#10192

REDUCING OCCUPANT EXPOSURE TO VOLATILE ORGANIC COMPOUNDS (VOCs) FROM OFFICE BUILDING CONSTRUCTION MATERIALS: NON-BINDING GUIDELINES

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Released: July 1996

PREFACE

This document has been prepared by Leon Alevantis, M.S., P.E., Indoor Air Quality Section (formerly Indoor Air Quality Program), California Department of Health Services, in response to a California legislative mandate (Chapter 1229, Statutes of 1990, AB 3588, Speier). This mandate required the Indoor Air Quality Program to develop non-binding guidelines for the reduction of exposure to volatile organic compounds (VOCs) from building construction materials in newly constructed or remodeled office buildings. The guidelines presented here represent a simple technical approach for evaluating, selecting, and installing building construction materials in order to minimize occupant exposures to VOCs emitted from these materials. Some information on costs associated with this approach is discussed. However, a detailed economic analysis of the cost effectiveness of this approach is beyond the scope of the guidelines.

The guidelines are intended for use by building professionals such as architects, engineers, building contractors, product specifiers, interior designers, building owners, managers, and operators, and others interested in reducing VOC concentrations in new construction. The guidelines do not present any new methods or techniques; rather, the guidelines summarize the most significant information available on this subject. The guidelines are designed for application to building projects of any size that use mechanical ventilation, although elements of the guidelines can be applied to buildings that use natural ventilation.

Disclaimer

This document has been reviewed in accordance with the policies of the California Department of Health Services and the Health and Welfare Agency of the State of California. The contents are based on currently available scientific and technical information on the issues presented. Following the recommendations contained herein will reduce occupant exposure to VOCs emitted from office building construction materials but may **not** provide complete protection in all situations or against all health hazards related to such exposure. The guidelines presented in this document are **exempt** from the procedures for adoption of regulations, including review and approval by the Office of Administrative Law, pursuant to Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of the Government Code.

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EXECUTIVE SUMMARY

The guidelines presented in this document are the result of Chapter 1229 of the Statutes of 1990 (AB 3588, Speier - see Appendix A) that required the Indoor Air Quality Program (now Indoor Air Quality Section) of the California Department of Health Services (CDHS) to "develop nonbinding guidelines for the reduction of exposure to volatile organic compounds (VOCs) from construction materials in newly constructed or remodeled office buildings." The originating legislation was the result of concern about increasing complaints of sick building syndrome (SBS). This is a situation in which building occupants report symptoms, such as mucous membrane irritation, headaches, stuffiness, lethargy, and drowsiness, and which the occupants associate with a building. Researchers have reported that VOCs play a role in many SBS complaints, particularly in new or newly renovated office buildings, which often have substantial amounts of building and furnishing materials that emit VOCs.

The guidelines consider building **construction materials** to include not only construction materials and products but also major furnishings, such as office workstations, installed as part of a building's overall architectural and interior design. In addition, the guidelines address those cleaning and maintenance materials and products, the use of which are directly associated with the building construction materials and products selected.

The guidelines do not cover many other potential VOC sources such as: (a) occupant activities; (b) office equipment; (c) cleaning and maintenance products (other than the ones directly associated with the building construction materials selected); and (d) biological contaminants. These can be significant VOC sources in buildings. In addition, the guidelines do not provide special design considerations for accommodating those building occupants who are especially sensitive to VOCs.

The guidelines provide the best currently available information on minimizing occupant exposures to VOCs from office building construction materials. It should be noted that information in this field is evolving rapidly. For example, a number of testing methods for various building materials (e.g., carpet and paints) are being developed and will become available in the next few years. Also many product manufacturers continue to reduce emissions from their products. While specific information may change, the general guidance presented here is based on general methods and procedures for evaluating, selecting, and installing new building materials and therefore will still be applicable as information evolves. The guidelines have been written primarily for application to office buildings of any size that use mechanical heating, ventilating, and air-conditioning (HVAC) systems. However, the guidelines can be applied to most building types such as mixed-use buildings (e.g. libraries and courthouses). In addition, elements of the guidelines can be applied to naturally ventilated buildings.

The guidelines are intended for use by building professionals such as architects, engineers, building contractors, product specifiers, interior designers, building owners and operators, and others interested in reducing VOC concentrations in new construction. The guidelines do not present any new methods or techniques; rather, they summarize the most significant information currently available on this subject. Finally, the guidelines are **non-binding** and have **no** regulatory authority

The guidelines recommend a five-step approach to reducing exposure to VOCs from building materials and products. These five steps are listed below.

Step 1. Evaluate and select low-VOC-impact building materials and products: This is the most critical step in minimizing human exposure to VOCs emitted from building materials and products. In order to assess the impact of emissions from building materials, the guidelines define a **low-VOC-impact building material or product** as one that when installed in a building results in minimal or reduced exposure of occupants to VOCs that are emitted from the material or product. Note that this definition does not necessarily imply that a low-VOC-impact material is also low-VOC emitting. The evaluation and selection of these materials and products is a four-step process as indicated in Figure 1 and discussed next.

Task 1: identification of target materials and products based on estimated installed quantities, proximity of installed materials and products to occupied zones, adsorption characteristics of some materials, and identification of materials and products with known high VOC emission rates;

Task 2: collection of more detailed VOC-related product information on candidate materials and products using manufacturers' lists of Material Safety Data Sheets (MSDSs) (MSDSs typically contain information about a material's chemical contents as well as information on the potential adverse health and safety effects resulting from exposure to these contents), product specifications listing chemical contents, results of emissions testing data, and other sources such as lists of carcinogenic contents;

Task 3: evaluation of building products and materials based on MSDSs, reactive VOC contents, calculated chemical emissions using vapor pressures and mass transfer coefficients, results of emissions testing, and estimated indoor concentrations; and

Task 4: selection of building products based on MSDSs and/or emissions testing results as shown on Figure 2. Selection of products based on MSDSs alone is complicated by the lack of industry standardization of the reported information, and the fact that MSDSs are sometimes incomplete or inaccurate failing to list all potentially hazardous substances. Furthermore, selection of products based on comparison of emissions testing data of functionally equivalent building products requires consideration of the following issues:

a) there is lack of standard emissions testing and reporting methods for VOCs (a summary of existing testing methods is presented);

b) total volatile organic compound (TVOC) results for the same mixture of components analyzed by different methods can vary by a factor of two or more due to differences in sample collection methods, TVOC calibration methods, and data reduction and analysis;

c) accuracy of TVOC results depends on the mixture of compounds being analyzed;

d) variation in history, age, condition of the tested material, and in environmental factors (i.e., ventilation, air velocities, temperature, and humidity of tested material samples) can affect reported emission factors by several orders of magnitude; and

e) delivered materials may have emissions different from tested samples (an issue that is difficult to address unless random testing of delivered materials is performed after delivery).

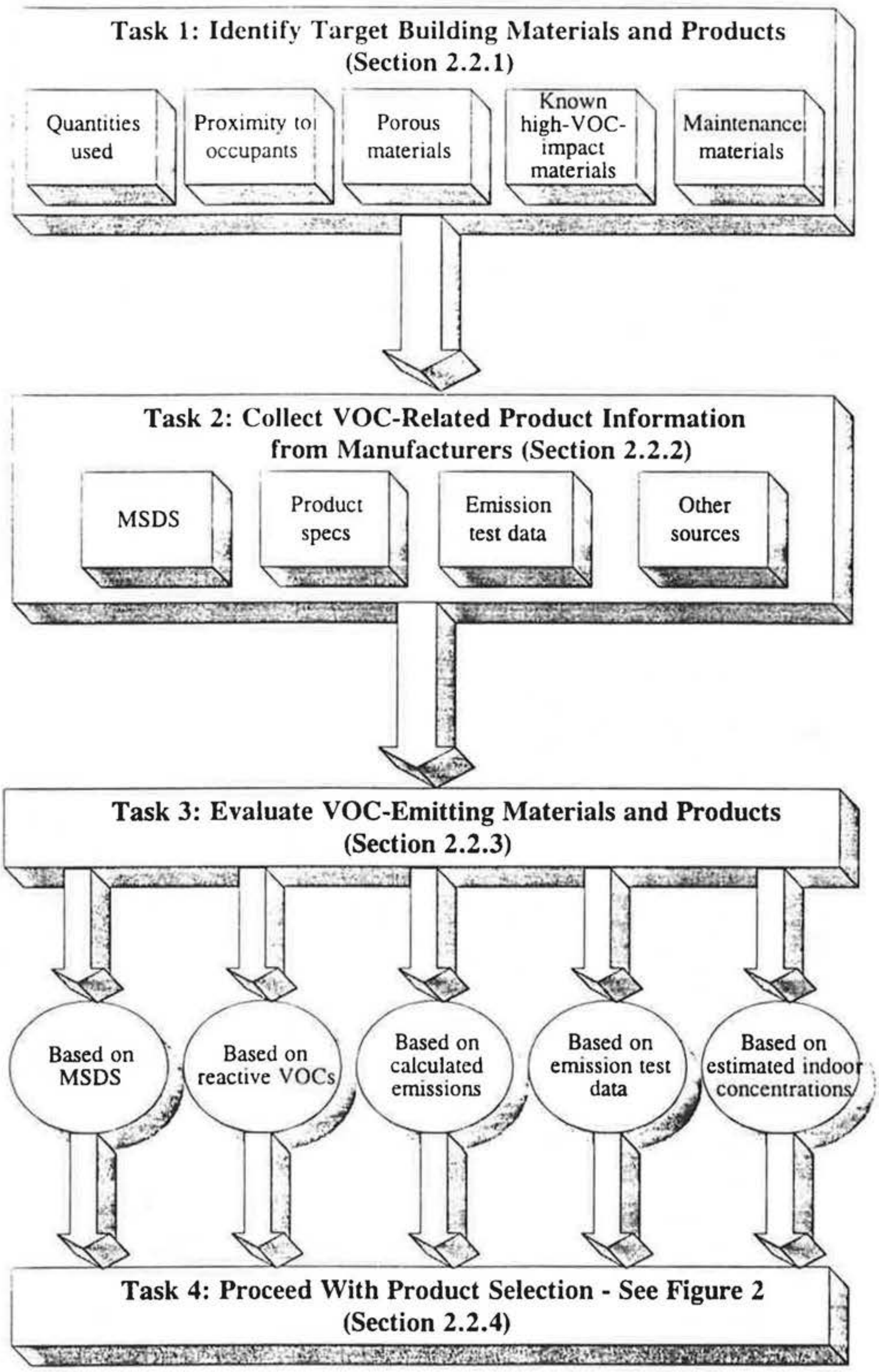

Figure 1. Four-Step Strategy for Evaluating and Selecting Building Materials and Products

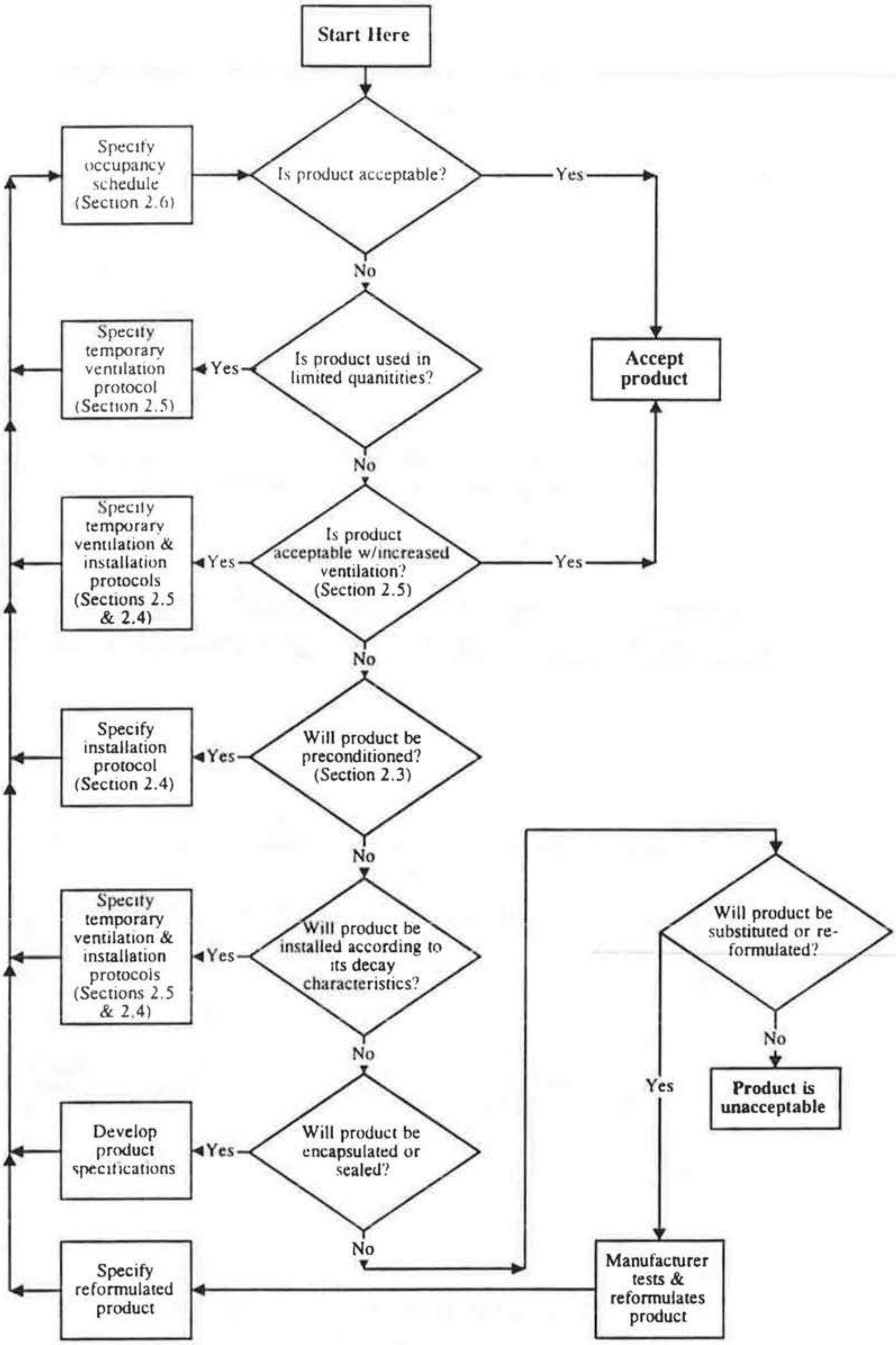

Figure 2. Flow Chart for Selecting Building Materials and Products

The above issues can be addressed before seeking bids from contractors and then should be verified in the submitted stage so that comparison of emission factors of functionally equivalent products can be made. Sample language for contract documents addressing the above issues is included in the present document. (Documents drawn in the pre-bid phase are referred to as **construction documents**.) Note that TVOC emission rates must be used to compare <u>similar</u> products with <u>similar</u> chemical compositions that have been tested using the <u>same</u> analytical methods.

Emissions testing data can assist a designer in comparing functionally equivalent products and making selections based on this comparison. However, it is difficult to select materials and products based on predictions of indoor VOC concentrations derived from emissions testing data because of the following uncertainties:

a) indoor VOC concentrations cannot be predicted accurately based on emissions testing data because of the time, space, and building dependency of such predictions (however, a simplified equation for estimating indoor concentrations from emission factors is presented); and

b) even if VOC concentrations could be predicted accurately based on emissions testing data, interpretation of indoor VOC concentrations would be difficult due to lack of health-based guidelines for most indoor pollutants found in non-industrial indoor environments. (A summary of existing guidelines for selected VOCs is presented as well as a survey of existing product labeling programs in the United States and Europe.)

Because of these complex issues, the guidelines focus on selecting building construction materials with low emission rates rather than on attempting to meet specific concentrations. It is important to note that considerations other than VOC emission rates may need to be made as part of the selection process of building materials. These considerations may include: acoustical properties, comfort properties, local building codes, architectural qualities, durability, warranty, and maintainability. (Note that the remaining four steps also have been incorporated in Figure 2.)

