission models available	**A - F**	F-3					
Samples collected for evaluation	**A - F**	F-4					
Benchtop laboratory methods							
Direct analysis	**A - F**	F-5					
Static headspace analysis	**A - F**	F-5					
Dynamic chamber testing							
Chamber characteristics adequate	**A - F**	F-6					
Test sample properly conditioned	**A - F**	F-7					
Test sample properly prepared	**A - F**	F-8					
Test conditions specified	**A - F**	F-9					
Chemical measurements described	**A - F**	F-10					
Emission rates determined	**A - F**	F-11					
Exposure Assessment							
Scenario developed	**A - F**	F-12					
IAQ/exposure model used	**A - F**	F-13					
Exposure concentration/dose determined	**A - F**	F-14					
Health/Risk Assessment							
Health hazards identified	**A - F**	F-15					
Qualitative assessment conducted	**A - F**	F-16					
Quantitative assessment conducted	**A - F**	F-17					

C. Semi-Quantitative Evaluation Protocol

Instead of using letter grades for the various program categories, a number grade (e.g., 1 – 10) could be used. This would provide the same information as the letter grading system, but would provide somewhat more flexibility. One of the problems with this approach is the potential for evaluators to add up all the scores. Since this system does not weigh the categories (like the quantitative system) programs, similar total scores would not indicate similar programs.

D. Recommendation

It is recommended that both the Quantitative Evaluation Protocol and the Qualitative Evaluation Protocol be used to evaluate existing material assessment programs. These evaluations will provide both a numerical score and a judgment of program quality. The Semi-Quantitative Evaluation Protocol is not recommended.

VII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The following conclusions are presented to highlight a few of the significant findings of the study. This list is not all-inclusive, but is intended to focus attention on some important issues.

1. Product/Material Assessment

"Green product" assessments rely on available information and cover a wide range of energy, environmental and life-cycle issues. Such programs generally do inadequate assessments of indoor emissions due to a lack of emissions information.

Product testing programs assign labels or certificates to products based on pass/fail criteria tied to emission limits determined by dynamic chamber testing. *Pass/fail emission limit criteria* include three types:

a. *Low emission limits* based on TVOC and a limited number of VOCs (e.g., Green Label, Indoor Advantage, Nordic Swan, Finland Emission Classification)

b. *Health effect limits* based on extensive lists of toxic compounds (e.g., California 01350/CHPS, FloorScore, Indoor Advantage Gold, CEN prEN 15052)

c. *Combination low emission and health effects limits* based on TVOC and individual VOCs with health based limits and product specific emissions (e.g., Greenguard and Green Label Plus limits for carpet and carpet adhesives)

2. Exposure Assessment

Existing programs use *simple one compartment, no sink, steady state IAQ models* to determine occupant exposure based on emission factors derived from dynamic chamber testing. Different *exposure scenarios* are used by the existing programs, so a direct comparison of emission factor limits between programs is difficult.

3. Health/Risk Assessment

There is little consistency among the existing certification programs. Various programs use *different health effects limits* for toxic air contaminants (e.g., ½ CREL, 1/10 TLV, 1/100 TLV) and *different lists of compounds* are used (California - CREL, ACGIH – TLV). Numerical limits are not assigned for *carcinogens or reproductive toxicants*.

4. Current Assessment/Certification Programs

Seven U.S. organizations have developed *product label/certification programs* that require emissions testing to validate emissions limits. At least seven additional programs provide limited indoor emissions assessments as part of *"green building" evaluations*. A large number of foreign assessment programs exist, including five European product/label certification programs.

5. Emissions Testing Laboratories

Only four U.S. laboratories provide *commercial indoor material emissions testing* services. While *accreditation programs* are available for analytical chemistry labs, no such programs exist for material emissions testing labs.

6. Evaluation Protocols for Rating Assessment Programs

Evaluation criteria for various aspects of assessment and testing programs were developed and presented in tabular form. *Quantitative and qualitative schemes* were also developed.

B. Recommendations

The following recommendations are intended to provide guidance for improving existing and future indoor emissions assessment programs:

1. *Assessments relying on available information, including "green building" programs, must inform the user of the limitations of the IAQ portion of the program*. These limitations include: no direct measurement of VOC emissions, no occupant exposure determination, and no quantitative health risk calculations.

2. For *material/product testing programs*, several improvements are needed:

a. *Testing laboratory accreditation standards should be developed*. Such standards should apply to all indoor product emission testing programs.

b. All program emission criteria should *include both emission factor and indoor concentration limits*. Indoor concentration limits should be expressed in units of $\mu g/m^3$. If ppm units are used, the equivalent $\mu g/m^3$ value must be provided.

c. All programs should *use the same occupant exposure scenarios* for equivalent products/materials to allow direct comparison of chamber test results.

d. *The use of TVOC emission limits should be minimized.* It is recognized that TVOC levels are not good predictors of health effects, but TVOC levels can be used as indications of "low-emitting" products. To the extent that TVOC limits are used,

the definition should be standardized based on the total area of the chromatogram between C5 to C17 or C6 to C16 assuming an FID or GC/MS response to toluene.

e. *Product specific emission limits should be developed*. Emission levels tailored to specific products can compare emissions to published health effects data (e.g., the Green Label Plus program specifies limits for known carpet emissions based on California CREL limits). This approach reduces the number of compounds to be measured. Even with a reduced number of compounds, VOC spikes not on the target list require evaluation.

3. The improvement most needed in the health/risk assessment portion of the programs is the *development of consistent criteria for indoor VOCs*. Comparison of existing programs shows wide disparity between the limiting concentrations (e.g., ½ CREL, 1/10 TLV, 1/100 TLV, CEN's LCI). In addition, the VOCs on the various lists are different. Also, the exposed population (children, elderly, healthy adult, etc.) should be considered. Finally, the limits on carcinogens and reproductive toxicants are not consistent between the programs.

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APPENDICES

APPENDIX A – Flow Charts Of IAQ Impact Of Indoor Materials And Products

IAQ Impact of Indoor Materials and Products

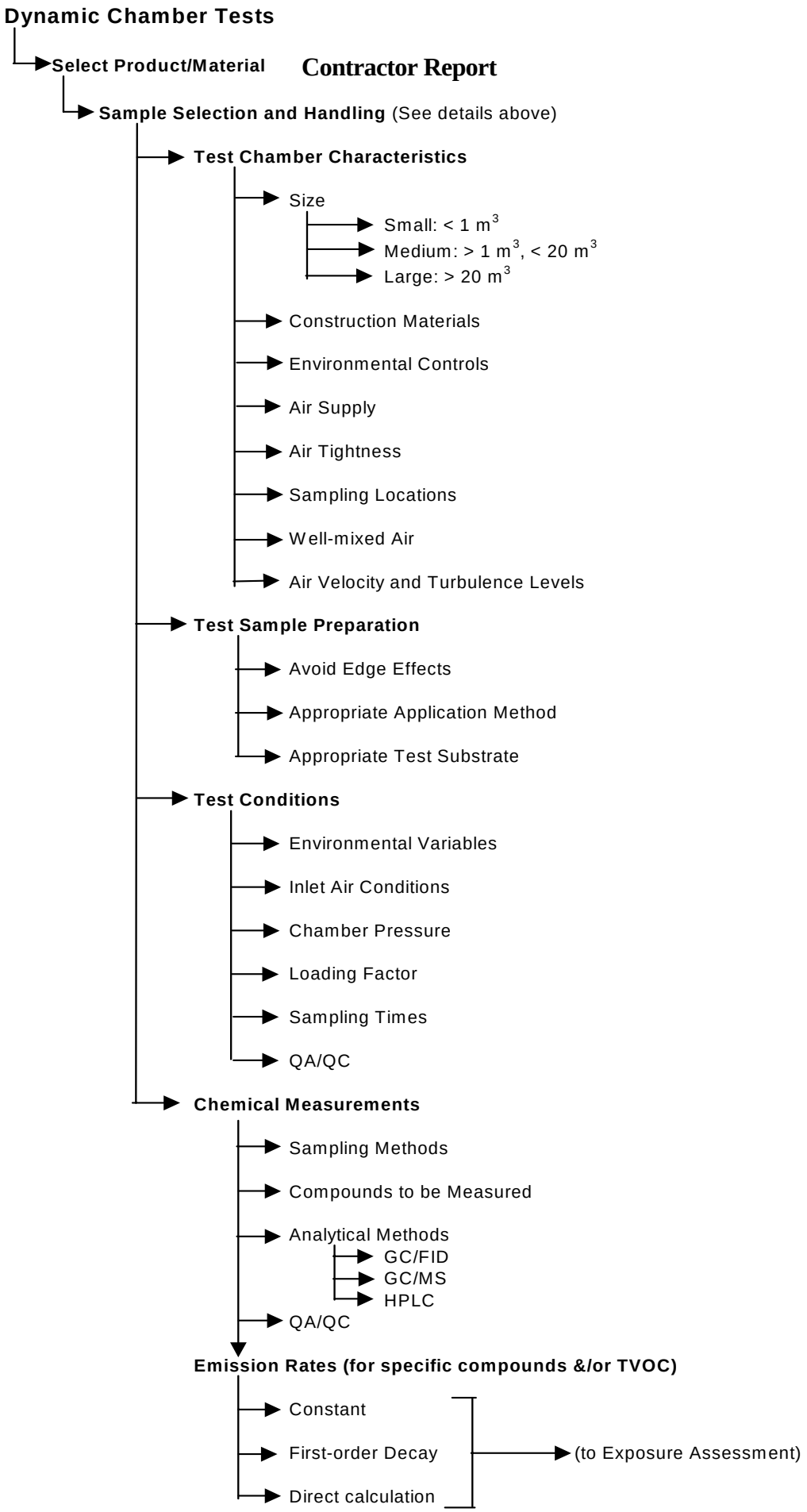
Product/Material Assessment

Use Available Information

- **Select Product/Material**
  - MSDS; VOC Content → (To Qualitative Health Assessment)
  - Source Emission Models → (To Exposure Assessment)