Step 2. <u>Pre-condition certain materials to minimize VOC emissions after installation</u>: This step includes conditioning of materials at the manufacturing or assembly facility, at a "bonded" warehouse with appropriate ventilation, or in a dry, well-ventilated area other than the one where the materials will be installed, until emissions have been reduced. Examples of these materials include office furniture and carpeting. Note that storage of certain materials after manufacturing is unavoidable especially in cases of special production orders or large quantities. For example, in the case of carpeting for a large-size building, there may be a time lag of several months between production and delivery of the product. In such cases storage is unavoidable and specifying a dry, well-ventilated space may not add a considerable cost to a project. There are no field data demonstrating the minimum length of time needed to effectively pre-condition various building products.

Step 3. <u>Install building materials and products based on their VOC emission decay rates</u>: This step involves the phased installation of building materials and products based on their emission and adsorption characteristics. Typically **wet** products such as paints, adhesives, and taping and deck leveling compounds should be installed first. Wet products are typically characterized by very high initial emissions followed by much lower emissions. This is because most solvents and other chemicals in wet products are emitted for a few hours or days after installation. Porous materials, such as carpets and fabric-covered office dividers, should be installed last. This technique minimizes adsorption by porous materials of the VOCs initially emitted by wet products and subsequent re-emission at a later time (a process known as the **sink effect**).

Step 4. Ventilate a building during and after installation of new materials and products: The maximum amount of outside air should be provided during and after installation of VOC-emitting materials for the maximum amount of time feasible (this process is known as a building **flush-out**). There are no data on the recommended duration for building flush-outs, but a conservative approach is to flush-out as long as economically feasible, but not less than continuously (i.e., 24 hr) for seven days. It should be noted that the maximum amount of ventilation provided by an HVAC system may be limited not only by the system's capacity but also by the temperature and humidity of the outdoor air. Special procedures during partial building renovation/remodeling (i.e., completely isolating the air between occupied areas and areas under construction) should be followed and are discussed. The guidelines summarize and encourage compliance with ASHRAE's recommendation on **HVAC commissioning** (i.e., a process that ensures that the performance of an HVAC system meets design parameters) in order not only to minimize exposure to VOCs but also to improve indoor air quality during the life of a building.

Step 5. Delay occupancy until VOC concentrations have been reduced adequately: Because VOC concentrations are highest during and immediately after construction, it is important to allow sufficient "flush-out" time before occupants move in. Air samples can be taken to verify that indoor VOC concentrations have been reduced sufficiently prior to occupancy. It should be noted that: (a) guidelines exist for only a few VOCs; (b) there are no standard testing methods for TVOCs; and (c) existing guidelines for TVOCs are not widely accepted. However, TVOC concentrations can be used to compare a building's indoor air with measurements taken in other non-problem buildings.

A detailed economic analysis of all the costs associated with the above five steps is beyond the scope of the guidelines. However, some of these costs are discussed. Unfortunately there is very limited published information on this subject. Based on this limited information, it appears that the highest cost of reducing occupant exposure to VOCs is associated with emissions testing of building materials, especially when many products must be tested. The cost of testing individual products based on the **headspace** sampling technique ranges between $1,000 and $2,000, whereas the cost of testing large-size products, such as complete office workstations, in **environmental chambers** exceeds $5,000 depending on many factors such as test duration, number of test air change rates, number of samples tested, etc. Other costs, such as design fees, cost of building materials, cost of increased ventilation, and cost of delayed occupancy, also need to be considered. Limited data indicate that design fees are low, accounting for less than 1 percent of the Architectural/Engineering (A/E) fees of a project (A/E fees for high-rise office buildings typically account for between 4 and 6 percent of the construction cost). Although the cost of building materials account for a major portion of the construction cost (typically between 30 and 60 percent), their cost is usually independent of their emission characteristics (i.e., lower VOC emissions do not necessarily imply higher cost). Small premiums charged for some low-VOC-emitting materials are likely to be reduced or eliminated as demand for these products increases. Finally, other costs such those resulting from increased ventilation and delayed occupancy are project-specific. It is important for building owners and employers to realize that if poor indoor quality increases the absenteeism rate by only 2.5 percent (OSHA estimated this rate to be 3 percent) then the increased annual costs associated with this increased absenteeism rate is comparable to the cost of utilities or maintenance and operation of a building. Other economic impacts of improved indoor air quality also must be considered. These include reduced liability exposure, improved building marketability, reduced health care costs, lower operating costs, and increased occupant comfort and productivity.

Other topics mandated by AB 3588 and discussed in the guidelines include the following:

1. Discussion of the appropriateness of mandatory regulations: Due to the limited information available for selecting low-VOC-impact materials and the lack of standard testing methods for building materials, consideration or development of mandatory regulations is inappropriate at this time. Compliance with the guidelines is encouraged on a non-binding, voluntary basis. Product manufacturers are encouraged to develop voluntary labeling programs as more standard testing methods for various building materials become available.

2. Discussion of the usefulness of formation of an ad hoc committee of professionals and other interested parties: The guidelines encourage the formation of a multi-disciplinary committee of professionals to further review the guidelines, to make recommendations for modifications, and to advise the CDHS on the practicality of the guidelines based on the field experience of the committee's members. In addition, the guidelines recommend the formation of a central repository for product emission information and current product regulations.

3. Discussion of a process known as building **bake-out**: This is a process designed to "artificially age" building materials and products by elevating the temperature of an unoccupied, newly constructed or remodeled building while supplying a fixed amount of ventilation, and flushing the building with the maximum possible ventilation after completion of the bake-out. Due to problems associated with this process and its questionable effectiveness, the guidelines do not recommend building bake-outs. Instead, the guidelines recommend selection and installation of low-VOC-impact materials and products followed by a building flush-out. However, some technical aspects of building bake-outs are discussed.

ACKNOWLEDGMENTS

Leon Alevantis, M.S., P.E., Indoor Air Quality Section, California Department of Health Services (CDHS), gratefully acknowledges the generous contribution of time and effort on the part of the many people who contributed to the development and review of the guidelines. **Peter Flessel**, Ph.D., Chief, Environmental Health Laboratory Branch (EHLB), CDHS, provided guidance and critical editorial comments during the development of this document. **Jed Waldman**, Ph.D., Chief, Indoor Air Quality Section, EHLB, CDHS, provided advice and support during the latter development stages of this document. A steering committee, formed during the initial stages of the development of the guidelines, provided general guidance on the scope of the guidelines (see page xviii for a list of steering committee members). Numerous individuals reviewed the guidelines, either in part or in their entirety, and helped shape its final form (see pages xix - xxii for a list of reviewers). (Note: Review of the Guidelines by an individual or organization does **not** imply their endorsement of the final version of the guidelines.) Portions of selected sections presented in this document were based on material originally written by: (a) the late **Steven Hayward**, Ph.D., Chief, Indoor Air Quality Section, EHLB, CDHS; and (b) **Hal Levin**, B.S., as published by him in *The Indoor Air Bulletin*. **Sharon Seidel**, Ph.D., Environmental Health Investigations Branch, CDHS, provided input on the health effects of VOCs (Sections E2 and E4 of Appendix E). **Jim Cone**, M.D., M.P.H., Hazardous Evaluation System and Information Services Section, Occupational Health Branch, CDHS, also provided input on the health effects of VOCs (Section E2 of Appendix E). **Peggy Jenkins**, Indoor Air Quality Program, California Air Resources Board, provided the text on the California regulations for architectural coatings and consumer products of Appendix H. **Richard Lam**, Ph.D., Indoor Air Risk Assessment Group, Air Toxicology and Epidemiology Section, Office of Environmental Health Hazard Assessment, California Environmental Protection Agency, provided input on the sensory effects of VOCs (Section E4 of Appendix E). **Janet M. Macher**, Sc.D., M.P.H., Indoor Air Quality Section, EHLB, CDHS provided critical editorial review.

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SECTION 1. INTRODUCTION

1.1 Statutory Mandate

Chapter 1229 of the Statutes of 1990 (AB 3588, Speier - see Appendix A) mandated the addition of Section 426.10 to the California Health and Safety Code (Appendix A). This legislation requires the Indoor Air Quality (IAQ) Program (now IAQ Section) of the California Department of Health Services (CDHS) to develop non-binding guidelines for reducing occupant exposure to volatile organic compounds (VOCs) from office building construction materials. The guidelines address the various mandated topics of this legislation in the following sections.

1. Mandated topic: "The type of building to which the guidelines shall apply."
   Addressed in: Section 1.1.

2. Mandated topic: "The methodology for identifying indoor sources of VOCs."
   Addressed in: Sections 1.5.2, 2.2, 2.3, 2.4, 2.5, and 2.6.

3. Mandated topic: "The bake-out procedures prior to occupancy for newly constructed buildings."
   Addressed in: Section 3.3 and Appendix D.

4. Mandated topic: "The procedures for VOC reduction during and after major remodeling of occupied buildings."
   Addressed in: Sections 1.5.2, 2.2, 2.3, 2.4, 2.5, and 2.6.

5. Mandated topic: "The need to establish mandatory regulations rather than nonbinding guidelines for the procedures to reduce VOC exposure in newly constructed buildings and during the remodeling of buildings and, in addition, the need for regulation regarding the occupancy of a newly constructed building or a building undergoing remodeling where VOC reduction is to be considered."
   Addressed in: Section 3.1.

6. Mandated topic: "The need to establish an ad hoc group of building construction material manufacturers, builders, building owners and managers, organized labor, sheetmetal contractors, plumbing contractors, mechanical engineers, architects, and building inspectors to advise the state department on procedures and costs related to implementing the proposed guidelines."
   Addressed in: Section 3.2.

The guidelines presented in this document are based on the best currently available knowledge in this field. Their application is likely to result in reduction of occupant exposures to VOCs from office building construction materials. The information presented covers a comprehensive technical approach for evaluating, selecting, and installing building construction materials. The guidelines have been written primarily for application to buildings that use mechanical heating, ventilating, and air-conditioning (HVAC) systems, although elements of the guidelines can be applied to buildings that use natural ventilation. The guidelines are non-binding and have no regulatory authority. They are intended for use with any size office building However, the guidelines are applicable to most building types such as mixed-use buildings (e.g., libraries and courthouses).

1.2 Purpose of the VOC Guidelines

The guidelines are intended for use by building professionals, such as architects, engineers, building contractors, product specifiers, interior designers, building owners and operators, and others interested in reducing VOC concentrations in new construction. The guidelines do not present any new methods or techniques; rather, they summarize the most significant information currently available on this subject.

It is not the purpose of the guidelines to teach building designers, owners, or other building professionals the basic principles of achieving or maintaining good indoor air quality. The reader is referred to *Building Air Quality: A Guide for Building Owners and Facility Managers* (USEPA, 1991) for such information. (See also Section K8 of Appendix K for other publications on indoor air quality.) It is also not the purpose of the guidelines to provide instruction on how to investigate or mitigate existing indoor air quality problems. Protocols for such activities have been published elsewhere [see, e.g., USEPA (1991)]. However, the guidelines provide a listing of other information resources, such as professional building-related organizations (see Appendix K: Information Resources).

1.3 The Need for Guidelines

Chapter 1229 of the Statutes of 1990 (AB 3588, Speier - see Appendix A) was the result of concern about increasing complaints of sick building syndrome (SBS). This is a situation in which building occupants experience symptoms, such as nose, eye, and throat irritation, sneezing, stuffy or running nose, fatigue or lethargy, headache, dizziness, nausea, irritability, and forgetfulness, and which the occupants associate with the building (USEPA, 1993b).

There have been various estimates on the number of buildings experiencing SBS symptoms. A committee of the World Health Organization (WHO) estimated that up to 30 percent of new and remodeled buildings worldwide may experience SBS (WHO, 1986; USEPA, 1993b). Based on a stratified random telephone survey of 600 U.S. office workers, Woods et al. (1987) concluded that 20 percent of office workers in the U.S. are exposed to SBS (OSHA, 1994a). In California, the Occupational Safety and Health Administration (Cal-OSHA) estimated that occupants in approximately 1,000 California buildings experience SBS each year (Cal-OSHA, 1985). Since most of these buildings have many occupants, SBS is a problem that can affect the health and productivity of many workers.

Researchers have reported that increased concentrations of indoor VOCs are often associated with increased occupant health complaints (Mølhave, 1990; Fisk et al., 1993; Mendell, 1993; Ten Brinke, 1995). It is well known that new building materials and products emit VOCs and that their emissions decrease with time at rates characteristic of each product or material. It is therefore not unusual for occupants of new and newly renovated office buildings with non-operable windows and substantial amounts of new building and furnishing materials to report a number of health complaints.

Mølhave (1990) estimated that 50 to 300 different VOCs are typically detected in the indoor air of non-industrial buildings. VOCs typically represent a broad range of chemical compounds sampled by absorption on a solid sorbent with boiling points between 50 and 260°C (WHO, 1987a). However, some other compounds are included for convenience although they do not have boiling points within 50 and 260°C [e.g., methylene chloride (boiling point: 40.1°C) and formaldehyde (boiling point: -19.5°C)].

VOCs are just one part of indoor air pollution that occupants of office buildings are exposed to. Other environmental factors, often beyond the control of most occupants in modern buildings, include amount of ventilation, temperature, humidity, dust, bioaerosols, air velocity, "radiant" temperature of surrounding surfaces, noise, and lighting.

1.3.1 Health Effects of VOCs

Indoor air pollution including exposure to VOCs may result in short- and long-term health effects at concentrations typically measured in non-industrial environments. The United States Environmental Protection Agency (USEPA) reported that long-term health effects "...can be severely debilitating or fatal" and "...may show up years after exposure has occurred or only after long or repeated periods of exposure" (USEPA, 1993a). According to the USEPA, long-term health effects include respiratory diseases and cancer. Short-term health effects are usually treatable and "...may appear after a single, high-dose exposure or repeated exposures" (USEPA, 1993a). Short-term health effects include "...irritation of eyes, nose, and throat, headaches, dizziness, and fatigue" (USEPA, 1993a).

Additional available information suggests that VOC exposures can result in adverse health effects at concentrations typically measured in non-industrial environments (Franck, 1986; Kjærgaard et al., 1990; Mølhave, 1990). These effects are typically concurrent with the exposure and may include: (a) sensory detection, often by odor, of the air contaminants; (b) physiological irritation or inflammation of exposed skin, eyes, and mucous membranes; and (c) stress reactions to the perceived chemical (Mølhave, 1990). Tearing of the eyes; runny nose; stinging, itching, or tingling feelings in exposed tissues; changes in skin temperature; headache; and drowsiness are some common symptoms seen with exposure to VOCs in non-industrial environments. Some health effects, such as nose and throat irritation, may occur with the first exposure to indoor VOCs, whereas other health effects, such as systemic and carcinogenic effects, may be delayed for years.

Health effects more serious and long-term than immediate irritation have been suggested to occur with repeated exposure to indoor VOCs. These include a wide range of systemic effects such as asthma and other chronic respiratory illnesses, reproductive effects, and cancer. There is very little direct evidence for the occurrence of these more serious effects in non-occupationally exposed humans, either in the general population or in sensitive sub-populations such as children, the elderly, and people with pre-existing respiratory conditions. However, studies of individual VOCs in animals, and in some cases occupational exposures in humans, have shown the potential for long-term effects at elevated levels of exposure.

Most information on the health effects of VOCs is related to exposures to individual compounds rather than to mixtures that could be combinations of tens to hundreds of such compounds. In addition, very little is known about some of the potentially irritating chemicals emitted by new materials, especially when people are exposed to combinations of such chemicals in non-industrial settings (e.g., offices). Furthermore, adequate information on the health effects of a large number of VOCs found in indoor air is not available and many chemicals present indoors are not reported due to analytical methods used or cost.

It should be noted that for a non-cancer-causing chemical, there is usually some level of exposure, or threshold, that is necessary before an adverse health effect occurs. Carcinogens, on the other hand, are believed to have no threshold of exposure, that is to say, even very low levels of exposure may carry some risk for developing cancer. Animal studies have suggested that a combined exposure to several common indoor VOCs over a lifetime may result in an excess cancer risk (McCann et al., 1988). It is noted that most of the available information on the carcinogenic effects of VOCs are based on individual VOCs tested on animals. However, a limited number of individual VOCs have human carcinogenic data (e.g., benzene).

1.3.2 Economic Impacts of Poor Indoor Air Quality

One of the major economic impacts of poor indoor air quality is reduced employee productivity. It is important for building owners and employers to realize that the employee costs (i.e., salaries and wages) far exceed building construction or leasing costs. Table 1 demonstrates this point by presenting typical annual costs associated with owning and operating buildings in the United States as reported by Woods (1989). Although actual costs may differ today, Table 1 clearly shows the relative differences among the various annual costs. The single most expensive item is salaries and wages. It is important to note that if poor indoor quality increases the absenteeism rate by only 2.5 percent (i.e., from a typical 5 to 7.5 percent) then the increased annual costs associated with this rate (i.e., 3 to 5 $\$/ft^2$; 28 to 55 $\$/m^2$) can be comparable to the cost of utilities or maintenance and operation of a building. The United States Occupational Safety and Health Administration (OSHA) estimated that employee productivity loss due to poor indoor air quality to be 3% (OSHA, 1994a). Thus poor indoor air quality could produce changes in productivity resulting in significant economic impacts especially if the situation persists for years. In extreme cases, a major SBS episode can disrupt drastically the productivity of a business for a long time.

However other economic impacts of improved indoor air quality must be considered. These include reduced liability exposure, improved building marketability, reduced health care costs, lower operating costs, and increased occupant comfort and productivity.

Table 1. Building- and Employee-Associated Costs Per Floor Area (Woods, 1989)

Item	Annual Cost, $\$/ft^2$ ($\$/m^2$)
Construction (net floor area)	8 to 40 (86 to 430)
Capital assets (furniture and equipment)	2 to 35 (22 to 380)
Maintenance and operation	2 to 4 (22 to 43)
Utilities	2 to 4 (22 to 43)
Rented or leased space	15 to 50 (160 to 540)
Salaries and wages	**100 to 200 (1100 to 2200)**
Typical absenteeism @ 5%	5 to 10 (55 to 110)
Increased absenteeism @ 7.5%	8 to 15 (83 to 165)

1.4 VOC Sources Addressed in the Guidelines

VOCs are organic compounds that have sufficiently high vapor pressures to exist as gases or vapors at ambient temperatures. Most materials and products used in the construction and finishing of interior office spaces are potential sources of VOCs. These include paints, adhesives, sealants, caulks, carpets, vinyl floor and wall coverings, composite wood products, drywall products such as taping compounds, concrete deck leveling compounds, furniture finishing products, and insulation materials. Furnishing materials, such as furniture and interior panels, are also likely VOC sources. Researchers have estimated that up to 300 different VOCs are typically detected in the indoor air of non-residential buildings. A selected number of VOCs that may be emitted from building materials and cleaning products and their potential indoor sources are listed in Appendix B.

However, building construction materials and furnishings are not the only sources of indoor VOCs. Heating, ventilating, and air conditioning (HVAC) systems, building maintenance and cleaning products, consumer products, combustion processes such as combustion appliances and tobacco smoking, and occupants themselves also are potential sources of indoor VOCs.

Section 426.10 of the California Health and Safety Code specifically requires that the CDHS "shall develop nonbinding guidelines for the reduction of exposure to VOCs from construction materials in newly constructed or remodeled office buildings." The guidelines presented in this document consider building **construction materials** to include not only construction materials and products but also major furnishings that are part of a building's overall architectural design. In addition, the guidelines address those cleaning and maintenance materials and products the use of which is directly associated with the selected building materials (as discussed in Section 2.2).

The guidelines do not cover other potentially significant sources of indoor VOCs such as: (a) occupant activities; (b) office equipment; (c) cleaning and maintenance products (other than those directly associated with the building materials selected); and (d) biological contaminants. In addition, the guidelines do not address any special design considerations or other issues related to occupants who are especially sensitive to VOCs.

1.5 Dynamics of VOC-Emitting Building Materials and Products and of VOC Sinks

As note above, most building materials and products emit various amounts of VOCS. Unfortunately, very little information exists in the literature on emission rates from specific products and materials. Researchers in the United States and Europe have reported limited amounts of information. Levin (1991) compiled information from nine of these studies and listed VOC emission data for various building materials and furnishings. According to Levin's list: (a) some of the higher-emitting materials include adhesives, vinyl floor coverings, and particleboard; and (b) reported emission factors for similar products and materials may vary by one or more orders of magnitude. For example, emission factor (i.e., mass of an individual volatile organic compound or mass of total measured volatile organic compounds emitted from a material per unit of material or product area per unit of time; emission factor unit is $\mu g/m^2 \cdot hr$) of adhesives used to glue down carpeting has been reported to be as low as 783 $\mu g/m^2 \cdot hr$ and as high as 153,000 $\mu g/m^2 \cdot hr$ (Levin, 1991). Although some of the reported differences may be due to the age of analyzed samples, the data indicate that large differences do exist for functionally equivalent products.

Manufacturers are increasingly likely to have their products tested and to make emission data available to the public because architects and other building professionals are requesting such information. For example, the Carpet and Rug Institute (CRI) has initiated a voluntary testing program and has established maximum emission factors for new styrene butadiene rubber (SBR) latex-backed carpets for four parameters: TVOCs, styrene, 4-PC (4-phenylcyclohexene), and formaldehyde (CRI, 1994a). (See Appendix C for a discussion of this and other product labeling programs.)

1.5.1 VOC Sinks

VOCs and other chemicals present in the indoor air may adsorb onto surfaces of many materials. Porous materials, often termed "fleecy," are of special concern. Such materials can be "VOC sinks" and include fabric upholstery, carpets, insulation, wallboard, and other porous indoor materials. The amount of VOCs adsorbed depends on their volatility, polarity, temperature and concentration as well as their affinity for the surface of a particular material. In general, the higher the surface area of a material the greater the sink potential. Glass and metal surfaces have the lowest adsorption characteristics, textiles have the highest, and wood and plastics have intermediate adsorption characteristics. Adsorption usually occurs in indoor environments with high VOC concentrations. When the concentration of VOCs in the air drops, the equilibrium between gas-phase VOCs and surface VOCs results in higher air concentrations for longer times than would result from the original source in absence of sinks. Thus the sink effect of VOCs can increase significantly the time required to reduce indoor VOC concentrations.

The following two examples show the importance of VOC sinks.

1. Tichenor et al. (1988, 1991) reported that para-dichlorobenzene, a constituent of moth repellants, was measured in significant concentrations in a house several days after the source was removed. Measurements in the same house a year after the source was removed showed higher indoor than outdoor concentrations of para-dichlorobenzene, thus indicating re-emission of this compound previously adsorbed on interior surfaces.

2. Seifert and Schmahl (1987) reported that the formaldehyde content of a 2-m^2 curtain was increased from 140 to 400 ng/cm^2 after storage for several days in a 12-m^3 aluminum test chamber containing urea formaldehyde foam (the resulting formaldehyde concentration within the chamber was 370 $\mu g/m^3$). The curtain subsequently was wrapped in aluminum foil and stored outside the test chamber while the chamber was ventilated to remove all remaining formaldehyde. When the curtain was returned to the chamber, the formaldehyde concentration increased to 170 $\mu g/m^3$.

1.5.2 Characterization of VOC Sources

VOC sources can be characterized according to the duration of their emissions, the type of application, or sink characteristics and are discussed next.

1.5.2.1 Characterization According to VOC Emissions.

Building materials can be characterized by the duration of their VOC emissions. Duration and amount of VOC emissions determine the level of occupant exposure. Materials may be classified in one of the following three categories based on whether VOC emissions decay slowly, intermediately, or rapidly (Tucker, 1991).

1. <u>Materials with slowly decaying VOC emissions</u>: These materials are characterized generally by low initial VOC emissions and **half-life** emission rates (i.e., time it takes for the initial emission rate to be reduced by one-half) of a year or more. As a result, these materials emit VOCs at fairly constant rates over long time periods. Examples of such materials include pressed wood products such as plywood and particleboard containing formaldehyde-based resins.

2. <u>Materials with intermediately decaying VOC emissions</u>: These materials are characterized by either high or low initial VOC emission rates and "half-life" emission rates ranging from a few weeks to

several months. As a result, VOCs from these materials can be detected for several weeks or months after installation. Examples of such materials include certain types of floor and wall coverings, and caulks and fillers applied in continuous beads.

3. Materials with rapidly decaying VOC emissions: These materials are characterized by high VOC emissions during and immediately after installation and by half lives ranging from a few minutes to a few days. As a result, most (i.e., 95 percent or more) of their lifetime emissions occur within hours or days after installation. Examples of such materials include thin-film, wet-applied products that dry very quickly, such as paints, sealants, and adhesives.

1.5.2.2 Characterization According to Application or Sink Characteristics.

VOC-emitting building materials can be categorized according to their application or sink characteristics (Levin, 1992a) as listed below.

1. "Wet" Products: These products include paints, wood stains, sealants, adhesives, caulks, and sealers. Most solvents and other chemicals in such products are emitted for a few hours or days after installation. However, some of these products, such as caulks and fillers applied in continuous beads, and latex paints applied to gypsum wallboards may have high initial emission rates, as do other wet products, but also may continue to emit VOCs at much lower rates (e.g., 1,000 to 10,000 times lower) for weeks, or even months, after installation.

2. "Dry" Products: These products include floor and ceiling products and solid and composite wood products. VOC emissions are usually due to solvents used in the manufacturing process of the product or its constituents. Dry products, unlike wet ones, initially emit low amounts of VOCs and may continue to emit for weeks, months [e.g., styrene butadiene rubber (SBR) latex-backed carpet], or even years (e.g., composite wood products made with formaldehyde-based resins). Typically, emission rates decrease with time by as much as 100 fold in a few weeks.

3. "Porous" Products: These products include textiles such as fabric upholstery, carpets, wood products, insulation, paper, gypsum wallboard, and other porous indoor materials. Porous products may act as secondary sources (i.e., sinks as discussed in Section 1.5.1) of the chemical compounds to which they were exposed and which they trapped. This process depends on the volatility, polarity, and concentration of the chemical compounds as well as their affinity for the surface of the porous product. Porous materials acting as secondary sources can affect considerably the decay rate of indoor VOC concentrations, thus prolonging the duration of exposure.

1.5.3 Factors Affecting VOC Emissions from Building Materials

At least six major factors influence the emissions rates and resulting indoor concentrations of VOCs from building materials (ASTM, 1990a; Tucker, 1991; Tichenor and Guo, 1991).

1. Total content of vaporizable constituents in the material. Listed constituents may not include impurities or other contaminants. For example, the manufacturer of a spray adhesive lists the following information (note that the **VOC content** refers to **reactive VOCs** as discussed in Appendix H):

a) VOC content: 682 g/L (5.69 lbs/gal); and

b) Contains: Dimethyl ether (CAS # 115-10-6), Pentane (CAS # 109-66-0), Cyclohexane (CAS # 110-82-7), Non-volatile components (N.J. Trade Secret Registry No. 04499600-5468P), and Naphthol spirits (CAS # 64742-48-9).

Similarly, the manufacturer of a spray adhesive remover lists the following information:

a) VOC content: 699 g/L (5.83 lbs/gal) or 92 percent; and

b) Contains: Isopropyl alcohol (CAS # 67-63-0), Naphthol spirits (CAS # 64742-48-9), Propane (CAS # 74-98-6), Amorphous silica (CAS # 7631-86-9), Ethylene glycol (CAS # 107-21-1), Isobutane (CAS # 75-28-5), Butane (CAS # 106-97-8), and Ethane (CAS # 74-84-0).

2. Distribution of VOCs within the mass of a material resulting in diffusion-dominated or surface-dominated processes. Thick solid materials, such as composite wood products, have slow emission rates because chemicals, such as formaldehyde, must migrate by diffusion from deep within the material to the surface before they evaporate into the air. Wet processes, such as paints and adhesives, have emission bursts during and after application, because most chemicals are at or near the surface of the material.

3. Age and history of material since manufacturing, assembly, or installation. This is a very important factor because most building materials have emission rates that decrease with time. Typically, emission rates of wet products decrease by several orders of magnitude within a few hours after installation, whereas, emission rates of other materials, such as pressed wood products, may take several years to decrease. For example, Tucker (1991) reported that the emission factor of a new particleboard was 2,000 $\mu g/m^2 \cdot hr$, whereas the emission factor of a two-year old particleboard was 200 $\mu g/m^2 \cdot hr$. Tucker also reported that the emission factor of a 0.2-m^2 strip of silicon caulk less than 10 hr after application was 13,000 $\mu g/m^2 \cdot hr$, and that the emission factor decreased to less than 2,000 $\mu g/m^2 \cdot hr$ after between 10 and 100 hr following application. The age of a material must be taken into consideration when comparing emission factors of functionally equivalent materials as discussed in Section 2.2.3.4.

   The history of a material (i.e., the conditions the material was exposed to during aging time) also can affect emission rates significantly. A material's history includes packaging (i.e., whether or not the material was tightly packed), temperature, humidity, and chemistry of the environment(s) it was exposed to. Therefore the history of a material must also be considered when interpreting emission data.

4. Surface area of a material relative to the floor area or volume of a space. The surface area of a material provides an indication of the amount of exposed material present in an indoor environment. [The ratio of the surface area of a material divided by the volume of the space where it is installed is defined as the **loading factor** or **product loading** (ASTM, 1990a)]. Levin (1989) suggests comparing the surface area of a material to that of the floor. In the case of floor coverings, the exposed area is 100 percent of the floor area, whereas in the case of T-bar suspended ceiling tiles in which both sides are exposed to indoor air, the percentage approaches 160 percent (Tshudy, 1995). The exposed area of work-station panels could range up to 350 percent of the floor area depending on occupant density and panel height.

5. Environmental factors such as temperature, humidity, and ventilation rate. In general, emission rates of products increase with temperature. Air movement and ventilation does not increase emission rates resulting from diffusion-dominated processes within dry materials such as carpets, but does affect emission rates resulting from surface-dominated processes of wet products such as paints in the early drying stage. The following section addresses the effect of increased ventilation on VOC emission rates and indoor air concentrations.

Reduction of VOCs from building materials may involve one or more of the above-listed factors. Material conditioning involves varying environmental factors such as increasing ventilation rates (see Section 2.5 for development of ventilation protocols) or temperatures (see Section 3.3 and Appendix D for a description of a process known as building "bake-out"). Material conditioning, although not always a practical solution, can be done at the manufacturing or assembly site, at a bonded storage facility, or after installation and before building occupancy (see Section 2.3 for development of material-conditioning protocols). Note that storage of certain materials after manufacturing is unavoidable especially in cases of special production orders or large quantities. A conditioning process for materials with slow-decaying emission rates must always be considered prior to installation.

1.5.4 Effect of Increased Ventilation on VOC Emission Rates and Indoor VOC Concentrations

VOC emission rates and ventilation rates affect the resulting indoor concentration from any indoor VOC source. Obviously, the stronger the source the more ventilation is needed to lower VOC concentrations. For example, Tichenor (1987) reported that for a caulking compound, total volatile organic compound (TVOC) emissions (i.e., sum of air concentrations of individual VOCs) in a small environmental chamber were insignificant after 6 hr at an air change rate of 1.8 air changes per hour (ACH). However at 0.36 ACH, significant emissions were measured 10 hr after application and emission rates were declining very slowly. Tichenor also reported that for a given source there can be differences in emission rates for individual compounds. For example in the case of caulking at 0.36 ACH, the emission rate of one compound (i.e., C4 ketone) decreased much faster than the rates of two other compounds (i.e., C8 alcohol and C7 ester) (Tichenor, 1987). In another study, Tichenor and Guo (1991) reported that: (a) the VOC emission rates of wood stain and polyurethane, respectively, increased when the ventilation rate was increased from 0.35 to 4.6 ACH and from 0.5 to 2.0 ACH; and (b) the VOC emission rates from floor wax were unaffected by increasing the ventilation rate from 0.25 to 2.0 ACH.