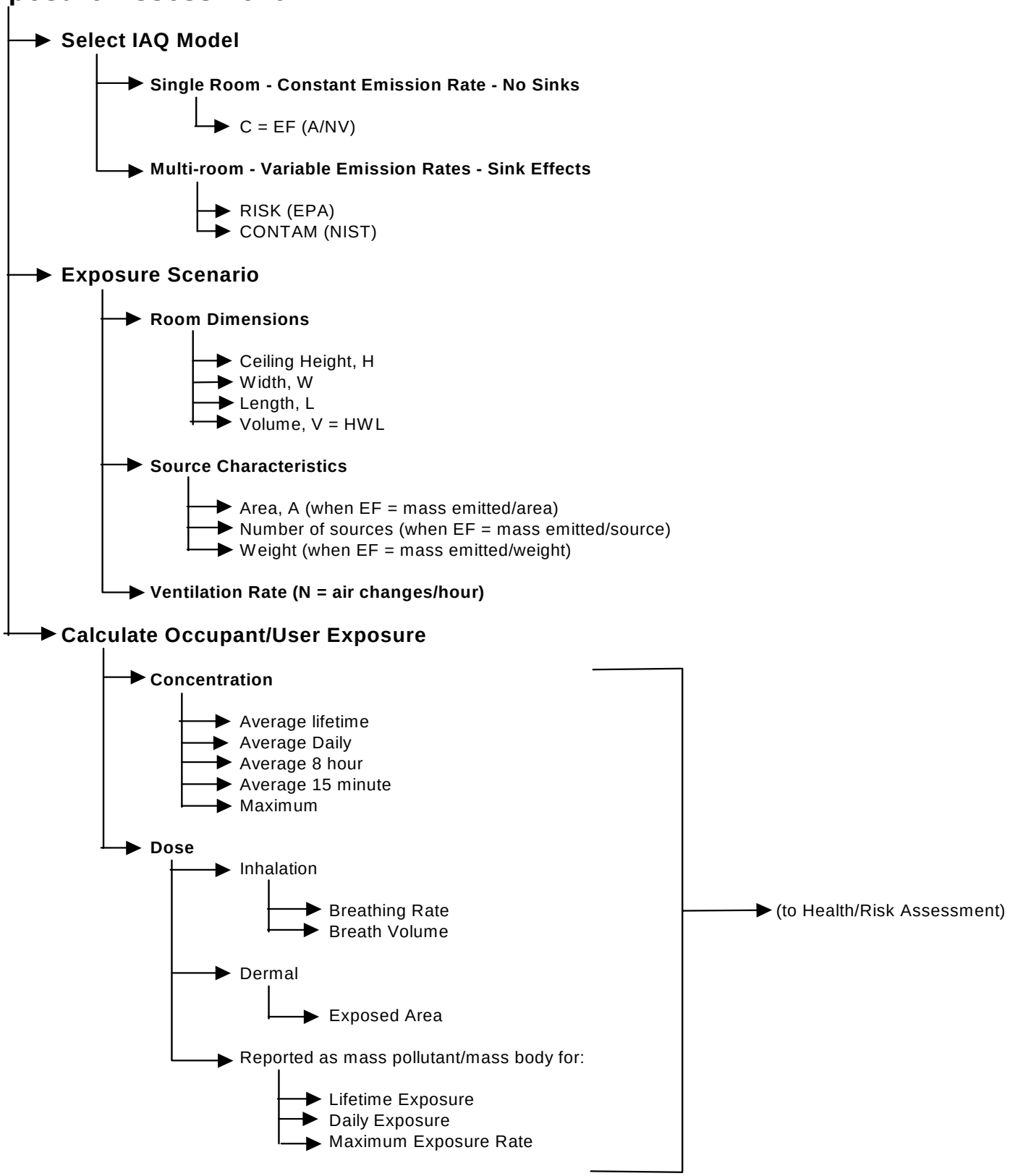
Benchtop Test Methods

- **Select Product/Material**
  - **Sample Selection and Handling**
    - Where is Sample Collected?
    - What Type of Sample is Collected?
    - What is the Sample Size?
    - How Often are Samples Collected?
    - Who Collects the Sample?
    - How is the Sample preserved, packaged, stored, and conditioned?
    - What is the Sample History?
    - ***Direct Product Analysis*** *(Also see Chemical Measurments below)*
      - Chemical Measurements (See details below)
        - *Product VOC Composition* → (To Qualitative Health Assessment)
    - ***Headspace Analysis*** *(Also see Chemical Measurments below)*
      - Chemical Measurements (See details below)
        - *Emission VOC Composition* → (To Qualitative Health Assessment)