However, there is a limitation on the effect of ventilation in reducing indoor VOC concentrations. For example, Gunnarsen et al. (1993) reported that emission rates of water-based acrylic paint applied on both sides of an aluminum plate in a chamber increased with increasing ventilation rates up to approximately 1.8 $ft^3/min{\cdot}ft^2$ (9 $L/s{\cdot}m^2$) floor. Further increase of the chamber's ventilation rate did not increase the emission rate of the paint. (Note that paint application is an evaporation-controlled process.) The authors also reported that emission rates of two other test samples (i.e., linoleum and silicone-based sealant) increased with increasing ventilation rates up to approximately 0.05 $ft^3/min{\cdot}ft^2$ (0.25 $L/s{\cdot}m^2$) and that there were no further increases in the emission rates of these test samples at higher ventilation rates.

Finally, indoor VOC concentrations may fluctuate when building and local ventilation rates vary as in the case of variable air volume (VAV) systems. These systems vary not only the amount of outdoor air supplied to a building, depending on the outdoor air conditions (i.e., temperature and humidity), but also vary the amount of supply air to various zones served by VAV boxes (i.e., local ventilation) in response to the thermal requirements of individual zones. As a result, indoor concentrations of building-related VOCs fluctuate in these buildings depending on building and local ventilation rates.

The reader is referred to Section 2.5 for guidance on using ventilation to reduce indoor exposures to VOCs and other contaminants. Section 2.5 also discusses factors that may limit the amount of ventilation that can be provided to a building.

1.6 Low-VOC-Impact Building Materials and Products

Low-VOC-impact building materials or products may be defined as those that, when installed in a building, result in minimal or reduced exposure of occupants to VOCs that are emitted from these materials or products. Although ambiguous, this definition may prove to be a useful concept. Currently there are very few specific VOC guidelines that a material or product must meet to be classified as low-emitting. Instead, continuous development of new building materials and products that emit less VOCs than similar materials and products on the market is encouraged based on available technology.

Even so-called **no-VOC emitting products** (sometimes also referred to as **zero-VOC emitting products**) can emit VOCs. This is because for the purposes of measuring the VOC content of paints and related coatings, the USEPA, the American Society for Testing and Materials (ASTM), and the California Air Resources Board (CARB) define **reactive VOCs** as "any compound of carbon,...which participates in atmospheric photochemical reactions." (USEPA, 1983; ASTM, 1993; CARB, 1993a). (The complete definition of reactive VOCs is shown in the glossary at the end of this document.) Therefore "no"-VOC emitting products may emit other VOCs, such as methylene chloride, that could cause human health effects. In California "no"-VOC and "low"-VOC emitting architectural coatings and consumer products generally have lower VOC contents than other similar products sold outside the state. This is because state and regional regulations limit the amount of reactive VOCs in various categories of coatings and products sold and used in California. These regulations are discussed further in Appendix H.

Several factors determine whether or not a building material has a low VOC impact. The most important factors are discussed below.

1. <u>Amount and chemical composition of emissions</u>: The amount and chemical composition of emissions from an indoor building material can help determine whether or not exposed occupants will experience health effects or odors. Materials that emit carcinogenic compounds or chemicals known to have reproductive or developmental effects should be discouraged especially if their use results in exposure levels exceeding the California Proposition 65 (1994) No Significant Risk Levels.

2. <u>Occupant exposure</u>: In addition to the emission rate of an indoor building material, VOC exposure depends on the building's ventilation rate, the proximity of the material to the occupants, the amount of material, the duration of the occupants' exposure, and the local air distribution pattern. Total exposure decreases with distance from a source and increases with longer exposure time. For example, emissions from workstations in the immediate proximity of office workers may result in high occupant exposures to VOCs during an 8-hr workday. In contrast, emissions from a remote source, such as duct and ceiling insulation, may result in lower occupant exposure to VOCs assuming good air mixing.

1.7 Costs Associated With the Reduction of Occupant Exposure to VOCs From Building Materials

Building owners may be reluctant to expend more money to minimize occupant exposure to VOCs unless information on the benefits of such measures is available or can be obtained with some reliability. Such benefits include increased productivity, decreased health care costs, improved building marketability, and reduced liability exposure. Design and building professionals should be prepared not only to justify but also to estimate the costs, if any, of measures to reduce occupant exposure to VOCs. Unfortunately, very little information is available in this area. Following is a discussion of these costs.

1. Cost of building materials: Building materials account for a large percentage of typical construction costs. Levin and Hodgson (1994) reported that this percentage is between 30 and 60 percent of the construction costs. Typically the price of building materials is independent of emissions characteristics. Although small premiums may be charged for some low-VOC-emitting materials, such as in the case of low-VOC-emitting paints, these premiums are likely to be reduced or eliminated as demand for these products increases. In the case of paints, more stringent ambient air regulations are likely also to result in reduction of these premiums. In addition, group purchases through building consortiums such as industry groups and school districts can reduce these premiums even further.

2. Emissions testing of building materials: For a typical product, the cost for VOC emissions testing varies depending on the sampling technique used (i.e., headspace, small or large-size chamber), duration of the test, number of test ventilation rates, and number and type of the chemical analyses. Levin and Hodgson (1994) reported that the cost of testing individual products based on the dynamic "headspace" sampling technique (see Item 4 of Section 2.2.2 for a description of emissions testing procedures) ranges between $1,000 to $2,000 per test. The cost of testing large-size products requiring environmental chambers, varies from between $400 and $1,500, such as in the case of testing particleboard and medium density fiberboard (MDF) for formaldehyde emissions (Groah and Margosian, 1995), to more than $5,000, such as in the case of testing complete office workstations for TVOCs. In addition to the cost of laboratory testing, other costs, such as the cost of shipping a product or material from the manufacturing site to the testing laboratory, also must be considered. Shipping costs, especially in the case of complete workstations, are not trivial. Also very few commercial laboratories are equipped with large-size chambers that are capable of performing long-term testing of samples. The cost of emissions testing is usually a small fraction of the purchase cost of a material on a single project (i.e., 0.1 to 1 percent of the purchase cost). The cost of emissions testing, and re-testing if necessary, is normally borne by the manufacturer as part of their product research and development. The larger the size of a project, the more vendors will tend to cooperate in providing VOC-related information, especially if such a requirement is included in the contract document specifications, i.e., product manufacturers may be more willing to provide emissions test data, on larger jobs than on smaller ones (see Appendix F for an example of contract document language). Also in the case of large corporations with multiple construction projects, a single strategy on emissions testing and selection of building materials could be applicable to other projects with similar design specifications.

   A number of manufacturers have already tested their products and may be willing to provide their results for review at no additional cost. However, some manufacturers may be reluctant to provide these data for a number of reasons such as: (a) concern that emission data, obtained under chamber conditions, may be misleading, inaccurate, and not representative on how their products actually impact indoor air quality under actual use conditions (such as in the case of carpet adhesives where another product is always installed over them); (b) confidentiality; (c) potential liability exposure; and (d) concern on how the data may be "misused" (Tshudy, 1995).

3. Design fees: The design team consists not only of an architect and a mechanical engineer, but of other professionals who may be involved with various aspects of the overall design for improved indoor air quality including an interior designer, a cost estimator, a specification writer, an IAQ consultant, and an acoustical consultant. The total design fee for improved indoor air quality includes, among others, selection of low-VOC-impact building materials and design and commissioning of the HVAC system(s) and, as such, it is based on the design team's total time and not on the quantity of materials purchased or size of the building. However, the total design time depends on various other factors such variety of materials used in a project, time needed for researching and obtaining product information, the project's complexity, etc.

   Because the task of selecting low-VOC-impact building materials and products is a new area for most Architectural/Engineering (A/E) firms, very little published information exists on the increased design fees associated with this task. For example, Bernheim (1993, 1995a) reported that the total estimated indoor air quality design fee (including not only material evaluation and selection, but also engineering time for HVAC commissioning) for a 391,000-ft^2 (36,325-m^2) library in California was 1.08 percent of the A/E fees. It is noted that Bernheim's reported costs are based on only one project and therefore is insufficient to draw any general conclusions about design fees.

4. Increased ventilation: The energy costs associated with increased ventilation may not be prohibitive as indicated by Eto and Meyer (1988) who calculated the energy costs resulting from increasing ventilation rates from 5 to 20 ft^3/min per person. The authors reported that annual energy costs increased by as little as 1 percent to as much as 8 percent for heating and from less than 1 to 14 percent for cooling. Although the increased energy costs of a building **flush-out** (i.e., a process during which a building is continuously ventilated for several days or weeks at the maximum possible outdoor air rate) are likely to be higher than those reported by Eto and Meyer (1988), they are unlikely to be prohibitive. The party responsible for the increased energy cost of ventilation during construction and building flush-out before occupancy must be identified early in the design and planning phases of a building.

5. Other costs: Other costs, such as material conditioning, delayed occupancy, and HVAC commissioning, also must be considered. These costs vary widely among projects and should be considered in the early stages of a building's design. No data exist on the costs of material conditioning and delayed occupancy. However, some very limited data is available on costs of HVAC commissioning. The average cost of commissioning a new office building is 2 to 5 percent of the installed equipment to be commissioned, and the cost of operating a commissioned building is 8 to 20 percent less than a similar non-commissioned building (Lawson, 1996). In addition, owners of buildings that have not been commissioned could lose \$4 to \$8 per ft^2 each year "...due to faulty design or installation of HVAC systems" (Lawson, 1996). However, the entire building commissioning procedure may not be appropriate or necessary in all projects, thus reducing the commissioning cost to about 1 percent of the mechanical systems cost (Bernheim, 1995b).

   Finally, it should be noted that local utility companies in certain areas offer incentives for lowering on-peak loads and for HVAC commissioning thus reducing owner's out-of-pocket expenses for building commissioning.

In summary, the limited information presented above indicates that the highest cost of reducing occupant exposure to VOCs is associated with emissions testing of building materials, especially when many products must be tested. However, design fees and costs of building materials, increased ventilation, and other costs must be considered during the project-planning phase. In most cases, costs other than emissions testing and design fees are project specific. For example, the cost of product reformulation may, in certain cases, exceed all other costs. However, improved marketability of that product may justify a manufacturer's cost of reformulation. Costs of testing and product reformulation should be borne by the manufacturer as part of their product research and development and should not be passed directly to the consumer. It is important to realize that the costs of reducing occupant exposure to VOCs can be justified on the basis of increased employee productivity, reduced health care costs, increased building marketability, and reduced liability exposure. A **life cycle** cost analysis enables a user to compare possible higher initial costs, if any, to reduced long term costs for the anticipated life of a product or material.

SECTION 2. GUIDELINES

2.1 The Recommended Strategy to Reduce Exposure to VOCs

The guidelines presented in this section consist of a five-step approach to reduce exposure to VOCs from building materials and products. The recommended approach must be included in the design phase of a building. The reader is referred to the related sections for a detailed discussion of each topic.

1. Evaluate and select low-VOC-impact building materials and products (Section 2.2).

2. Pre-condition materials to minimize VOC emissions after installation (Section 2.3).

3. Install building materials and products based on their VOC emission decay rates (Section 2.4).

4. Ventilate during and after installation of new materials and products (Section 2.5).

5. Delay occupancy until VOC concentrations have been reduced substantially (Section 2.6).

2.2 Evaluation and Selection of Low-VOC-Impact Building Materials

Evaluation and selection of low-VOC-impact building materials is the first step in minimizing occupant exposure to VOCs. The procedure described here is equally applicable for new construction, renovation, remodeling, and refurbishing. It is imperative that design professionals, as well as building owners and managers responsible for building material selection, understand: (a) the impact of building materials on the quality of indoor air; and (b) the importance of selecting low-VOC-impact building materials and products. Figure 3 summarizes the four-step strategy for evaluating and selecting low-VOC-impact building materials and products. Sections 2.2.1 through 2.2.4 discuss each of these steps in detail.

2.2.1 Step 1 - Identification of Target Building Materials and Products

In general, wet-applied products, such as adhesives, paints, caulks, sealants, and finishes, dry quickly (typically in few hours or days) and have high emissions of short durations (typically a few hours). Other products, such as particleboard and plywood, have low emissions lasting long time periods (typically a few months or years). However some wet products, such as carpet adhesives, have long-term emission rates that are significantly higher than many dry products.

Factors other than emission rates also need to be considered when choosing building materials and products. The most important of these factors are described below.

1. Quantities of the materials used: Because selection of a material depends on its installed quantity, it is important to identify the quantities of all VOC-emitting materials. Materials used in large quantities may be of concern even if they are low-emitting.

   As described earlier, Levin (1989) suggested comparing the surface area of a material to that of the floor. In the case of floor coverings, the exposed area is 100 percent of the floor area, whereas in the case of T-bar suspended ceiling tiles in which both sides are exposed to indoor air, the percentage approaches 160 percent (Tshudy, 1995). Openings in the T-bar ceiling, such as light

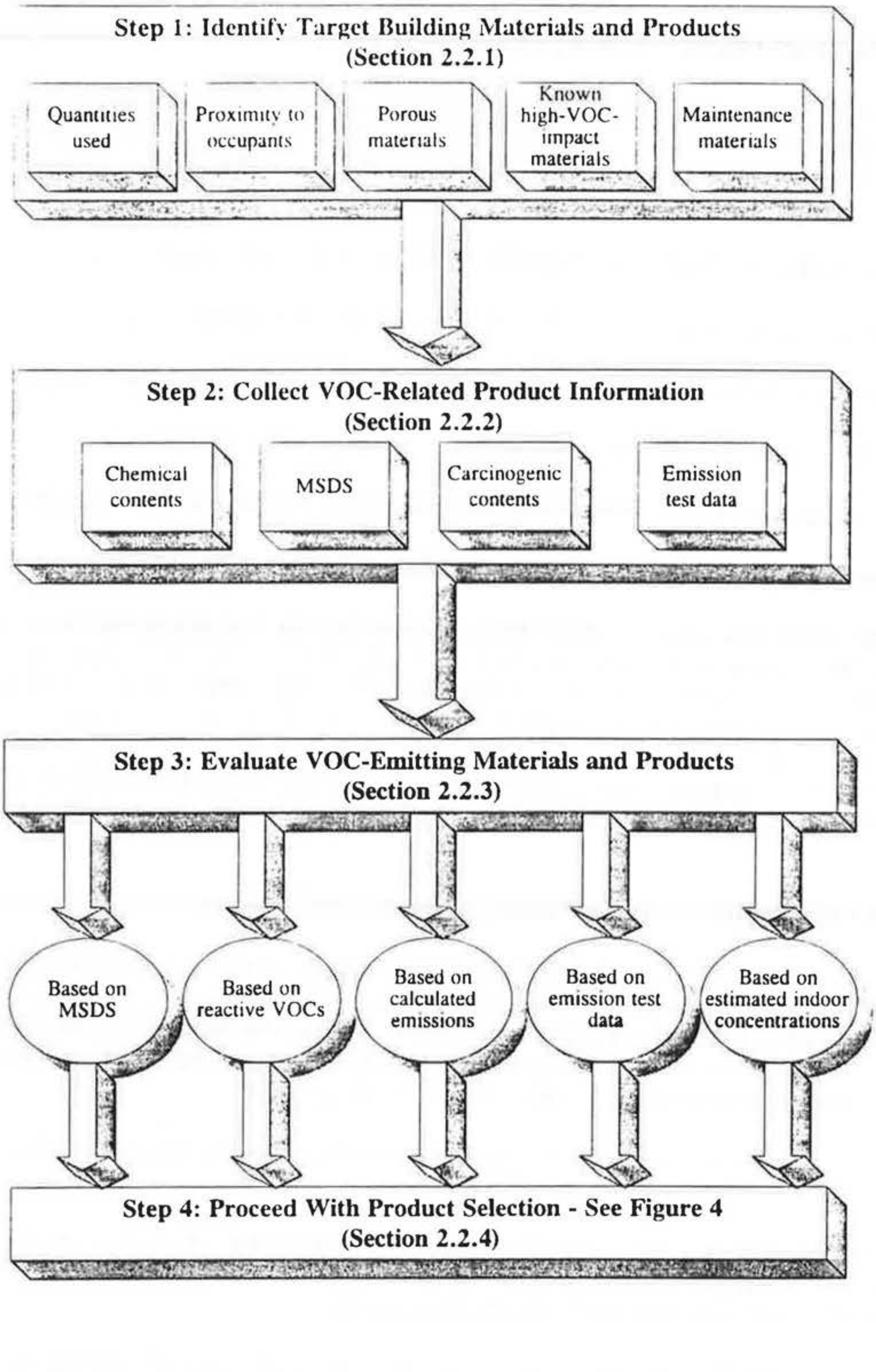

Figure 3. Four-Step Strategy for Evaluating and Selecting Building Materials and Products

fixtures and ventilation registers must be taken into consideration when calculating percentage of ceiling exposed area. The exposed area of work-station panels range up to 350 percent of the floor area depending on occupant density and panel height (Levin, 1989). Materials with high loading factors (i.e., surface area of installed material divided by the volume or floor area of the indoor environment where the material is installed) are of particular interest due to the amounts of these materials present in indoor environments.

2. Proximity of a material to occupants, such as in the case of work stations and interior partitions: Exposure of occupants to VOCs emitted from a material increases as the distance between the material and the occupants decreases. Exposure of occupants also depends on the degree of air mixing in the occupied space. For example, if the supply air short-circuits to the return opening before mixing with the room air then VOC concentrations will be higher in the occupied space than would have been if supply air mixed thoroughly with the room air before it was exhausted.

3. "Porous" materials: Identification of these materials is important because they act as "sinks" adsorbing and re-emitting VOCs originating from other sources (see Section 1.5.1 for a description of the characteristics of VOC sinks). Porous materials include carpets, acoustic and thermal insulation materials, and fabric-covered partitions.

4. Known high-VOC-impact materials: Known high-VOC materials can be identified using existing knowledge on product emissions. Because of the continuous development of new, lower VOC-emitting materials and products, it is important that current emission data be used for this evaluation. Use of known high-VOC emitters should be avoided.

5. Maintenance products used, such as waxes, polishes, disinfectants, and cleaners associated with target building materials: Although not part of the construction process, the use of such products is directly associated with the installed materials. For example, installation of sheet vinyl flooring requires more frequent maintenance with chemical-containing materials such as cleaning and waxing products than other floor coverings such as ceramic tile or hardwood.

2.2.2 Step 2 - Collection of VOC-Related Product Information

The extent of the collection process of VOC-related product information relates to the scope and size of a project. Manufacturers may be reluctant to provide some of the VOC-related product information but recently, due to an increased awareness of the importance of good indoor air quality among design professionals, more building product manufacturers have their products tested and thus information is increasingly available. Some product manufacturers, such as carpet, particleboard, medium density fiberboard (MDF), and plywood manufacturers, have already initiated voluntary testing programs (see Appendix C for descriptions of various labeling programs). Obviously the extent of product testing depends on the scope and size of a project.

The following information should be collected from product manufacturers.

1. Copies of MSDSs (Material Safety Data Sheets): MSDSs should be obtained for each material or product used. Secondary suppliers and manufacturers should also be asked to provide these lists. (See Section 2.2.3.1 for a description of information that can be obtained from MSDSs).

2. Product specifications: Product specifications usually include lists of chemical contents. However, availability of information on chemical contents is highly variable throughout the industry. Some manufacturers even consider this information proprietary and may be unwilling to release it,

whereas others provide related information in their published literature. It is unreasonable to expect architects or other building designers to conduct the necessary literature review for collection of such information.

It is noted that delivered products may not have the same chemical contents as those published by the manufacturer. This is because chemical contents may change due to manufacturing variations, batch-to-batch variations in product formulation, and variations in curing time. One way of ensuring that delivered and tested products have the same chemical composition as those tested and reported is to require that the manufacturer provides an appropriate certificate. Note that it is common practice for manufacturers to issue certificates for other product characteristics, such as pile height in the case of carpets, in order to assure a customer that the delivered product will have the same characteristics as the display sample.

3. Emissions testing data: VOCs can be measured either individually or collectively as TVOCs. Results can be presented either as emission factors or total emissions from the time a product is installed until it is completely dry.

   Testing of a product for emissions can be conducted either in an environmental chamber or from a "headspace" apparatus. Environmental chamber testing is conducted in small-size chambers [e.g., 1 L or less (ASTM, 1990a)], in medium-size chambers (i.e., few liters to 5 m^3), or in large-size chambers (i.e., above 5 m^3) capable of accommodating full-scale samples (e.g. office furniture). Large-size chambers are expensive to build and operate. In contrast, headspace testing involves placing a product sample (e.g., a section from a carpet roll, a piece of plywood, etc.) in a closed container for a pre-determined period of time and then sampling the air in the "head space" above the sample in the container. Both static (i.e., closed container) and dynamic (i.e., air flowing through the container) headspace analyses are used. The reader is referred to the ASTM Standard Guide D 5116 - 90 (ASTM, 1990a) for more information on available techniques for measuring VOC emissions from building materials using small-scale environmental chambers.

   Reporting of emission testing results should include (see Appendix F for a sample of contract language incorporating most of the items listed below):

   a) emission factors of TVOCs and any individual VOCs of special concern due to their toxicity or irritability, such as formaldehyde;

   b) time and history since product manufacturing or product installation when samples were taken;

   c) test and environmental conditions such as sample preparation details, analytical methods, amount of ventilation, temperature, relative humidity, and air velocities; and

   d) product loading factor, i.e., exposed surface area of the material tested in relation to chamber's volume or floor area.

   Standard testing methods exist for some products and materials [e.g., ASTM E 1333 - 90: *Standard Test Method for Determining Formaldehyde Levels from Pressed Wood Products Under Defined Test Conditions Using a Large Chamber* (ASTM, 1990b).] Appendix G lists a survey of existing test methods. A number of standard test methods are now being developed and should become available in the next few years. Drafts of proposed test methods may be included in contract proposals for some construction projects (e.g., see Appendix F for an example of a contract document language). It is important to ensure that the product tested is the same product that is installed in the building. This can be achieved by incorporating appropriate certification language in the contract documents. Note that it is common practice for manufacturers to issue certificates for other product characteristics, such as pile height in the case of carpets, in order to assure a customer that the delivered product will have the same characteristics as the display sample.

VOC-related information also should be collected for all cleaning products associated with target building materials as described above.

4. Other sources: These may include lists of any known or suspected carcinogens or reproductive or developmental toxicants: Product manufacturers should identify any VOCs that are known or suspected carcinogens or reproductive or developmental toxicants, as listed by the State of California (California Proposition 65, 1994; CARB, 1993b) and the International Agency for Research on Cancer (IARC) as published by WHO in the *IARC Monograms on the Evaluation of Carcinogenic Risks to Humans* (IARC, 1987, 1989, or most recent edition). Materials that emit carcinogenic compounds or chemicals known to have reproductive or developmental effects should be discouraged especially if their use results in exposure levels exceeding the California Proposition 65 No Significant Risk Levels. (Table E8 of Appendix E identifies some of the most common VOCs emitted from building materials that are on the Proposition 65 list and/or the IARC list.) Formaldehyde should be reported and listed separately.

2.2.3 Step 3 - Evaluation of VOC-Emitting Products

Building products can be evaluated based on: (a) MSDSs; (b) reactive VOCs; (c) calculated chemical emissions using vapor pressures and mass transfer coefficients; and (d) results of emissions testing. These four evaluation methods are discussed next.

2.2.3.1 Evaluation of Building Products Based on MSDSs.

MSDSs are documents mandated by the OSHA in Section 1910.1200(g)5 of Title 29 of the Code of Federal Regulations (CFR) (1994) and by the California Occupational Safety and Health Administration (Cal-OSHA) in Section 5194(g) of Title 8 of the California Code of Regulations (CCR) (1994) for all types of work environments. The purpose of an MSDS is to list all **hazardous substances** contained in a specific product. Cal-OSHA defines a hazardous substance as "any substance which is a physical hazard or a health hazard or is included in the List of Hazardous Substances prepared by the Director pursuant to Labor Code section 6382" (CCR, 1994). Furthermore, Cal-OSHA defines **health hazard** as "a substance for which there is statistically significant evidence based on at least one study conducted in accordance with established scientific principles that acute or chronic health effects may occur in exposed employees." Included in this category are "...substances which are carcinogens, toxic or highly toxic agents, reproductive toxins, irritants, corrosives, sensitizers, hepatotoxins, nephrotoxins, agents which act on the hematopoietic system, and agents which damage the lungs, skin, eyes, or mucous membranes" (CCR, 1994).

MSDSs are available for most building products and employees must have access to MSDSs for each hazardous substance-containing product if the amount of product they use exceeds the amount that a person would typically use at home. For example, an office worker is not required to have an MSDS for a household cleaning product such as window cleaning detergent if the worker uses this product to clean the inside of his/her office windows once a month, a use comparable to a typical home use of this product. However, a building janitor who uses several gallons of the same window detergent each day must have access to these documents. During building construction, MSDSs must be accessible to workers that are potentially exposed to materials and products which contain hazardous substances.

Products deemed as "articles" such as curtains do not need to have MSDSs.

An MSDS is organized into various sections, each section providing information in a specific safety area. The following list offers section-by-section guidance on the uses and limitations of MSDSs.

1. Components: This section identifies hazardous substances contained in a product. If the hazardous substance is a mixture that has not been tested as a whole then the following are listed.

   a. The names of all ingredients that: (i) have been determined to be health hazards; and (ii) comprise 1 percent or greater of the composition. Substances identified as carcinogens are listed if concentrations are 0.1 percent or greater. However, ingredients comprising 1 percent or less of a mixture's composition, or carcinogens comprising less than 0.1 percent of this composition, are listed if there is evidence that ingredients could be released from the mixture in concentrations exceeding established OSHA Permissible Exposure Limits (PELs), ACGIH Threshold Limit Values (TLVs), or could present a health hazard to employees.

   b. The names of all ingredients that have been determined to present a physical hazard when present in the mixture.

   Some hazardous substances may be listed as proprietary and thus information on their compositions are not disclosed and are protected as trade secrets (e.g., see Section 1.5.3; Item 1; first example). However, information on the properties and effects of substances covered under trade secrets must be disclosed. Also byproducts unknowingly formed during the manufacturing or installation process may not be listed. In addition, some MSDSs: (a) list percentage ranges of the contents and in some cases these ranges are fairly large; and (b) list contents of several products having similar hazards and mixture contents with specific chemical composition varying from mixture to mixture. Finally MSDSs do not cover variations in the manufacturing process, batch-to-batch variations in formulation, and variations in curing, packaging, storage, and transportation.

2. Emergency and First Aid Procedures: The emergency and first aid instructions listed under this section are applicable to high-level, worst-case exposures, such as in the case of spills, and not to the exposures resulting from intended use of the product.

3. Health Hazard Effects: This section lists health effects based on animal and human studies. The listed carcinogenic effects are primarily due to exposure of experimental animals to concentrations that are much higher than those typical of office environments. In addition, acute and chronic health effects for high-concentration exposure are listed if known. Nuisance effects also may be listed if known.

4. Physical Data: This section provides information on odor, volatility, and reactivity. The listed odor descriptions may be useful in identifying sources; the listed volatility information (i.e., boiling point, flash point, vapor pressure, vapor density, evaporation rate, etc.) as well as stability may suggest which substances are likely to become airborne; and reactivity information may be useful in determining compatibility with other chemicals. However, interpretation of physical data to predict indoor concentrations is difficult because of lack of information on the diffusion characteristics of building materials (see Section 2.2.3.3: Evaluation of Building Products Based on Calculation of Chemical Emissions for more information on this topic).

5. Fire Fighting Measures: This section describes expected combustion products in the event of a fire. This information may be useful in the development of fire safety procedures.

6. Hazardous Reactivity Data: The hazardous reactivity data listed in this section may be useful for developing proper storage and installation procedures for a product or material. In addition, compatibility with other chemicals may be determined from the listed data.

7. Handling, Storage, and Spill Control Measures: The information on proper storage, transportation, and packaging procedures listed in this section may not be applicable to office environments where chemicals are used in smaller quantities than in industrial environments. Cleaning procedures and protective measures in the event of spills and leaks also are identified in this section. However, controls for reducing emissions from indoor use of a product or material are not specified in this section.

However, some caution should be exercised in the use of MSDSs because sometimes they are incomplete or inaccurate, failing to list all potentially hazardous substances. Kolp et al. (1995) reported that of the 150 MSDSs they evaluated for accuracy and completeness they found that: (a) 89 percent provided "identifiable chemical names"; (b) only 37 percent had accurate health effects data with acute data being more correct than chronic; (c) 76 percent provided "adequate first-aid information"; and (d) only 47 percent were "judged to have an accurate information for personal protective equipment."

2.2.3.2 Evaluation of Building Products Based on Reactive VOCs.

Architectural coatings, aerosol coatings, and certain categories of consumer products, including cleaning products, can be evaluated based on their **reactive VOC** content. However, caution must be exercised when using such data. As was mentioned in Section 1.6, the USEPA, the ASTM, and the CARB define reactive VOCs as those VOCs that "participate in atmospheric photochemical reactions" (see glossary at the end of this document for complete definition). However some indoor VOCs, such as methylene chloride, are excluded from the definition of reactive VOCs. In addition, manufacturers of building materials other than the ones listed above, such as carpet and office furniture, are not required to supply such information.

In California, the CARB, the local air quality management districts (AQMDs), and the air pollution control districts (APCDs) regulate the maximum amount of reactive VOCs contained in architectural coatings, aerosol sprays and consumer products. Therefore products sold and used in California to build, decorate, maintain, and clean office buildings must meet at least the applicable state and local regulations on reactive VOCs. Appendix H gives a summary of background information on these regulations and lists the maximum allowable quantities of reactive VOCs for selected product categories.

2.2.3.3 Evaluation of Building Products Based on Calculation of Chemical Emissions

Calculation of emission rates based on vapor pressures and mass transfer coefficients for chemicals of concern is theoretically possible and can be made based on the following equation (ASTM, 1990a).

$$E = K_m \, (VP_s - VP_a) \qquad (1)$$

where:
E = emission rate
K_m = mass transfer coefficient
VP_s = vapor pressure at the surface of the material
VP_a = vapor pressure in the air above the surface of the material

However, such calculation requires knowledge of the diffusion characteristics of the material. For example, in the case of carpet containing 4-PC an odorous compound, the diffusion characteristics of 4-PC in the carpet must be known. In the case of wet products, a film develops shortly after application and therefore knowledge of the film's characteristics is important. Another problem associated with using Equation 1 is that it requires knowledge of the chemical contents of a product or a material. Unfortunately accurate information on the chemical contents of a product may be difficult to obtain. For example, MSDSs may be incomplete or not accurate enough for such calculations.

Both empirical and fundamental mass transfer models are being developed to predict emission rates of building materials. It is beyond the scope of the guidelines presented in this document to discuss these complex diffusion-based mass-transfer models. Instead, the interested reader is referred to Tichenor et al. (1993), Clausen et al. (1993), Little et al. (1994), and Tichenor (1995).

2.2.3.4 Evaluation of Building Products Based on Emissions Testing

Emissions testing data can be used to compare functionally equivalent materials or products. However, such a comparison must be done carefully keeping in mind the following.