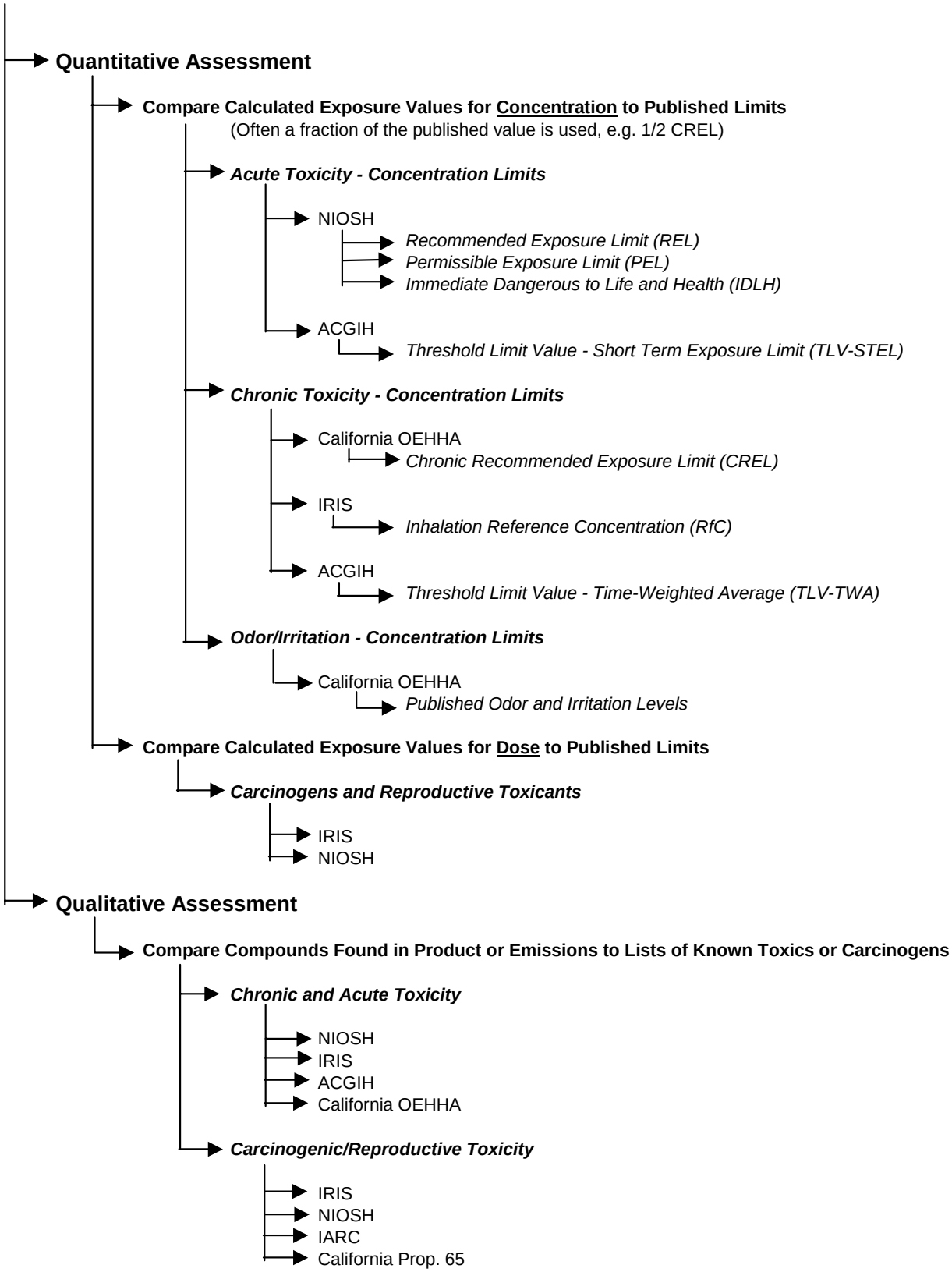

Dynamic Chamber Tests
Select Product/Material
Contractor Report
Sample Selection and Handling (See details above)
Test Chamber Characteristics
Size
Small: < 1 m3
Medium: > 1 m3, < 20 m3
Large: > 20 m3
Construction Materials
Environmental Controls
Air Supply
Air Tightness
Sampling Locations
Well-mixed Air
Air Velocity and Turbulence Levels
Test Sample Preparation
Avoid Edge Effects
Appropriate Application Method
Appropriate Test Substrate
Test Conditions
Environmental Variables
Inlet Air Conditions
Chamber Pressure
Loading Factor
Sampling Times
QA/QC
Chemical Measurements
Sampling Methods
Compounds to be Measured
Analytical Methods
GC/FID
GC/MS
HPLC
QA/QC
Emission Rates (for specific compounds &/or TVOC)
Constant
First-order Decay
Direct calculation
(to Exposure Assessment)

IAQ Impact of Indoor Materials and Products

Exposure Assessment



Health/Risk Assessment



APPENDIX B – Processes And Factors Affecting Emission Rates

Many factors affect the emission rates of VOCs from indoor materials. Some of the factors are related to the source, others are dependent on the environment where the source is used or tested. The factors fall into three categories:

A) Mass Transfer Processes

Fundamental mass transfer processes that control the emissions of VOCs include: evaporation, sorption, diffusion, and convection. (Guo, 2002a; Sparks *et al*, 1996; Little and Hodgson, 1996).

1) Evaporation is the predominant mechanism controlling the initial emissions from wet materials. For a given VOC:

$$E_V = k_m(C_s - C_a) \qquad \text{(B-1)}$$

where E_V is the evaporation rate, k_m is the mass transfer coefficient, C_s is the vapor concentration at the surface of the material, and C_a is the vapor concentration in the overlying air. The mass transfer coefficient is a function of the velocity and turbulence of the air above the material.

2) Sorption processes describe how VOC molecules interact at the surface of the material. VOC adsorption to and desorption from material surfaces is often called the "sink effect". Several sorption isotherm theories (Langmuir, Freundlich, Brunauer-Emmett-Teller [BET]) can be used to determine the sorption rates. For a given VOC and material, the Langmuir theory is expressed as:

$$k_a C_a = k_d M_e \qquad \text{(B-2)}$$

where k_a is the adsorption rate constant, C_a is the equilibrium VOC concentration in the air, k_d is the desorption rate constant, and M_e is the equilibrium VOC mass in the sink material. Thus, according to the Langmuir theory, the adsorption rate is proportional to the VOC concentration in the air and the desorption rate is proportional to the VOC mass in the sink (Tichenor *et al*, 1991).

3) Diffusion processes determine emission rates in two ways:

- The movement of VOC molecules within a material affects the emissions at the surface. This *internal diffusion* is often the limiting factor for the VOC emission rate from dry materials, including dried paints. Internal diffusion of a specific VOC in a material can be represented by Fick's Law as:

$$F(x) = -D(dC/dx) \qquad \text{(B-3)}$$

where F(x) is the mass flux of the VOC at a distance x from the surface of the material, D is the diffusion coefficient of the VOC in the material, and dC/dx is the concentration gradient in the material.

- After a molecule is emitted from a material it must diffuse through the boundary layer above the surface. The rate of this *external diffusion* is controlled by the VOC diffusion coefficient in air, the level of turbulence, and the thickness of the boundary layer.

4) Convection describes the bulk flow of air away from the emitting surface. Convective mass transfer moves the VOCs into the air and contributes to mixing. Without convection, the air above the emitting surface would become saturated and the emission rate would tend towards zero.

B) Environmental Variables

Based on the mass transfer phenomena discussed above, a number of environmental variables are important in determining the emission rates of VOCs (ASTM, 2001). The following parameters may be critical in testing for VOC emissions: temperature, humidity, air change rate, air velocity, and air turbulence.

1) Temperature affects the following: vapor pressure, adsorption rate, desorption rate, and diffusion rate. Thus, higher temperatures will mean higher emission rates due to evaporation, desorption, and diffusion.

2) Humidity generally has little effect on emission rates, except for formaldehyde and other water soluble gases. An increase in humidity can cause increases in emission rates for such compounds.

3) Air change rate describes the exchange of indoor and outdoor air. Often called the *ventilation rate*, it is usually reported as ACH (air changes per hour) and is defined as the volume of air entering (and leaving) a given space in one hour divided by the volume of the space. The higher the ACH, the greater the dilution of the indoor air and the lower the concentration of VOCs emitted from indoor sources. For evaporative sources, the emission rate would increase with higher ACH due to the lower value of C_a (see Eq. B-1). For sources with emission rates limited by internal diffusion, variations in the ACH are not critical. For a well-mixed space, indoor concentration is related to air change rate as follows:

$$C_t = C_0(e^{-Nt}) \qquad \text{(B-4)}$$

where C_t is the concentration at time t, C_0 is the concentration at time zero, and N is the air change rate. This describes the dilution of an indoor space with no sources as shown in Figure B-1.

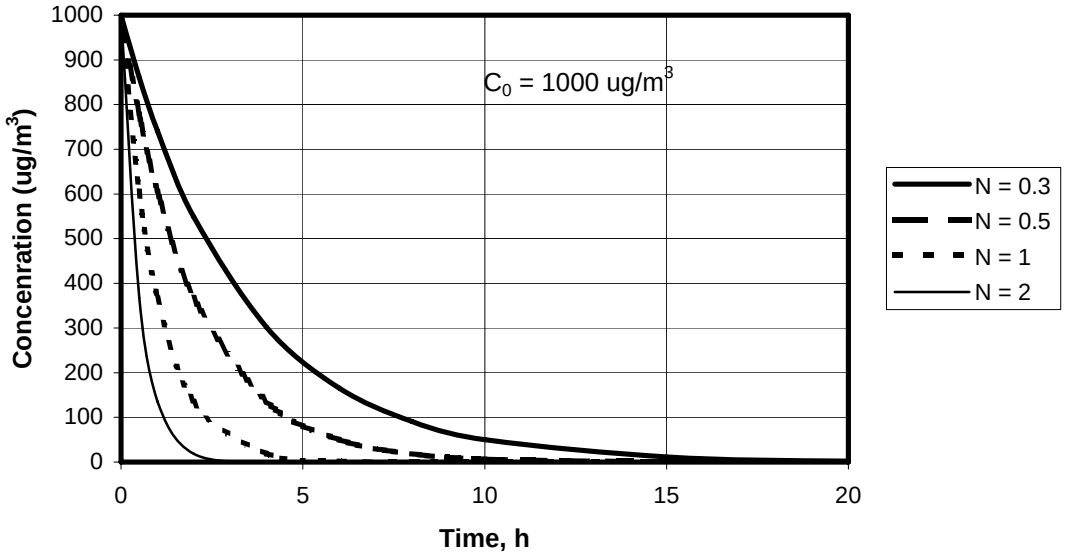


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Figure B-1 – Concentration Decay by Dilution

4) Velocity and turbulence affect the mass transfer rate at the surface of the emitting material. Generally, the higher the velocity and greater the turbulence, the faster the mass transfer. In a practical sense, above a certain velocity and level of turbulence, the resistance to mass transfer in the boundary layer is minimized (i.e., the mass transfer coefficient reaches its maximum value.)

C) Product Characteristics and Composition

The characteristics and composition of indoor materials and products play a major role regarding their emissions. The number and types of chemical in their make-up are of obvious importance. The chemical properties (e.g., vapor pressure, diffusion coefficients, molecular weight and size) impact the emission rates. As discussed previously, wet and dry material have distinctly different emission rate profiles, especially early in the testing process. Finally, whether the material is a single product (e.g., paint) or a complex assemblage (i.e., furniture) will affect its emission characteristics.

APPENDIX C – Calculating Emission Rates from Dynamic Chamber Data

Dynamic chamber test results are used to determine emission rates of individual VOCs and TVOC. Equation III-4 is the basic mass balance equation applied to dynamic chambers:

$$V[dC(t)/dt] = ER(t) - Q[C(t) - C(in)] \quad \text{(III-4)}$$

This relationship can be used to develop equations for several emission rate scenarios, including constant emissions, first order emission rate decay, and direct calculation independent of any model.