1. There are no standard testing and reporting methods for TVOCs. A number of researchers reported the following:

   (a) Hodgson (1995) reported that TVOC results for the same mixture of compounds analyzed by different methods can easily vary by a factor of two or more and that reported TVOC results from laboratories analyzing the same TVOC mixture and using the same analytical instrumentation methods may vary due to differences in: (i) sample collection methods; (ii) TVOC calibration methods; and (iii) data reduction and analysis. Hodgson also reported that the accuracy of TVOC results depends on the mixture of compounds and that not a single analysis method is appropriate or sensitive for all VOCs.

   (b) Brown et al. (1994) in a review of concentration of VOCs in indoor air noted the lack of consistency among investigators in the definition of TVOC; and

   (c) Colombo et al. (1993) and DeBortoli et al. (1995) demonstrated in two separate comparisons of 20 laboratories that large variations existed among these laboratories in reported TVOC measurements for a selected number of building materials.

   Therefore TVOC emission factors should be used to compare similar products emitting similar VOCs that have been tested using the same methods.

2. Age and condition of tested materials may vary. Typically, older materials have lower emission rates than newer materials.

3. The environmental conditions of a test chamber (i.e., temperature, humidity, ventilation rate, and air velocities), the size of a test chamber, and the adsorption characteristics of a chamber can affect

the reported emission factors. For example, Hodgson et al. (1993) measured VOCs emitted from four carpet samples both in small-volume (i.e., 4-L) chambers and in a large-volume (i.e., 20-m^3) environmental chamber and reported the following:

a) the concentrations of the "least volatile compounds" measured, i.e., 4-PC and butylated hydroxytoluene (BHT), were two to three times lower in the small-volume chambers; and

b) the concentrations of some "relatively volatile compounds", such as 4-ethenylcyclohexene, styrene, and hexamethylcyclotrisiloxane, were one order of magnitude lower in the small-volume chambers.

4. VOC emissions from tested products may differ from those delivered for installation, due to a number of reasons including variations in manufacturing process, batch-to-batch variations in formulation, and variations in curing, packaging, storage, and transportation.

Table E1 of Appendix E lists a suggested classification scheme for selected building materials. Levin (1995b, 1996) reported that published data indicate that in most buildings, building-wide average TVOC source strengths (i.e., emission factors calculated from measured TVOC concentrations and building ventilation rates) typically range from about 500 to 1,500 $\mu g/m^2 \cdot hr$. Levin also reported that in "clean" buildings, published TVOC source strengths are well below 500 $\mu g/m^2 \cdot hr$, whereas, in other "less clean" buildings, published source strengths are between 2,000 and 10,000 $\mu g/m^2 \cdot hr$. A study conducted in 56 office buildings in nine European countries reported that the "total mean chemical pollution load" (i.e., emission factor) was 1080 $\mu g/m^2 \cdot hr$ (Bluyssen et al., 1995a, 1995b)

It is desirable that materials and products have VOC emission data. The use of materials and products without such data should be discouraged. Emission data can be obtained by submitting samples to reputable laboratories for testing (see Section 1.7 for typical costs of emissions testing).

2.2.3.4.1 Prediction of Indoor VOC Concentrations Based on Emissions Data

Prediction of indoor VOC concentrations can be based on emissions data and building ventilation rates. One of the primary advantages of this method is that indoor VOC concentrations can be predicted for various materials and products before construction, thus avoiding chemical sampling and possible expensive mitigation (Alevantis and Petreas, 1995). Once all the building parameters are entered in the computer, a designer can choose various alternatives and calculate immediately the resulting indoor concentrations. However, such predictions are complicated for the following reasons:

a) prediction of product emissions over periods of several months based on extrapolation of emissions data collected under controlled conditions over a few hours or days may not be accurate because emissions may not decay at a constant rate; and

b) the effect of all potential sinks within a building is difficult to estimate.

Mason et al. (1995) reported that a modeling effort in one building failed to predict actual building concentrations. For these reasons, quantitative prediction of indoor VOC concentrations based on emissions data may not be practical for widespread use in the field. At the present time such models exist and are used primarily in research and experimental studies [e.g., Sparks et al. (1989, 1991); Sparks and Tucker (1990); Walton (1994); Tichenor et al. (1991); Axley (1991)]. However, estimates of VOC concentrations based on emission data and simplified models can be useful for range-finding purposes during material and product selection process. See Appendix I for a simplified method of estimating indoor concentrations from emission factors.

2.2.3.4.2 Evaluation of Materials and Products Based on Indoor VOC Concentrations

Evaluation of materials and products based on VOC concentrations requires expertise in chemistry, material sciences, toxicology, and medicine. Because there is limited data available in these fields, assistance of consultants may be needed to interpret and compare data from competing manufacturers. See Appendix I for two examples of product comparisons based on predicted indoor VOC concentrations. The information in the following appendices can be used to interpret emission factors.

1. Appendix E: This appendix discusses the following:

   a) Guidelines for TVOCs: Section E1 discusses the European guidelines, Tucker's classification scheme of building materials, and the State of Washington's requirements. As was stated previously in Section 2.2.3.4 (Item 1) the TVOC concept should be used only as a screening tool to determine whether or not VOC concentrations in buildings are within a typical range. See the end of this section for reported "typical" TVOC concentrations.

   b) Health effects of selected VOCs: At this time the relation of TVOCs to health effects is highly controversial. Until more studies are conducted to clearly define this relation, it appears that a more rational approach is to rely on specifically identified VOCs whose health effects are known. Section E2 discusses the sources, exposure routes, health effects including short-term exposure thresholds, and any applicable guidelines for six selected VOCs. The VOCs discussed are benzene, formaldehyde, methylene chloride, styrene, tetrachloroethylene, and toluene and were selected because: (a) they are common indoor air contaminants; (b) they are listed by the CARB as toxic air contaminants (CARB, 1993b); and (c) they have significant adverse health effects.

   c) Carcinogen and Reproductive Toxicants: Section E3 lists those VOCs known or suspected to be emitted from building materials presented in Appendix B, that are also listed by Proposition 65, the IARC, or the CARB.

   d) Sensory effects of VOCs: Section E4 discusses the odor and irritant effects of VOCs and lists odor thresholds and irritation characteristics for 58 VOCs that can be emitted from building materials and products presented in Appendix B. (See Section K9 of Appendix K for additional sources of information on chemical irritants and toxicants.)

2. Appendix C: This appendix provides a survey of existing product labeling programs in the United States (including the CRI's labeling program and the Hardwood Plywood and Veneer Association's as well as the National Particleboard Association's formaldehyde labeling programs) and in Europe. The VOC requirements that must be met in some of these programs are also listed.

Several studies have reported TVOC concentrations in occupied office buildings. The results of some of these studies are listed below in order to assist the reader in interpreting these concentrations.

1. Wallace et al. (1991) reported that TVOC concentrations in 10 buildings (three of which were new) in several U.S. cities were between 1,000 $\mu g/m^3$ and 42,000 $\mu g/m^3$ with a geometric mean of 2,300 $\mu g/m^3$ (the highest TVOC concentrations were measured in the three new buildings).

2. Daisey et al. (1994) reported that TVOC concentrations in twelve occupied California office buildings ranged from 230 to 7,000 $\mu g/m^3$ with a geometric mean of 510 $\mu g/m^3$ (the highest TVOC concentrations were measured in two buildings with wet-process copiers; the geometric mean excluding these two buildings was 410 $\mu g/m^3$).

3. Bluyssen et al. (1995a) and Bernhard et al. (1995) reported that building-average TVOC concentrations in 56 office buildings in nine European countries ranged between 40 and 1,840 $\mu g/m^3$ with a geometric mean of 230 $\mu g/m^3$.

4. An ongoing cross-sectional study of public and commercial occupied office buildings is being conducted by the USEPA (Womble et al., 1995; Girman et al., 1995; Brightman et al., 1996). In this Building Assessment Survey and Evaluation (BASE) study, TVOC measurements are being collected. TVOC measurements are measured in three sites at each building with each site having a target population of 50 occupants and no more than two air handling units. Brightman et al. (1996) reported that TVOC concentrations in 16 buildings ranged from 33 to 515 $\mu g/m^3$ with the exception of one building in which TVOC concentrations were as high as 2108 $\mu g/m^3$ due to high dichlorodifluoromethane concentrations. Table 2 lists the results for each test site.

The results of the above studies can be used as a guide in interpreting TVOC concentrations. The reader is reminded that TVOC concentrations should be used as a screening tool to determine whether or not building TVOC concentrations are within "typical" ranges. Levin (1996) suggested that indoor TVOC concentration of occupied buildings, other than new on newly renovated, exceeding 1,500 $\mu g/m^3$ "suggest the need for investigation of sources and mitigation."

Building ID	TVOC Concentration, $\mu g/m^3$				
	Indoor			Outdoor	
	Site 1	Site 2	Site 3	Primary Sample	Duplicate Sample
LAGW04	462	424	515	28	32
LAGW05	206	178	199	113	112
LAGW06	284	212	223	14	58
SCDW01	144	140	313	38	39
SCDW02	101	199	149	32	33
NVAW02	1935 $^{\alpha}$	1358 $^{\alpha}$	2108 $^{\alpha}$	204	248
NVAW01	69	64	160	47	38
NVAW03	58	70	119	38	26
CAEW09	63	83	103	35	97
CAEW07	47	33	53	23	23
AZHS04	174	159	191	297	24
AZHS02	69	126	94	49	33
FLGS04	441	394	440	72	45
FLGS01	-	119	146	81	53
PABS04	260	174	165	29	130
PABS03	388	371	460	44	57

Table 2. TVOCs Concentrations for 16 Large Buildings Measured Under the USEPA's BASE Study Using EPA TO-14 Standard Testing Method (Brightman et al., 1996)

$^{\alpha}$ High dichlorodifluoromethane concentrations.

2.2.3.5 Evaluation of Cleaning Products

The procedures described in Steps 1 and 2 (Section 2.2.1: Step 1- Identification of Target Building Materials and Products; and Section 2.2.2: Step 2 - Collection of VOC-Related Product Information) above also can be used to evaluate cleaning products. The following must be considered when evaluating cleaning products: (a) residues of surfactants and detergents on fabrics and carpets may cause skin irritation and, when aerosolized, may cause eye and mucous membrane irritation; (b) cleaning solvents containing reactive hydrocarbons may result in adverse health effects; (c) cleaning powders for soiling removal could become aerosolized if not properly removed; and (d) application of polishes and waxes to hard surfaces may result in VOC emissions, especially when applied with rotary cleaning equipment. If ozone (O_3) is used during cleaning or deodorizing, then it may, depending on the resulting indoor concentrations: (a) react with other VOCs in a building, in a process similar to combustion, to form oxidized compounds such as organic acids and aldehydes which have low odor thresholds; and (b) result in odors or adverse health effects (Berry, 1994). Berry (1994) provides general guidelines on cleaning products and specific recommendations for carpet and fabric cleaning.

In California, as was mentioned in Section 2.2.3.2, the CARB regulates the maximum amounts of **reactive VOCs** (i.e., VOCs that participate in atmospheric photochemical reactions) contained in consumer products including cleaning products. These regulations can be found in the California Code of Regulations (CCR, 1993) and are listed according to the maximum percentage of VOCs allowed per product category. At a minimum, cleaning products sold or supplied for use in California buildings must meet these requirements. Table H3 of Appendix H lists these requirements for various cleaning product categories.

2.2.4 Step 4 - Selection of Low-VOC-Impact Materials

2.2.4.1 Pre-selection Process

During the pre-selection step, design professionals should consider several issues before selecting products. These considerations include the following.

1. Chemical substitution or product reformulation: It is important that design professionals communicate directly with product manufacturers and encourage them to develop low-emitting materials. If a product contains undesirable organic compounds, an effective communication process could result in chemical substitution or product reformulation by the manufacturer. For example, a manufacturer may be able to substitute a less hazardous ingredient in a paint or develop a low-emitting adhesive.

2. Product substitution: Product substitution may be a consideration in some cases. However, considerations other than VOC emission rates may need to be made when substitute products are used. These considerations may include: acoustical properties, comfort properties, local building codes, architectural characteristics (e.g., color, texture, and appearance), cost, durability, warranty, and maintainability.

   Examples of product substitution include selecting steel cabinets instead of plywood; installing pre-finished, nailed-down hardwood flooring instead of carpeting; and installing masonry flooring such as ceramic tile or marble instead of carpeting.

3. Product encapsulation: Product encapsulation may be another alternative. Examples include complete lamination of particleboard surfaces and coating of thermal and fireproofing insulation with a smooth impermeable membrane to reduce VOC emissions and/or adsorption and subsequent re-emissions. Care must be taken to insure that the encapsulation process does not alter the thermal, fire, acoustical or other properties of the product being encapsulated.

4. Cleaning products: Cleaning products need to be considered during the building material selection process. The following two examples of functionally equivalent building materials with different cleaning characteristics illustrate such considerations. Considerations other than VOC emissions rates of cleaning products must also be made. These considerations include acoustical, thermal, and aesthetical issues.

a. Comparing plastic laminates and chemical-coated fabrics for furniture: Plastic laminates are easy to clean with a damp cloth using detergent and water, rinsing with clean water, and drying with a clean cloth to prevent streaking. In contrast, chemical-coated fabrics have the following disadvantages: (i) a brush must used to remove embedded soil from their surfaces; and (ii) fabrics require regular cleaning to reduce adsorption of VOCs and the resulting deterioration of the fabric.

b. Comparing hard floors and carpets: Hard floors have smooth surfaces and therefore removal of particles is easier than from carpets, which are difficult to keep free of particles. Removal of dust from hard floors can be done using soap and water. In contrast, carpets require vacuuming and shampooing which may result in release of VOCs in the indoor air. Berry (1994) states that 85 percent of the soil deposited on carpets is the result of tracked-in particulate matter and that the first two or three steps of a building entrance (i.e., 6 to 9 ft) contain most of the soil tracked inside and deposited from shoes. As a result, selection of hard flooring surfaces such as polyurethane-coated (preferably pre-finished) hardwood floors or tile floors near entrances are preferred to carpeting. In addition, appropriate mats for wiping shoes must be placed at entrances in order reduce the amount of particulate matter tracked inside a building. Placement of hard surfaces with appropriate mats at entrances could facilitate cleaning and reduce potential problems associated with cleaning of carpets in these areas.

2.2.4.2 Selection Process

Based on the results of the material evaluation process (Section 2.2.3: Step 3 - Evaluation of VOC-Emitting Products), the lowest-VOC-impact materials and products that meet each task's performance requirements should be considered. Materials that dry quickly should be preferred if functionally equivalent and similar in performance to slow-drying materials.

Figure 4 depicts a flow chart that summarizes the product selection process. Note that the chart also includes material-conditioning, installation, ventilation, and delayed occupancy considerations that are discussed in the latter sections (i.e., Sections 2.3 through 2.6).

Following is a list of product considerations for various building materials incorporating some of the factors presented in Figure 4. Note that the considerations listed below are in addition to the recommended guidelines described in Section 2 of this document.

1. Acoustical ceilings: Of particular concern are T-bar suspended ceilings used as return air plenums because both sides of the panels come in contact with indoor air. In addition penetrations for sprinklers, alarms, and smoke detectors may increase exposed emission areas considerably. Temperatures near ceiling surfaces and in return air plenums are usually higher than those in occupied zones and, as a result, increased emissions from ceiling materials may occur. Carefully consider the acoustic, fire, and aesthetic requirements for each space prior to ceiling material selection. Non-porous materials are now available that combine aesthetics and acoustical and fire code requirements (*Building Operating Management*, 1996). If porous acoustical panels are specified, follow the four-step selection process described earlier (Sections 2.2.1 through 2.2.4). Note that some acoustical panels may emit formaldehyde and that sealing of panel surfaces in order to reduce emissions and minimize VOC adsorption must be done with caution to ensure that: (a) the acoustical and fire characteristics of the panels will not be altered; and (b) application of the sealer will not result in new VOC emissions after installation.