For *constant emission rates* (or when the emission rate is changing very slowly), $dC(t)/dt \simeq 0$ and equation (III-4) converts to:

$$ER(t) = Q[C(t) - C(in)] \quad \text{(C-1)}$$

Assuming $C(in) \simeq 0$, this equation is often presented as:

$$EF = C\,(N/L) \quad \text{(C-2)}$$

where, using typical units, EF is the emission factor ($\mu g/m^2$-hr), C is the chamber concentration ($\mu g/m^3$), N is the air change rate (1/h), and L (loading factor) is the ratio of the sample area to the chamber volume (m^2/m^3).

In some cases, empirical models are used to describe the emission rate decay. For some wet sources, a *first order decay* is assumed:

$$EF(t) = EF(0)e^{-kt} \quad \text{(C-3)}$$

where EF(0) is the emission factor at time 0 and k is the first order decay rate. Substituting equation (C-3) into equation (III-4) gives:

$$V/A[dC(t)/dt] = EF(0)e^{-kt} - Q/A[C(t) - C(0)] \quad \text{(C-4)}$$

where A is the sample area (m^2). For a constant emission rate, k = 0, and the solution for equation (C-4) is:

$$C = L(EF)(e^{-Nt})/N \quad \text{(C-5)}$$

The following graph (Figure C-1) shows how the concentration in test chamber (or well mixed room) would change over time for various air change rates (N) with a constant emission factor (EF = 100 $\mu g/m^2$-hr) and a product loading (L) of 0.4 m^2/m^3.

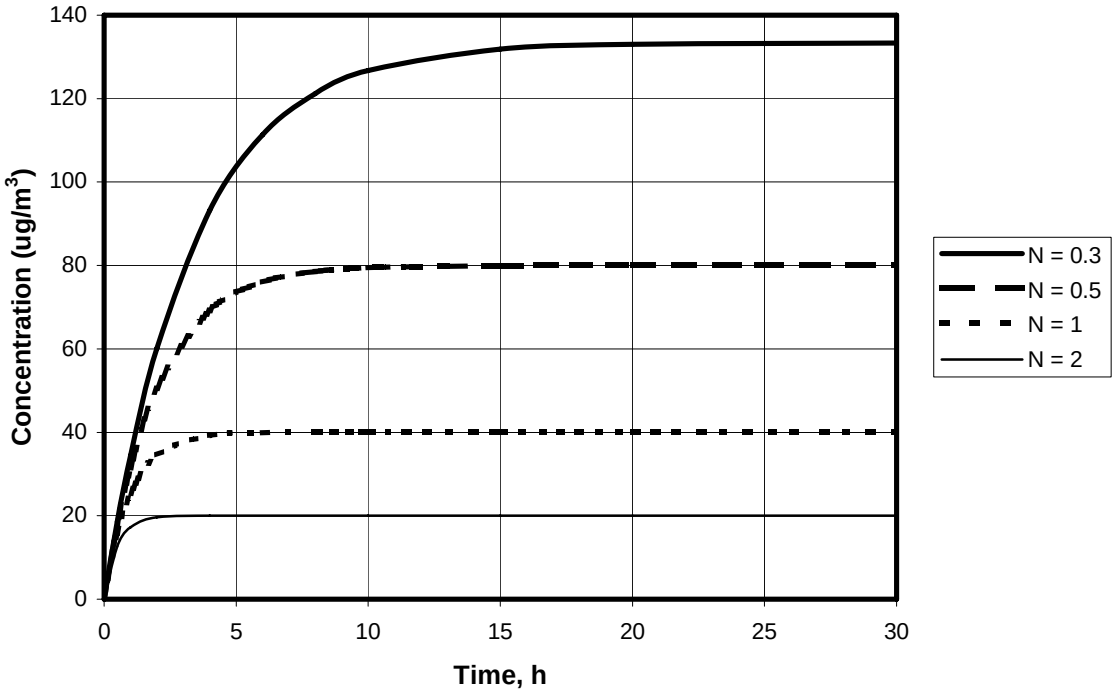

Figure C-1 – Effect of Air Change Rate (N) on Concentration for Constant Emission Rates

The solution to equation (C-4) can be used with non-linear regression techniques to fit the chamber concentration vs. time data to obtain EF(0) and k. A subroutine in the IAQ model RISK (Sparks, 2005) performs this function:

Step 1 – On the first screen after starting the model, click on the Scenarios button.

Step 2 – On the next screen click on the Rooms button.

Step 3 – Set the Number of Sources to 1 and set the Source Model to R0k.

Step 4 – Click on Calculate, then R0k.

Step 5 – Maximize the screen and insert the chamber information into the Environmental Data, including an estimate of the maximum concentration and time it occurs.

Step 6 – Enter the time/concentration data from the chamber test. (If available in a spreadsheet, the data can be copied and pasted using the edit command in the upper left hand corner.) Click on Calculate, then R0k. The model calculates R0 (EF_0) and k. The model will also calculate the predicted chamber concentration that follows the 1st order decay and plot the results.

When a specified emission rate model is not assumed, the *ASTM direct calculation method* can be used (ASTM, 1997). The chamber concentration vs. time data are analyzed by the following equation:

$$EF(t_1) = (\Delta C(t_1)/\Delta t_1 + NC(t_1)/L) \qquad \text{(C-6)}$$

Where $\Delta C(t_1)/\Delta t_1$ is the slope of the concentration vs. time curve at time t_i. Electronic spreadsheets are used to make these calculations. (An Excel spreadsheet has been prepared and can be made available.)

The following table and graph illustrate these calculations. Table C-1 shows the concentration vs. time data for a typical small chamber test (N = 1 h^{-1}, L = 0.4 m^2/m^3).

Table C-1 – Concentration vs. Time for a Small Chamber Test

Time, h	Chamber Concentration, µg/m^3
0	0
0.5	70
1	100
2	160
4	200
6	150
8	120
10	100
15	50
20	40
30	20

The data in Table C-1 were used in the RISK subroutine, as described above, to determine the coefficients assuming a 1st order decay: EF_0 = 535 µg/m^2-hr and k = 0.0832 h^{-1}. An Excel spreadsheet was used to directly calculate the emission factors using the ASTM method of equation (C-6). Finally, equation (C-2) was used to calculate emission factors. (Equation (C-2) is commonly used to calculate emission factors from chamber data in this manner, even though the emission rates are not constant.)

Figure C-2 shows the chamber data and predicted concentrations based on the 1st order decay coefficients. The figure also shows three sets of emission factors: a) emission factors calculated directly using the ASTM method, b) a curve showing the 1st order decay emission factors, and c) emission factors assuming constant emission rates. Note that the emissions factors calculated from the three methods vary widely early in the chamber test when the concentrations are changing rapidly. (During this time period, the ASTM method gives the most realistic values.) Later on, when the concentrations are changing more slowly, the emission factors from the three methods converge to similar values.

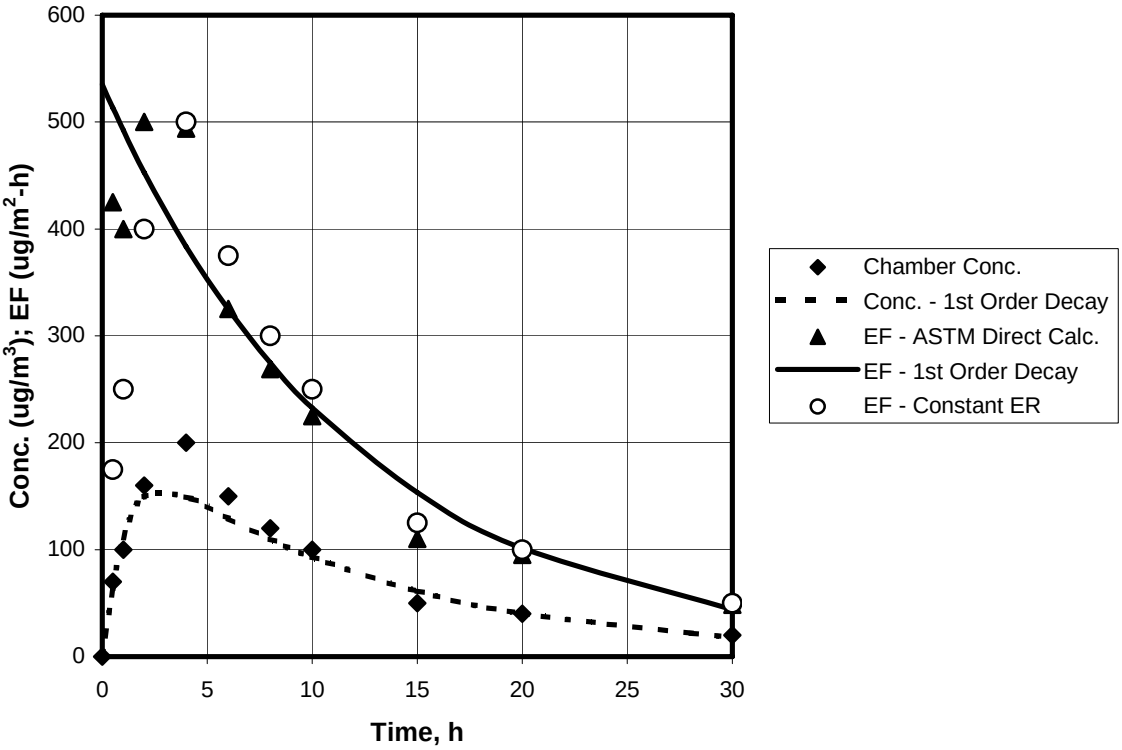

Figure C-2 – Chamber Concentration and Emission Factors – Three Calculation Methods

APPENDIX D – Sample MSDS

MATERIAL SAFETY DATA SHEET — 16 Sections

SECTION 1 — CHEMICAL PRODUCT AND COMPANY IDENTIFICATION

Product Identifier			[WHMIS Classification]
Product Use			
Manufacturer's Name		Supplier's Name	
Street Address		Street Address	
City	Province	City	Province
Postal Code	Emergency Telephone	Postal Code	Emergency Telephone
Date MSDS Prepared	MSDS Prepared By		Phone Number

SECTION 2 — COMPOSITION/INFORMATION ON INGREDIENTS

Hazardous Ingredients *(specific)*	%	CAS Number	LD_{50} of Ingredient *(specify species and route)*	LC_{50} of Ingredient *(specify species)*

SECTION 3 — HAZARDS IDENTIFICATION

Route of Entry ☐ Skin Contact ☐ Skin Absorption ☐ Eye Contact ☐ Inhalation ☐ Ingestion

[Emergency Overview]

[WHMIS Symbols]

[Potential Health Effects]

SECTION 4 — FIRST AID MEASURES

Skin Contact

Eye Contact

Inhalation

Ingestion

SAMPLE FORMAT PROVIDED BY THE WORKERS' COMPENSATION BOARD OF BRITISH COLUMBIA

57M6 (6/90)

Please continue on reverse side

[Optional, not required under WHMIS]

Product Identifier	– 2 –

SECTION 5 — FIRE FIGHTING MEASURES

Flammable ☐ Yes ☐ No	If yes, under which conditions?	
Means of Extinction		
Flashpoint [° C] and Method	Upper Flammable Limit (% by volume)	Lower Flammable Limit (% by volume)
Autoignition Temperature [° C]	Explosion Data — Sensitivity to Impact	Explosion Data — Sensitivity to Static Discharge
Hazardous Combustion Products		
[NFPA]		

SECTION 6 — ACCIDENTAL RELEASE MEASURES

Leak and Spill Procedures

SECTION 7 — HANDLING AND STORAGE

Handling Procedures and Equipment
Storage Requirements

SECTION 8 — EXPOSURE CONTROL / PERSONAL PROTECTION

Exposure Limits ☐ ACGIH TLV ☐ OSHA PEL ☐ Other (specify)						
Specific Engineering Controls (such as ventilation, enclosed process)						
Personal Protective Equipment ☐ Gloves ☐ Respirator ☐ Eye ☐ Footwear ☐ Clothing ☐ Other						
If checked, please specify type						

[*Optional, not required under WHMIS*]

Product Identifier

SECTION 9 — PHYSICAL AND CHEMICAL PROPERTIES

Physical State	Odour and Appearance	Odour Threshold (ppm)
Specific Gravity	Vapour Density (air = 1)	Vapour Pressure (mm Hg)
Evaporation Rate	Boiling Point (°C)	Freezing Point (°C)
pH	Coefficient of Water/ Oil Distribution	[Solubility in Water]

SECTION 10 — STABILITY AND REACTIVITY

Chemical Stability ☐ Yes ☐ No	If no, under which conditions?
Incompatibility with Other Substances ☐ Yes ☐ No	If yes, which ones?
Reactivity, and under what conditions?	
Hazardous Decomposition Products	

SECTION 11 — TOXICOLOGICAL INFORMATION

Effects of Acute Exposure	
Effects of Chronic Exposure	
Irritancy of Product	
Skin Sensitization	Respiratory Sensitization
Carcinogenicity – IARC	Carcinogenicity – ACGIH
Reproductive Toxicity	Teratogenicity
Embryotoxicity	Mutagenicity
Names of Synergistic Products/ Effects	

[*Optional, not required under WHMIS*]

Please continue on reverse side

Product Identifier	- 4 -

SECTION 12 — ECOLOGICAL INFORMATION

[Aquatic Toxicity]

SECTION 13 — DISPOSAL CONSIDERATIONS

Waste Disposal

SECTION 14 — TRANSPORT INFORMATION

Special Shipping Information	
	PIN
TDG	[DOT]
[IMO]	[ICAO]

SECTION 15 — REGULATORY INFORMATION

[WHMIS classification]	[OSHA]
[SCPA]	[TSCA]
This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all of the information required by CPR.	

SECTION 16 — OTHER INFORMATION

[Optional, not required under WHMIS]

APPENDIX E – Testing and Ventilation Standards

A. Testing Standards

A number of organizations provide guidance for testing and evaluating indoor products and materials. In the US, ASTM (American Society for Testing and Materials) has developed a number of standards in this area. ANSI (American National Standards Institute) is an umbrella organization that pulls together standards from various US interests. ASTM standards are available through ANSI. Outside the US, the two most prominent standards setting organizations are ISO and CEN.

1. American Society for Testing and Materials - ASTM

As shown in the following table, IAQ test methods have been developed into ASTM Standards in three areas: emissions testing, sampling and analysis methods, and exposure assessment. The following ASTM standards are available for purchase at www.astm.org.

ASTM Std. No.	Title	Area
E1333-96	Standard Test Method for Determining Formaldehyde Concentrations in Air and Emission Rates from Wood Products Using a Large Chamber	Emissions Testing
D5582-00	Standard Test Method for Determining Formaldehyde Levels from Wood Products Using a Desiccator	Emissions Testing
D5116-97	Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products	Emissions Testing
D6165-97	Standard Guide on the Composition, Detection, and Identification of the Odors of Paints, Inks, and Related Materials	Emissions Testing
D6177-97	Standard Practice for Determining Emission Profiles of Volatile Organic Chemicals Emitted from Bedding Sets	Emissions Testing
D6330-98	Standard Practice for Determination of Volatile Organic Compounds (Excluding Formaldehyde) Emissions from Wood-Based Panels Using Small Environmental Chambers Under Defined Test Conditions	Emissions Testing
D6670-01	Standard Practice for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials/Products	Emissions Testing
D6803-02	Standard Practice for Testing and Sampling of Volatile Organic Compounds (Including Carbonyl Compounds) Emitted from Paint Using Small Environmental Chambers	Emissions Testing
D7143-05	Standard Practice for Emission Cells for the	Emissions Testing

	Determination of Volatile Organic Emissions from Indoor Materials/Products	
D4507-03	Standard Practice for Sampling Workplace Atmospheres to Collect Gasses or Vapors with Solid Sorbent Diffusive Samplers	Sampling and Analysis
D4947-05	Standard Test Method for Chlordane and Heptachlor Residues in Indoor Air	Sampling and Analysis
D5014-94	Standard Test Method for Measurement of Formaldehyde in Indoor Air (Passive Sampler Methodology)	Sampling and Analysis
D5074-01	Standard Test Method for Nicotine and 3-Ethenylpyridine in Indoor Air	Sampling and Analysis
D6196-03	Standard Practice for Selection of Sorbents, Sampling, and Thermal Desorption Analysis Procedures for Volatile Organic Compounds in Air	Sampling and Analysis
D6306-98	Standard Guide for Placement and Use of Diffusion Controlled Passive Monitors for Gaseous Pollutants in Indoor Air	Sampling and Analysis
D6399-04	Standard Guide for Selecting Instruments and Methods for Measuring Air Quality in Aircraft Cabins	Sampling and Analysis
D5157-97	Standard Guide for Statistical Evaluation of Indoor Air Quality Models	Exposure Assessment
D5791-95	Standard Guide for Using Probability Sampling Methods in Studies of Indoor Air Quality In Buildings	Exposure Assessment
D6178-97	Standard Practice for Estimation of Short-Term Inhalation Exposure to Volatile Organic Chemicals Emitted from Bedding Sets	Exposure Assessment
D6245-98	Standard Guide for Using Indoor Carbon Dioxide Concentrations to Evaluate Indoor Air Quality and Ventilation	Exposure Assessment
D6485-99	Standard Guide for Risk Characterization of Acute and Irritant Effects of Short-Term Exposure to Volatile Organic Chemicals Emitted from Bedding Sets	Exposure Assessment
D6669-01a	Standard Practice for Selecting and Constructing Exposure Scenarios for Assessment of Exposures to Alkyd and Latex Interior Paints	Exposure Assessment