2. Adhesives, sealants, and caulks: Specify application of only the minimum amounts of these materials necessary for satisfactory completion of each installation task. Require that adhesives have the lowest possible content of toxic or irritating VOCs while meeting other performance requirements. Require that the manufacturers of adhesives, sealants, and caulks submit results of emission tests as well as drying times for each product. Exercise caution when interpreting adhesive emission data because such data are usually provided without the associated installed products (e.g., flooring materials) and emissions from installed assemblies may be different from manufacturers' reported adhesive emission rates.

   Ensure that maximum ventilation is supplied during and after application of these products (see Section 2.5). In the case of sealants and caulks, also specify low-shrinkage products.

3. Carpet: Specify carpets having CRI's indoor air quality label (see Section C1 of Appendix C for a description of CRI's labeling program). Conditioning of carpets may be done: (a) prior to shipment; (b) after delivery in a dry, well-ventilated space other than the area where it will be installed; or (c) after installation. However, conditioning of carpet after installation is possible but not preferable to selecting low-VOC emitting carpeting (see Section 2.5 for a discussion of building flush outs; see Section 3.3 and Appendix D for a discussion of building bake-outs). It should be recognized that: (a) carpet emissions accelerate with increased temperature; (b) carpet emissions do not accelerate with increased air movement and ventilation because emissions from carpeting is a slow, diffusion-dominated process within the material; and (c) a carpet assembly consists not only of the carpet itself but also of the adhesives used for its installation (if any), padding, seaming and "floor-prep" compounds, and the underlayment or substrate. Therefore emissions from these products must also be considered.

   Refer to the CRI's Standard 104 titled *Standard for Installation of Commercial Textile Floorcovering Materials* (CRI, 1994b) for guidance on proper carpet installation. Also refer to CRI's *Carpet and Indoor Air Quality in Commercial Installations* (CRI, 1994c) for general information on their installation, maintenance, and labeling program.

4. Composite wood products (e.g., particleboard, plywood, medium density fiberboard (MDF), flakeboard, and hardboard): Specify low-formaldehyde-emitting products meeting HUD, HPVA, and NPA's guidelines (see Section C2 of Appendix C for a description of these guidelines), and consider completely sealing or encapsulating all exposed surfaces, including any penetrations, to minimize emissions. Complete encapsulation of all particleboard penetrations may not be possible due to addition of grommets for various applications such as power and data, that can not be accounted for in the initial building design. Note that VOC-emitting wood preservatives may be used in some of these products.

5. Fireproofing: Spray-on fireproofing can cause indoor air quality problems when chemical components are released into the air as a result of mechanical damage, air erosion, or deterioration of the binder. Also because spray-on materials have large surface areas, they can act as sinks for adsorption of VOCs. If possible, seal the surface of spray-on fireproofing to reduce adsorption of VOCs. Ensure that the sealer: (a) will not change fire characteristics of the original fireproofing material; and (b) is not a high-VOC emitter. Also seal any penetrations of surfaces sprayed with fireproofing material to prevent damage of the material in the vicinity of penetrations.

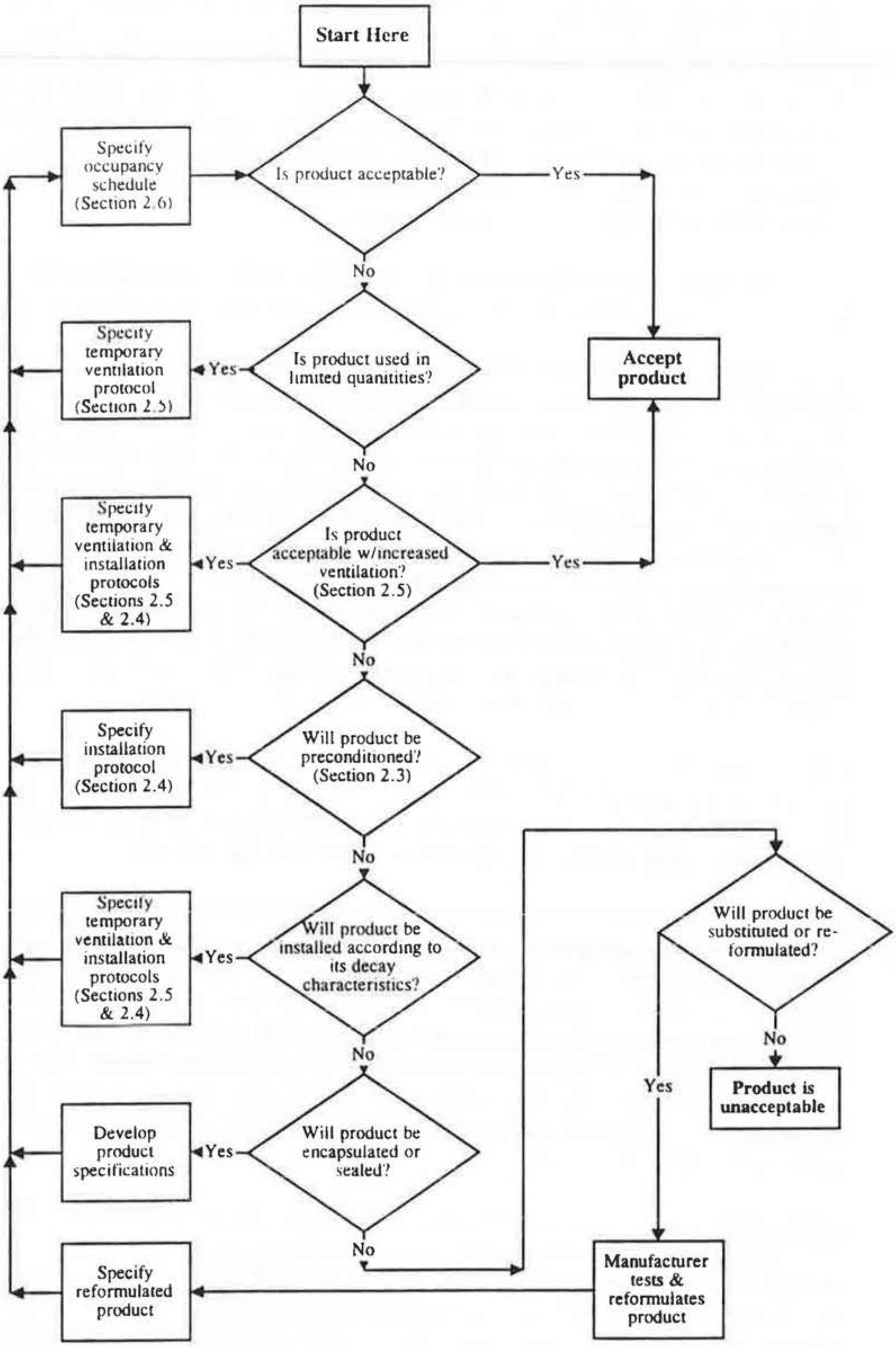

Figure 4. Flow Chart for Selecting Building Materials and Products

6. Porous materials: Pay particular attention to the sequence of installation of various products and materials, e.g., install wet-applied products first and porous materials last. When considering products that are non-porous but functionally-equivalent to porous materials ensure that acoustical and fire properties as well as aesthetics are also considered. Where acceptable, apply insulation on the exterior of HVAC ductwork and use sound baffles for noise attenuation.

7. Gypsum wallboard: Gypsum may be reasonably inert and extremely low in VOC emissions. However, additives used to produce waterproof gypsum wallboard (i.e., "green board"), fire-resistant gypsum wallboard, or to improve the workability of the slurry during manufacture may include compounds that emit VOCs. Also the paper covering on both sides of gypsum wallboard may contain chemicals from previous uses, such as in the case of recycled materials, and additives or chemicals used in the production of the paper itself. Note that VOC emissions from gypsum wallboard can be reduced considerably, but not eliminated, by painting or laminating the surfaces. The more impervious the coating or covering, the greater will be the reduction in VOC emissions from gypsum wallboard (however, VOC emissions from surface treatment materials also must be considered).

   Gypsum wallboard could act as a sink for other VOCs in the indoor air. Chang and Guo (1992) reported that unpainted gypsum wallboard has been shown to be a stronger sink for formaldehyde than painted gypsum wallboard is for other VOCs. Therefore, it is important to avoid exposing unpainted gypsum wallboard to indoor environments where strong emissions from other VOC sources exist.

   Taping and topping compounds can contain considerable quantities of VOCs. Ventilation and heat are important to accelerate the drying process of these materials. Note that formaldehyde may be present in the latex used to formulate ready-mixed joint compounds.

8. Interior panels with fabric coverings: Condition panels at the factory before packaging and shipping. Specify wrapping material that minimizes the possibility of fabric soiling and maximizes the exchange of air between the panels and the outside of the wrapping material. Also consider airing out panels prior to installation in a dry, well-ventilated space outside the building. Keep in mind that fabric coverings are porous materials capable of adsorbing chemical compounds, and therefore do not place them in environments with high concentrations of VOCs, delaying installation until emissions from high VOC sources have decreased. If cleaning or stain prevention solvents [such as 1,1,1-trichloroethane, an eye and skin irritant (see Table E9 of Appendix E)] are used prior to shipping, specify an adequate airing-out period at an appropriate enclosed, dry, well-ventilated space other than the area where the panels will be installed (see Section 2.3) prior to installation.

   Note that conditioning prior to installation may not be always practical or economical. This is due to space requirements and additional handling of panels. Space requirements may increase the delivered cost of the panels, whereas additional handling has the potential for damage.

   Also note that the surface area of interior panels varies with occupant or work station density. The surface area may approach 200 percent of the floor area in open office areas, whereas in denser installations with taller partitions this ratio can approach 350 percent. It is also important to note that both sides of interior partitions come in contact with the indoor air, and that partitions are generally located in close proximity to office workers.

9. Lath and plaster: These materials are used less in construction today than in the past. When cured, the surfaces are hard and stable, and VOC emissions are limited to those due to additives used for faster drying, better finish, or to improve other characteristics of the finished product. Use the selection process described in Section 2.2 (Evaluation and Selection of Low-VOC-impact Building Materials) if specifying plaster with additives.

10. Manufactured casework: Particleboard is frequently used in casework because of its workability and low cost. Formaldehyde emissions from particleboard can contribute to elevated indoor concentrations. Emissions can be reduced by specifying low-emitting particleboard such as MDF and by completely sealing or encapsulating it. Small penetrations in the sealant or encapsulant should be sealed to minimize VOC emissions.

11. Paints: Minimize the use of solvent-based paints indoors. Do not use any coating indoors that is intended for exterior use. Although the use of water-based paints has been increasing over the last few years, these paints are not VOC-free and have longer drying times than solvent-based paints. Ensure that maximum ventilation is supplied during and after application of paints (see Section 2.5 for a discussion on the development of ventilation protocols).

12. Resilient flooring: Although some vinyl composition tile and other similar commercial sheet flooring may be low-emitting, these products require considerations similar to those described for carpets and carpet adhesives. It is important to specify and use the minimum quantities of low-VOC-impact adhesives that will meet the installation requirements.

13. Stone and unit masonry flooring: Stone, unit masonry, concrete, or ceramic tile flooring systems are attractive alternatives from an indoor air quality perspective. Such flooring typically utilize installation and maintenance materials and products with low VOC emissions. For example, wet-mopping typically can remove accumulated dust effectively. These materials typically are used in exteriors, utilitarian, and high-traffic areas. Note that acoustic, thermal, and aesthetic considerations must be made when using these materials in a building's interior space.

    Exercise caution when specifying sealants and finishes on these floor surfaces. The selection process described in Section 2.2 (Evaluation and Selection of Low-VOC-impact Building Materials) should be utilized for these products.

14. Tile: Sealants used on tiles or grout can be sources of VOCs. These products are formulated to dry soon after application and as a result they contain highly volatile solvents. Additional sources of VOCs include solvents, active ingredients for forming seals, additives for imparting color or changing performance and curing, and self-leveling cements. Note that excessive use of self-leveling compounds may result in expensive remediation (Light et al., 1995).

15. Treated wood: If treated wood comes in contact with indoor air, seal or encapsulate exposed surfaces. Wood treated with pentachlorophenol (PCP), an eye, nose, throat, and skin irritant (see Table E9 of Appendix E), should not be used inside buildings.

16. Wall coverings: Wall coverings can be significant sources of VOC emissions. The wall area may be as much as two to three times the room floor area in enclosed offices or conference rooms. In addition, the material area to room volume ratio (i.e., the loading factor) may be as high as 0.3 to 0.4 ft^2/ft^3.

Fabrics, plastics, and paper wall coverings have potential for VOC emissions. In addition, adhesives and backings are also important components of wall-covering assemblies. Only the minimal amount of adhesive that meets the installation criteria should be used. Selection and installation methods similar to these for carpet adhesives (Item 2 above) can be used.

17. Waterproofing and dampproofing: Whenever application of these products is made on surfaces that come in direct contact with indoor air, choose products following the four-step selection process described previously (Sections 2.2.1 through 2.2.4).

18. Wood flooring: Hardwood flooring is an attractive option from an indoor-air-quality perspective if it is installed with mechanical fastening (i.e., is nailed down). Installation of hardwood flooring may not be appropriate or suitable for all office environments such as public buildings. Pre-finished wood-flooring products are available and their installation does not require use of any finishing products. If unfinished wood flooring is installed, adequate ventilation and curing time should be allowed during and after the application of field-applied finishes and before furniture installation or occupancy.

19. Work surfaces: Office work surfaces (e.g., desktops, countertops, and conference tables) can vary from 15 to 35 percent of the floor area. In many cases, desktop materials also are used as shelving in workstation closets adding 10 to 20 percent to the coverage ratio. Exposures to VOCs from work surfaces can be significant because both sides of these materials come in contact with the indoor air. In addition, work surfaces are in close proximity to office workers. Many work surfaces are constructed with a plastic laminate covering wood and particleboard cores. To reduce emissions, specify products which encapsulate exposed surfaces with laminates.

2.3 Development of Material-Conditioning Protocols.

One way of reducing VOC emissions from some building materials with fast-decaying VOC emission rates is by **conditioning** them prior to installation. Conditioning of building materials is a process during which materials are placed in a dry, well-ventilated area for a period of time varying from a few days to a few weeks, depending on the decay characteristics of the material being conditioned, until emission rates have been reduced to a pre-determined acceptable level. Building materials may be conditioned at the manufacturing or assembly facility, or at a bonded warehouse before shipment to the construction site in order to remove excess VOCs contained in or adsorbed on the materials. Material conditioning should be done in a clean, dry, enclosed, and well-ventilated space that is free from strong contaminant sources or residues. However, material conditioning may not be appropriate or economical in all cases. The cost of space for material conditioning may not be trivial particularly if it is done at the manufacturing or assembly site. In addition, the cost of handling a product several additional times as well as the increased potential for damage during these times also must be considered. Note that storage of certain materials after manufacturing is unavoidable especially in cases of special production orders or large quantities. For example, in the case of carpeting for a large-size building, there may be a time lag of several months between production and delivery of the product. In such cases storage is unavoidable and specifying a dry, well-ventilated space may not add a considerable cost to a project. However, rolling or packaging products after production minimizes the effects of subsequent airing out.

Materials also may be conditioned after installation. However, this is not recommended due to the possibility of VOC adsorption by porous materials. See Section 2.5 for a discussion of building flush outs and Section 3.3 and Appendix D for a discussion of building bake-outs.

Some materials may also require special handling protocols for shipping. For example, interior panels with fabric coverings treated with cleaning solvents shortly before packaging and shipment may require special wrapping materials that not only minimize the possibility of soiling but also maximize the exchange of air between the panels and the air outside the wrapping material.

2.4 Development of Material Installation Protocols (based on emissions testing)

Material installation protocols should be specified according to VOC decay rates. Materials with fast decay curves are preferable to functionally equivalent materials with slow decay rates. If materials with slow decay rates must be installed, then their impact on indoor air quality should be assessed. An extended flush-out period may be specified for several weeks after occupancy (see Section 2.5 for a discussion on the development of ventilation protocols). Schedule the installation of porous materials after VOC emissions from other materials have been reduced substantially.