In addition, the following future ASTM Standards, designated as Work Items, are being developed by ASTM sub-committee D22-05 – Indoor Air:

ASTM WK No.	Title	Area
WK2616	Standard Practice for Environmental Chamber Determinations of Indoor-Relevant Emissions of Volatile Organic Compounds and Aldehydes from Small Samples of Building Products	Emissions Testing
WK2618	Standard Practice For Conducting Emission Tests From Carpet Using Small Environmental Chambers	Emissions Testing
WK3118	Standard Practice for Determination of Volatile Organic Compound Emission Factors From Spray-Applied Rigid Polyurethane Cellular Plastic Thermal Insulation Using Small Environmental Chambers Under Defined Test Conditions	Emissions Testing
WK3119	Standard Practice for Determination of Volatile Organic Chemical Emission Factors From Sealant Products Using Small Environmental Chambers Under Defined Test Conditions	Emissions Testing
WK3464	Standard Test Method for Determination of Volatile Organic Compounds in Carpet using Specific Sorbent Tubes and Thermal Desorption/Gas Chromatography	Sampling and Analysis

2. International Organization for Standardization – ISO

ISO is a worldwide standards setting organization comprised of representatives from a multitude of countries; ANSI is the US representative in ISO. ISO's web site is: http://www.iso.org/iso/en/ISOOnline.frontpage. As shown in the following table ISO has developed several standards related to indoor air emissions:

+

ISO No.	Title	Status
16000-1: 2004	Indoor Air – Part 1: General Aspects of Sampling Strategy	Approved
16000-2: 2004	Indoor Air - Part 2: Sampling Strategy for Formaldehyde	Approved
16000-3: 2001	Indoor Air - Part 3: Determination of Formaldehyde and Other Carbonyl Compounds – Active Sampling Method	Approved
16000-4: 2004	Indoor Air – Part 4: Determination of Formaldehyde – Diffusive Sampling Method	Approved
16000-5	Indoor Air – Part 5: Measurement Strategy for Volatile Organic Compounds (VOCs)	Pending
16000-6: 2004	Indoor Air – Part 6: Determination of Volatile Organic Compounds by Active Sampling on Tenax TA Sorbent, Thermal Desorption and Gas Chromatography using MS/FID	Approved
16000-7	Indoor Air – Part 7: Sampling Strategy for Determining	Pending

	Airborne Asbestos Fibre Concentration	
16000-8	Indoor Air – Part 8: Ventilation Rate Measurement	Pending
16000-9	Indoor Air – Part 9: Determination of the Emissions of Volatile Organic Compounds – Emission Test Chamber Method	Approved
16000-10	Indoor Air – Part 10: Determination of the Emissions of Volatile Organic Compounds – Emission Test Cell Method	Approved
16000-11	Indoor Air – Part 11: Determination of the Emission of Volatile Organic Compounds – Sampling, Storage of Samples, and Preparation of Test Specimens	Approved
16017-1: 2002	Indoor, Ambient, and Workplace Air – Sampling and Analysis of Volatile Organic Compounds by Sorbent Tube/Thermal Desorption/capillary Gas Chromatograph – Part 1: Pumped Sampling	Approved
16017-2: 2003	Indoor, Ambient, and Workplace Air – Sampling and Analysis of Volatile Organic Compounds by Sorbent Tube/Thermal Desorption/capillary Gas Chromatograph – Part 2: Diffusive Sampling	Approved

3. European Committee for Standardization – CEN

CEN was founded in 1961 by the national standards bodies in the European Economic Community and EFTA countries. The CEN includes 28 countries (the EU, plus Iceland, Norway, and Switzerland). The purpose of the CEN is to develop voluntary technical standards which promote free trade, the safety of workers and consumers, interoperability of networks, environmental protection, exploitation of research and development programs, and public procurement. The CEN web site is: http://www.cenorm.be/cenorm/index.htm. Relevant CEN standards are given below. Note the correlation with ISO standards.

CEN No.	Title	Status
ENV 13419-1: 1999	Building Products – Determination of the Emission of Volatile Organic Compounds – Part 1: Emission Test Chamber Method	Approved
ENV 13419-2: 1999	Building Products – Determination of the Emission of Volatile Organic Compounds – Part 2: Emission Test Cell Method	Approved
ENV 13419-3: 1999	Building Products - Determination of the Emission of Volatile Organic Compounds – Part 3: Sampling, Storage of Samples, and Preparation of Test Specimens	Approved
EN ISO 16017-1: 2002	See ISO 16017-1: 2002 above	Approved
EN ISO 16017-2: 2003	See ISO 16017-2: 2003 above	Approved

In addition, CEN is developing draft standard No. prEN 15052 – "Resilient, textile, and laminated floor coverings – Evaluation and requirements of volatile organic compounds (VOC) emissions". This dynamic chamber testing standard proposes emission limits based on an extensive list of VOCs with recommended LCI (Lowest Concentration of Interest) values. (This list and the LCI values are not comparable to or consistent with the California CREL list)

B. Ventilation Standards

ASHRAE (American Society of Heading, Refrigeration and Air-conditioning Engineers) has developed IAQ standards that specify ventilation requirements to achieve acceptable IAQ. The following standards are available for purchase at www.ashrae.org. ASHRAE standards are also available from ANSI.

1. Standard 62.1 – Ventilation for Acceptable Indoor Air Quality

This standard specifies minimum ventilation rates and indoor air quality that will be acceptable to human occupants and to minimize the potential for adverse health effects. This standard is intended for regulatory application to new buildings, additions to existing buildings, and changes to existing buildings. This standard is also used to guide the improvement of indoor air quality in existing buildings. Two methods are used to determine ventilation rates: The *Ventilation Rate Procedure* specifies minimum ventilation rates based on the use of the space (e.g., office, classroom, kitchen, etc.). The *IAQ Procedure* uses contaminant emission rates and IAQ modeling to determine minimum ventilation rates. ASHRAE has developed a Users Manual to assist in applying the standard to specific situations

2. Standard 62.2 - Ventilation for Acceptable Indoor Air Quality in Low-Rise Residential Buildings

This standard defines the minimum requirements for mechanical and natural ventilation systems to provide acceptable indoor air quality in low-rise residential buildings. This standard applies to single-family houses and multifamily structures of three stories or fewer above grade, including manufactured and modular houses. It does not apply to transient housing such as hotels, motels, nursing homes, dormitories, or jails. This standard considers chemical, physical, and biological contaminants that can affect air quality. While acceptable indoor air quality is the goal of this standard, it will not necessarily be achieved due to factors such as: diversity of sources and contaminants, the range of susceptibility in the population, occupant perception and acceptance of indoor air quality, unacceptable outdoor air, improperly operated and maintained ventilation systems, and occurrence of high-polluting events. This standard does not address unvented combustion space heaters.

APPENDIX F – Evaluation Criteria Tables

The following tables provide the quantitative rating criteria for evaluating assessment programs based on the scientific and technical issues presented earlier. In addition, five columns are included for inserting scores for specific programs.

Table F-1 - Overall Scoring Criteria for IAQ Impact of Product/Material Emissions

Maximum Points = 100

			Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**See Table**	**I**	**II**	**III**	**IV**	**V**
Product/Material Assessment	***50***						
Use existing information							
MSDS	**10**	F-2					
VOC content/Manufacturer supplied information	**5**	F-2					
Source emission models available	**10**	F-3					
Samples collected for evaluation	**5**	F-4					
Benchtop laboratory methods							
Direct analysis	**10**	F-5					
Static headspace analysis	**10**	F-5					
Dynamic chamber testing							
Chamber characteristics adequate	**10**	F-6					
Test sample properly conditioned	**5**	F-7					
Test sample properly prepared	**5**	F-8					
Test conditions specified	**10**	F-9					
Chemical measurements described	**5**	F-10					
Emission rates determined	**10**	F-11					
Exposure Assessment	***25***						
Scenario developed	**10**	F-12					
IAQ/exposure model used	**5**	F-13					
Exposure concentration/dose determined	**10**	F-14					
Health/Risk Assessment	***25***						
Health hazards identified	**5**	F-15					
Qualitative assessment conducted	**5**	F-16					
Quantitative assessment conducted	**15**	F-17					
TOTAL POINTS =							

Table F-2 – Scoring Criteria for Product Assessment Using Available Information

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
MSDS available/used						
Hazardous ingredients listed	**2**					
Product composition provided	**2**					
Exposure limits given (PEL, TLV, etc.)	**2**					
Health hazard information						
Route of entry	**1**					
Toxicity	**1**					
Carcinogenicity	**1**					
Reproductive effects	**1**					
VOC content provided	**4**					
Paint/coating (gm/liter, lb/gal)						
Consumer product (% VOC by weight)						
Other information provided by manufacturer	**1**					
TOTAL POINTS =	***15***					

Table F-3 – Scoring Criteria for Source Emission Models

Max**imum Points = 10**

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Source information available	**2**					
Chemical composition						
Application rate (e.g., kg/m^2 for paint)						
Empirical models*						
Parameters available	**3**					
Model validated	**2**					
Theoretical models*						
Coefficients available	**3**					
Model validated	**2**					
All model inputs available	**2**					
Model results are "reasonable"	**1**					
TOTAL POINTS =						

* Models are either empirical or theoretical, so only 5 points are available for both.

Table F-4 – Scoring Criteria for Sample Selection and Handling

Program Evaluation Points

Evaluation Criteria	Max. Points	I	II	III	IV	V
Product/material manufacturer	**1**					
Identification						
Location						
Manufacture date						
Sample collection	**1**					
Location						
Location consistent with project objectives						
Collection date						
Sample size (area, weight, volume, etc.)						
Number of samples						
Collection frequency						
Collection personnel	**1**					
Name						
Contact information						
Sample handling specified	**2**					
Sample preservation						
Sample packaging						
Sample transportation requirements						
Transportation dates						
TOTAL POINTS =	***5***					

Table F-5 – Scoring Criteria for Direct Product Analysis and Static Headspace Testing

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Direct product analysis	***10***					
Test method specified (e.g., EPA Method 24)	**1**					
Analytical equipment identified	**1**					
VOC content reported	**3**					
Individual compounds identified	**5**					
Static headspace analysis	***10***					
Test method specified (e.g., EPA Method 3810)	**1**					
Analytical equipment identified	**1**					
VOC emissions reported	**3**					
Individual compounds identified	**5**					
TOTAL POINTS =	***20***					

Table F-6 – Scoring Criteria for Dynamic Test Chamber Characteristics

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Construction						
Non- adsorptive, non-reactive interior surfaces	**3**					
Stainless steel						
Glass						
Non-adsorptive, non-reactive seals						
Air tight construction	**1**					
Well-mixed air	**1**					
Fan						
Inlet/outlet diffusers						
Environmental controls	**2**					
Temperature control						
Humidity control						
Flow control						
Air supply	**2**					
VOC control – activated carbon						
VOC control – catalytic oxidation						
VOC control - other						
Particulate control – HEPA filters						
Sampling locations	**1**					
Small chamber – at outlet						
Large chamber – multiple locations						
TOTAL POINTS =	***10***					

Table F-7 – Scoring Criteria for Sample Conditioning

Evaluation Criteria	Target Value	Accuracy	Max. Points	Program Evaluation Points I	II	III	IV	V
Environmental controls								
Air flow	1 – 2 ACH	± 0.4 ACH	**1**					
Temperature	23°C	± 2°C	**1**					
Relative humidity	50%	± 10%	**1**					
Inlet air quality								
Individual VOCs, incl. formaldehyde	≤ 5 μg/m^3	± 2 μg/m^3	**1**					
Total VOCs (as toluene)	≤ 25 μg/m^3	± 5 μg/m^3	**1**					
		TOTAL POINTS =	***5***					

Table F-8 – Scoring Criteria for Test Sample Preparation

Evaluation Criteria	Max. Points	Program Evaluation Points I	II	III	IV	V
Edge effects avoided or treated consistent with use	**1**					
Edges sealed or treated consistently						
Sample tray used						
Application method defined	**2**					
Paint – brush, roller, spray, slit applicator						
Adhesive – saw tooth or square tooth applicator						
Caulk – bead applicator (caulking "gun")						
Test substrate specified	**2**					
TOTAL POINTS =	***5***					

Table F-9 – Scoring Criteria for Dynamic Chamber Testing Conditions

Evaluation Criteria	Target Value	QA/QC Limits Accuracy / Precision	Max. Points	Program Evaluation Points I	II	III	IV	V
Environmental variables								
Air flow	1.0 ACH*	±0.03ACH / ±0.05ACH	**1**					
Temperature	23°C	±0.5°C / ±1°C	**1**					
Relative humidity	50%	±5% / ±5%	**1**					
Velocity over sample surface	0 – 0.2 m/s	Based on method used						
Inlet air quality								
Specified individual VOCs	< 2 μg/m^3	±2 μg/m^3 / ±15% RSD	**2**					
Formaldehyde	< 5 μg/m^3	±2 μg/m^3 / ±15% RSD	**1**					
Total VOCs (as toluene)	< 25 μg/m^3	±10 μg/m^3 / ±15% RSD	**1**					
Chamber pressure	10 – 30 Pa	±5 Pa / ±5 Pa	**1**					
Sample size			**1**					
Area	Based on loading	±1% / ±1%						
Mass (weight)	-	±1% / ±1%						
Sampling times	Mid-point of sampling interval specified	±1% / ±1%	**1**					
		TOTAL POINTS =	***10***					

* An air change rate of 1 ACH is a default value. Testing conditions (chamber size, sample loading, and testing goals) may justify different values.

Table F-10 – Scoring Criteria for Chemical Emissions Measurements

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Compounds to be measured	**2**					
Target compounds						
Large "spike" compounds						
TVOC						
Chamber air sampling methods	**1**					
Closed loop sampling						
Whole air samples – canisters, syringes						
Sorbent samples						
Analytical methods	**1**					
GC/FID – for TVOC						
GC/MS – for individual VOCs						
HPLD – for aldehydes						
Sample volume	**1**					
Sampling flow rate (e.g., 300 cc/min)						
Sampling durations (e.g., 1 hour)						
TOTAL POINTS =	***5***					

Table F-11 – Scoring Criteria for Emission Rate Determinations

Maximum Points = 10

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Constant emission rate						
C_b = chamber background concentration ($\mu g/m^3$)	**2**					
C = chamber concentration ($\mu g/m^3$)	**2**					
N = air change rate (hr^{-1})	**2**					
L = chamber loading (m^2/m^3)	**2**					
EF = C(N/L) = emission factor ($\mu g/m^2$-hr)	**2**					
First order emission rate decay ($EF_t = EF_0e^{-kt}$)						
Chamber concentration vs. time data provided	**4**					
Curve fit program specified	**2**					
EF_0 and k determined	**4**					
Direct calculation per ASTM method						
Chamber concentration vs. time data provided	**4**					
EF provided at all sampling times	**4**					
Other calculation method	**5**					
TOTAL POINTS =						

Note that the total of the Max. Points column is greater than 10 due to some mutually exclusive scores. For example, if emission rates are assumed to be constant, the other methods are not used.

Table F-12 – Scoring Criteria for Exposure Scenarios

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Source emissions model						
Area (amount) of source given	**1**					
Emission rate available	**1**					
Spatial dimensions established	**2**					
Length						
Width						
Height						
Single compartment						
Ventilation parameters provided	**2**					
Constant ventilation (ACH)						
Variable ventilation						
HVAC system operation						
Other factors	**2**					
Furniture volume deducted						
Doors and windows accounted for						
Sink effects considered						
Occupant activity patterns	**2**					
Location						
Time History						
TOTAL POINTS =	***10***					

Table F-13 – Scoring Criteria for IAQ Model Selection

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Source emission model	**2**					
Constant emission rate						
Variable emission rate						
Empirical model parameters available						
Mass transfer model coefficients available						
Ventilation rates	**1**					
Constant						
Variable						
Compartments/Zones/Rooms	**1**					
Single						
Multiple						
Sink effects	**1**					
No sinks						
Sink model parameters available						
TOTAL POINTS =	***5***					

Table F-14 – Scoring Criteria for Determining Occupant Exposure

Evaluation Criteria	Max. Points	Program Evaluation Points I	II	III	IV	V
Exposure model available	**1**					
Exposure concentrations determined	**4**					
Instantaneous concentrations						
C_{Peak} (highest instantaneous concentration)						
$C_{15\text{-}min}$ (highest 15-minute average concentration)						
$C_{8\text{-}hour}$ (highest 8-hour average concentration)						
Lifetime average daily concentration (LADC)						
Average daily concentration (ADC)						
Inhalation doses determined	**4**					
Lifetime average daily dose (LADD)						
Average daily dose (ADD)						
Acute potential dose rate (APDR)						
Single event dose						
Time parameters	**1**					
Time of APDR						
Time of peak concentration						
Time of exposure above a specific concentration						
TOTAL POINTS =	***10***					

Table F-15 – Scoring Criteria for Health Hazard Identification

Evaluation Criteria	Max. Points	Program Evaluation Points I	II	III	IV	V
Specific health effects						
Toxicity	**1**					
Acute						
Chronic						
Cancer	**2**					
Reproductive effects	**1**					
Odor/Irritation	**1**					
TOTAL POINTS =	***5***					

Table F-16 – Scoring Criteria for Qualitative Health Assessment

Evaluation Criteria	Max. Points	Program Evaluation Points I	II	III	IV	V
Potential source emissions identified	**1**					
Compounds found in database	**1**					
Specific health effect noted	**2**					
Toxicity						
Acute						
Chronic						
Cancer						
Reproductive effects						
Odor/Irritation						
Compound not found in database						
Analogous compound identified/found in database	**1**					
TOTAL POINTS =	***5***					

Table F-17 – Scoring Criteria for Quantitative Health Assessment

		Program Evaluation Points				
Evaluation Criteria	**Max. Points**	**I**	**II**	**III**	**IV**	**V**
Exposure parameters (concentration/dose) quantified	**2**					
Compounds found in database	**2**					
Specific health effect limit established						
Toxicity						
Acute	**2**					
Chronic	**3**					
Cancer	**3**					
Reproductive effects	**1**					
Odor/Irritation	**1**					
Compound not found in database						
Analogous compound identified/found in database	**1**					
TOTAL POINTS =	***15***					

Table F-18 - Overall Grades for IAQ Impact of Product/Material Emissions

			Program Evaluation Grade				
Evaluation Criteria	**Letter Grade**	**See Table**	**I**	**II**	**III**	**IV**	**V**
Product/Material Assessment							
Use existing information							
MSDS	**A - F**	F-2					
VOC content/Manufacturer supplied information	**A - F**	F-2					
Source emission models available	**A - F**	F-3					
Samples collected for evaluation	**A - F**	F-4					
Benchtop laboratory methods							
Direct analysis	**A - F**	F-5					
Static headspace analysis	**A - F**	F-5					
Dynamic chamber testing							
Chamber characteristics adequate	**A - F**	F-6					
Test sample properly conditioned	**A - F**	F-7					
Test sample properly prepared	**A - F**	F-8					
Test conditions specified	**A - F**	F-9					
Chemical measurements described	**A - F**	F-10					
Emission rates determined	**A - F**	F-11					
Exposure Assessment							
Scenario developed	**A - F**	F-12					
IAQ/exposure model used	**A - F**	F-13					
Exposure concentration/dose determined	**A - F**	F-14					
Health/Risk Assessment							
Health hazards identified	**A - F**	F-15					
Qualitative assessment conducted	**A - F**	F-16					
Quantitative assessment conducted	**A - F**	F-17					

APPENDIX G – Definitions, Abbreviations, Symbols, and Units

The following material provides definitions for terms and acronyms found in the report. Commonly used symbols and their associated units are also given.

1. Definitions and Abbreviations

Accuracy – deviation from the true value
ACGIH – American Conference of Governmental Industrial Hygienists
ACH - air changes per hour, a measure of ventilation rate
AIHA – American Industrial Hygiene Association
ANSI – American National Standards Institute
AQS – Air Quality Sciences
ASHRAE - American Society of Heading, Refrigeration and Air-conditioning Engineers
Assessment - a process that provides information useful to the consumer/user of a material or product with respect to its impact on indoor air quality
ASTM – American Society for Testing and Materials

BAA – Berkeley Analytical Associates
BEES - Building for Environmental and Economic Sustainability
BIFMA - Business and Institutional Furniture Manufacturers Association International

California OEHHA - California Office of Environmental Health Hazard Assessment
CAS – Chemical Abstract Service
CCRIS - Chemical Carcinogenesis Research Information System
CEN - European Committee for Standardization
CHPS - Collaborative for High Performance Schools
CLIMPAC - a special dynamic test chamber that couples the chemical determination of the emissions with a sensory output
Constant emission rate – the emission rate (or emission factor) does not vary over time
CONTAM – an IAQ model developed by NIST
CRI - Carpet and Rug Institute

Dynamic test chamber – flow-through environmental chamber

Empirical models – models with coefficients based on curve “fits” of experimental data
EPP - Environmentally Preferred Purchasing
EU - European Union
Exposure assessment - provides information on the amount (concentration or dose) of a particular pollutant that can affect individuals in specific indoor environments
Exposure model – software used to predict occupant exposures to indoor pollutants
Exposure scenario – source emission rate, the volume of the space, the ventilation rate, and the material/product loading

FLEC - Field and Laboratory Emission Cell
FID – Flame Ionization Detector

First order decay model – an empirical model, often applied to wet sources, that predicts an emission factor decay defined by $EF_t = EF_0e^{-kt}$

GC - Gas Chromatograph
GEI - Greenguard Environmental Institute
GEN - Global Ecolabelling Network
GGHC - Green Guide for Health Care

HAP - hazardous air pollutants
Headspace analysis –measurement of the VOC content in the vapor overlying a liquid or solid
Health/risk assessment - the identification and quantification of the health hazard associated with an exposure
HEPA filter – High Efficiency Particulate Air filter
HPLC – High Performance Liquid Chromatograph
HPVA - The Hardwood Plywood and Veneer Association
HSDB - Hazardous Substances Data Bank
HUD - Department of Housing and Urban Development
HVAC – heating, ventilation, and air conditioning

IAQ – Indoor Air Quality
IAQ model – software that couples source emissions with ventilation parameters to predict indoor concentrations
IAQX models – a suite of simple IAQ models developed by EPA
IARC - The International Agency for Research on Cancer
IHLAP - Industrial Hygiene Laboratory Accreditation Program
IRIS - Integrated Risk Information System
ISO - International Organization for Standardization

LEED - Leadership in Energy and Environmental Design – USGBC Green Building Rating System®
Loading factor - sample area/test chamber volume; material area/room volume

MAS - Material Analytical Services
Mass transfer models – source emissions models based on physical principles
MCCEM - Multi-Chamber Concentration and Exposure Model
MS – Mass Spectrometer
MSDS - Material Safety Data Sheet

NAAQS - National Ambient Air Quality Standards
NIBS - National Institute of Building Sciences
NIH – National Institutes of Health
NIOSH - National Institute for Occupational Safety and Health
NIST - National Institute of Standards and Technology
NLM - National Library of Medicine
NTP - National Toxicology Program

OSHA - Occupational Safety and Health Administration
OPPTP - Office of Pollution Prevention and Toxics

Prop 65 - California's Safe Drinking Water and Toxic Enforcement Act of 1986 requires the state to annually list all "Chemicals Known to the State to Cause Cancer or Reproductive Toxicity"
Precision – ability to obtain repeatable results
Power law decay model - an empirical model that predicts an emission factor decay defined by: $EF_t = at^{-b}$

QA/QC - Quality Assurance/Quality Control

RFCI - Resilient Floor Covering Institute
RISK – an IAQ model developed by US EPA
RTECS - Registry of Toxic Effects of Chemical Substances

SARA - Superfund Amendments and Reauthorization Act of 1986
SBS - sick building syndrome
SCAQMD - South Coast Air Quality Management District
SCS - Scientific Certification Systems
Sink effects - adsorption to and desorption from interior surfaces
Source emission model – model or equation that predicts a product's emission rate

Testing – a process that subjects a material or product to a specific procedure to obtain information on its emissions to the indoor environment.
TVOC – Total Volatile Organic Compounds

US EPA – United States Environmental Protection Agency
USGBC – United States Green Building Council

VOC - Volatile Organic Compound; for indoor air all VOCs are considered including those exempt by 40 CFR 51.100(s)

WBDG - Whole Building Design Guide
WPEM - Wall Paint Exposure Model

2. Symbols and Units

Symbol	Definition	Typical Units
	PHYSICAL FACTORS	
EF_t or EF(t)	Emission Factor at time t	$\mu g/m^2$-h
EF_0 or EF(0)	Initial Emission Factor at time zero	$\mu g/m^2$-h
ER	Emission Rate	µg/h
k	First order decay rate	h^{-1}
L	Product Loading	m^2/m^3
N	Air Change Rate (ACH)	h^{-1}
C	Concentration	$\mu g/m^3$
V	Volume	m^3
Q	Air flow	m^3/h
T	Temperature	^oC
RH	Relative Humidity	%
	EXPOSURE LIMITS	
CREL	Chronic Exposure Level	$\mu g/m^3$
LCI	Lowest Concentration of Interest	$\mu g/m^3$
REL	Recommended Exposure Limit	mg/m^3
PEL	Permissible Exposure Limit	mg/m^3
IDLH	Immediate Danger to Life and Health	mg/m^3
TLV	Threshold Limit Value	mg/m^3 or ppm*
TWA	Time Weight Average – 8 h/day; 5 days/week	mg/m^3 or ppm
STEL	Short Term Exposure Limit – 15 minutes	mg/m^3 or ppm
RfD	Oral Reference Dose	mg/kg-day
RfC	Inhalation Reference Dose	mg/m^3
LADD	Lifetime Average Daily Dose	mg/kg-days
ADD	Average Daily Dose	mg/kg-days
APDR	Acute Potential Dose Rate - highest 24 hour dose rate	mg/kg-days
LADC	Lifetime Average Daily Concentration	mg/m^3
ADC	Average Daily Concentration	mg/m^3
C_{Peak}	Highest instantaneous concentration	mg/m^3

*To convert mg/m^3 to ppm (or $\mu g/m^3$ to ppb), multiply by 24/MW, where MW is the molecular weight of the compound. For example, formaldehyde has a MW of 30; so a formaldehyde concentration of 1 mg/m^3 is equal to 0.8 ppm.