2.4.1 General Considerations During Partial Building Renovation/Remodeling

Modifications in installation methods during partial remodeling/renovation can reduce VOC concentrations considerably. For example, construction could be specified to occur after hours while maximum ventilation is provided. As discussed in Section 2.5.1: Special Ventilation Considerations During Partial Building Renovation and/or Construction, air from construction areas should be exhausted directly to the outside and should not be allowed to recirculate or spread to occupied areas. Materials with high surface areas, such as carpets, could be installed in sections to reduce maximum concentrations and exposures, especially in cases where isolation of construction or remodeled areas is not possible. When installing sections of a high-surface material, enough time should be allowed between section replacement for VOC concentrations to decay.

2.5 Development of Ventilation Protocols

Two types of ventilation are commonly used to reduce indoor exposures to VOCs and other contaminants in office buildings: **dilution ventilation** and **local exhaust ventilation** (ACGIH, 1995). Dilution ventilation reduces VOC and other contaminant concentrations by providing "contaminant-free" air and removing an equal volume of indoor air. Local exhaust ventilation removes VOCs and other contaminants near their sources before they mix with indoor air.

Development of a dilution ventilation protocol during and after material and product installation is very important in reducing VOC concentrations and thus minimizing adsorption onto porous surfaces. In addition, ventilation helps accelerate drying of wet-applied materials. Therefore, a building's HVAC system should be operational during installation of all new materials including carpets and furnishings. Wet-applied materials, such as caulks, paints, adhesives, sealants, fillers, and coatings, should not be installed without supply of adequate air movement and maximum ventilation. A ventilation protocol also must specify that all building air be exhausted to the outside without passing through any return air ducts (especially any internally lined ducts). Building air can be exhausted to the outside through open windows, by removing the glass from non-operable windows, or by installing temporary exhaust fans and ducts.

Maximum ventilation should be provided continuously (i.e., 24 hr per day) for several days, weeks, or even months after material and product installation. This procedure is usually referred to as a **building flush out**. Preferably the flush out should start before substantial completion of the building and before the occupancy certificate has been issued. However, HVAC systems may not be fully operation before completion of construction. There is limited information on the length of time required for a proper flush out, but a conservative approach is to ventilate a building for as long as economically feasible, but not less than seven days. Buildings should be flushed out at occupant comfort temperatures. Flush out at elevated temperatures (e.g., 95°F or above) is not recommended due to problems associated with this procedure, such as adsorption by porous surfaces, and its questionable effectiveness (see Section 3.3 and Appendix D for a discussion of building bake-outs).

The State of Washington (1989) is one of the few public entities that recommended a flush out protocol in a major building project (see Section E1.3 of Appendix E for a brief description of Washington's East Campus Plus program). This protocol recommended that: (a) the building flush out period to begin 90 days before occupancy; (b) all VOC-emitting material, furniture excluded, to be installed at the beginning of the flush out period; (c) furniture could not be brought in the building earlier than 30 days after the start of the flush out; and (d) the designer/builder was encouraged to continue the flush out before occupancy by the owner.

The following must be identified during the design phase of a building:

1. The need for a ventilation protocol.

2. The person(s) responsible for the operation of the HVAC system(s) during construction, before occupancy, and immediately after occupancy.

2. The party responsible for the cost of operating the HVAC system(s) during the various phases of construction.

The maximum amount of ventilation that can be provided during construction and flush out <u>may be limited</u> for a number of reasons some of which are listed below.

1. <u>Airflow capacity of an HVAC system</u>: Ventilation systems in office buildings typically can provide a maximum of 4 to 6 ACH total supply air. During typical occupied conditions, the supply air is a mixture of outdoor and recirculated air depending on outdoor temperature and humidity. However, during construction and flush out all the supply air should be <u>outdoor air</u> and no building air should be recirculated. Therefore, an HVAC system operating under increased ventilation conditions may not be able to provide the maximum amount of total supply air that could have provided under normal operating conditions as explained next.

2. <u>Heating or cooling capacity of an HVAC system:</u> The amount of ventilation may be limited depending on the outdoor air temperature and humidity and the capacity of the HVAC system. The maximum amount of outdoor air can be supplied during mild weather conditions (i.e., when outdoor air temperature and humidity are close to the design indoor parameters).

3. <u>Quality of the outdoor air</u>: In some cases, the amount of outdoor air in occupied buildings may be limited if the ambient air quality standards established by the USEPA or the California Air Resources Board (CARB) are exceeded. Weschler et al. (1992) reported that because of the potential reaction of ozone with indoor VOCs, VOC measurements at ozone concentrations above 30 ppb may be different in kind and concentration from measurements taken at ozone concentrations below 10 ppb. Weschler et al. (1992) observed that concentrations of some VOCs (e.g., 4-PC and styrene) emitted from various carpet samples in a chamber were reduced between one-third and one-tenth to their pre-ozone levels, whereas concentrations of other VOCs (e.g., formaldehyde and acetaldehyde) increased by as much as 20 times. This suggest that building flush out might be carried out during times that outdoor air pollutant concentrations typically

decrease such as during nights and weekends.

4. Unavoidable scheduling conflicts: During certain testing tasks prior to issuance of an occupancy certificate the HVAC system may not be available for a continuous flush out. These tasks include testing, adjusting, balancing, and commissioning the HVAC system(s) as well as the building life safety systems. As a result, a building flush out may have to be interrupted for several hours at a time while these tasks occur. However, a building flush out can continue when such tests are not performed (e.g., during the night).

The proper amount of dilution ventilation, as required by the California Energy Commission (CEC) in the most recent version of the non-residential energy standard (CEC, 1995) must be supplied to a building after completion of a flush-out to ensure acceptable indoor air quality and thermal comfort. The 1995 *California Energy Efficiency Standards for Residential and Nonresidential Buildings* requires that: (a) 15 cfm per person must be supplied to a building when occupied; (b) 15 cfm per person or 3 ACH, whichever is less, must be supplied one hour before normal occupancy; and (c) before an occupancy permit is granted, supply of the minimum ventilation rates must be determined and documented.

Ensuring that the minimum amount of ventilation is supplied before and during occupancy is part of an HVAC commissioning process. Section 2.5.2 discusses a five-phase HVAC commissioning process starting before the HVAC system is designed and continuing through the useful life of a building.

2.5.1 Special Ventilation Considerations During Partial Building Renovation and/or Remodeling

Ventilation protocols are more difficult to specify in cases of partial renovation or remodeling of an occupied building. It is important to isolate physically the area under construction from the rest of the building so that air from a construction area does not enter the rest of the building. Physical isolation of a construction area includes installation of temporary physical barriers, such as polyethylene sheeting, and ensuring that return air from the construction area does not enter occupied zone(s). Air from the construction area should be exhausted directly to the outside using temporary exhaust fans. Building return air ductwork should not be used to exhaust air to the outside. The amount of exhausted air from the construction area should be adjusted so that the construction area is under negative pressure with respect to any adjacent occupied zones. There is very little information on the magnitude of the negative pressure that can effectively contain the air within a certain area. For example, OSHA (1994b) recommends a negative pressure of 0.02 inch of water (in. H_2O) gage (5 Pa) for negative pressure enclosure (NPE) areas undergoing asbestos abatement. In addition, Alevantis et al. (1995) reported that negative pressures above 0.03 in. H_2O gage (7 Pa) resulted in only 0.1 percent or less of air from enclosed smoking areas reaching adjoining non-smoking areas. Pressure readings between the construction area and the adjacent occupied zone(s) should be taken frequently to ensure continuous containment of the air within the construction area. Smoke tubes could be used occasionally to verify that airflow direction is from the occupied zone(s) to the construction area.

The interested reader is also referred to *IAQ Guidelines for Occupied Buildings Under Construction*, a publication available from the Sheet Metal and Air Conditioning Contractors' National Association, Inc. for more considerations for occupied buildings under construction (SMACNA, 1995).

2.5.2 HVAC Commissioning

An HVAC system performing according to design specifications is required to minimize occupant complaints related to indoor air quality including thermal comfort and airborne contaminants in new, newly renovated, and older buildings. Unfortunately in many cases, newly installed or existing HVAC systems do not meet design specifications under typical operating conditions. This is partially due to the fact that the process known as **HVAC system testing, adjusting, and balancing** is done under atypical airflow conditions, i.e., maximum-airflow conditions, and not under more typical conditions, i.e., partial-airflow conditions. Other reasons for failure to meet design specifications include incorrect testing, adjusting, and balancing of HVAC components; inability to achieve design airflows due to design and/or component installation errors; increased number of occupants, remodeling, or renovation without proper engineering evaluation of the HVAC system; and HVAC equipment failure.

A process known as **HVAC commissioning** ensures, through proper documentation and verification, that the performance of an HVAC system meets design parameters. HVAC commissioning helps reduce indoor VOC concentrations by ensuring that the proper amount of ventilation is supplied into a building. In addition, HVAC commissioning also improves thermal comfort and reduces energy consumption. HVAC commissioning should be done either: (a) by an independent party other than the HVAC designer, HVAC installer, HVAC contractor, etc., who has no vested interest in the results; or (b) by a commissioning "team." ASHRAE Guideline 1-1989, titled *Guideline for Commissioning HVAC Systems* (ASHRAE, 1989), describes five phases of HVAC commissioning that commence before initiation of the design process and continue through the life of a building. These five phases are described below.

1. Pre-design phase: During this phase, the HVAC commissioning parameters are set, the responsibilities of the various parties are established, and the documentation requirements are specified. All baseline information is collected, such as occupancy, building loads, budget considerations, etc.

2. Design phase: During this phase, the design requirements of an HVAC system are outlined. The design documents should include the following:

   a) design criteria and assumptions (ASHRAE Guideline 1-1989 lists 20 parameters including temperature, humidity, and ventilation);

   b) description of the HVAC system (such as system type, components, capacity and sizing criteria, and temperature control) and intended operation and maintenance (such as seasonal operation, occupied/unoccupied modes, and energy conservation procedures);

   c) commissioning plan, which details the implementation of the commissioning process and identifies responsibilities of key parties;

   d) documentation requirements for test procedures, checklists, report forms, calibration data, etc.;

   e) verification procedures, which include testing, adjusting and balancing, equipment performance, automatic controls, etc.; and

   f) commissioning documentation, which covers testing, adjusting and balancing, equipment performance, control schematics, operation and maintenance instructions, and as-built documents.

3. Construction phase: During this phase, the independent consultant or the commissioning team should observe all pressure tests of the piping and duct systems, as well as all start-up, testing,

adjusting and balancing, and calibration procedures. Also, the operation and maintenance personnel should be present during this phase to observe the installation of HVAC components and receive training on HVAC operations.

4. Acceptance phase: After verifying that certain pre-requisites have been met (such as hydrostatic testing, flushing, cleaning, etc.), a series of functional performance tests are conducted on all equipment, using checklists developed during the design phase. Tests are conducted under all normal modes of operation, including full-load, part-load, and abnormal (i.e., emergency) conditions.

   Training of the building operator(s) continues in the acceptance phase. Operators should have a good understanding of all equipment, components, and systems and should know how to use the various operations and maintenance manuals. In addition, operators should be trained on equipment operation under all modes of operation (such as warm-up and cool-down), on acceptable tolerances for system adjustments in all modes of operations, and on abnormal and emergency procedures.

5. Post-acceptance phase: During this phase, the as-built documents are revised and any equipment changes are monitored and documented. A maintenance and service program is developed for the HVAC equipment based on the manufacturer's recommendations. A record of all maintenance and service performed also must be kept. Periodically, the HVAC system must be re-tested to measure actual performance. If actual performance is different than expected, then a re-commissioning may have to be considered. Finally, a log of all occupant complaints related to HVAC systems must be maintained. Post-occupancy commissioning or "fine tuning" is essential in ensuring that HVAC system(s) operate as designed under normal operating conditions.

HVAC commissioning is a complex process that must be followed thoroughly to ensure proper HVAC operation. The additional costs of such a process easily can be recovered from direct and indirect savings during the life of a building. Direct savings result from more efficient equipment operation and prolonged equipment serviceable life, whereas, indirect savings may include increased employee productivity and decreased absenteeism. Some utilities companies now subsidize the cost of HVAC commissioning. Building owners and managers also must realize the importance of operator training, regular equipment maintenance, and proper record-keeping. Although a mandatory HVAC commissioning program does not exist in California at this time, there are special requirements for the operation of building HVAC systems. Section 5142 of the General Industry Safety Orders, Title 8, of the California Safety Code published in 1987 titled *Mechanically-Driven Heating, Ventilating and Air-Conditioning (HVAC) Systems to Provide Minimum Building Ventilation* requires the following:

a) design ventilation rates must be supplied continuously when buildings are occupied;

b) HVAC systems must be inspected at least annually; and

c) maintenance records for HVAC system(s) must be kept and be available for inspection.

The complete language of this minimum ventilation standard is presented in Appendix J.

2.6 Development of Occupancy Schedule

Concentrations of VOCs are often highest during and immediately after construction or renovation. As a result, occupant complaints may be highest during this period. It is therefore important that occupancy of newly constructed or renovated areas be delayed until:

a) all construction has been completed including installation of floor coverings and office furniture;

b) the HVAC system has been commissioned as was discussed in Section 2.5.2; and

c) adequate time has been allowed to flush out the construction area(s) as was discussed in Section 2.5.

The adequacy of the flush out can be determined by testing the indoor air before allowing the occupants to move in. It should be noted that: (a) guidelines exist for only a few VOCs; (b) there are no standard testing methods exist for TVOCs; and (c) existing guidelines for TVOCs are not widely accepted. However, TVOC concentrations can be used to compare a building's indoor air with measurements taken in other non-problem buildings as discussed in Section 2.2.3.4.2. Due to financial constraints, building owners and managers are often pressured to move occupants into newly constructed or renovated areas as soon as they can be occupied and in some cases before construction is even completed. However, as was discussed in Section 1.3.2, the cost of an increase in absenteeism rate of only 2.5 percent can be comparable to the cost of utilities or maintenance and operation of a building.

2.7 Air Cleaning

Air cleaning has been used traditionally for particle removal. Air cleaning equipment for particles include panel-type filters, extended-surface filters, high efficiency particulate air (HEPA) filters, electrostatic precipitators, and air washers. Removal of VOCs and other gaseous pollutants with specially designed air cleaning equipment is more difficult. Activated charcoal is one of the most widely used media in gaseous air cleaning equipment for removing VOCs by sorption. However, disadvantages of charcoal include: (a) it absorbs water vapor; (b) its sorption efficiency for water-soluble compounds can be reduced in environments of high humidity; and (c) its sorption efficiency varies among specific VOCs. Recently, air cleaning systems have been developed that utilize both charcoal and active sorbents. Presently there are no standard methods for testing gaseous air cleaning equipment.

In most cases, using air cleaning equipment to reduce VOCs and odors (such as "new carpet" odor) in buildings is not practical due to: (a) the large airflow rates that must pass through large amounts of sorbent materials; and (b) the ongoing cost of replacing the sorbent media at regular time intervals. However in some special applications (e.g., small construction areas), use of sorbent materials may be practical.

Given today's technology of air cleaning equipment and the lack of standard testing methods, use of air cleaning equipment as the primary method for reducing occupant exposure to VOCs from office building construction materials is not recommended. However, it is possible that new equipment may be developed in the future that can remove VOCs from large amounts of air in reasonable time for a low cost.

SECTION 3. OTHER MANDATED TOPICS

3.1 Appropriateness of Mandatory Regulations

The information presented in this document is the best knowledge currently available for reducing occupant exposure to VOCs from office building construction materials. However, as discussed in Section 2, available information for selecting low-VOC-impact building products and materials is limited. In addition, few standard testing methods exist for building materials and products at this time. Therefore, it is inappropriate to consider mandatory regulations for reducing occupant exposure to VOCs from building construction materials. Compliance with the guidelines is encouraged on a non-binding, voluntary basis. Product manufacturers are encouraged to develop voluntary labeling programs as more standard testing methods for various building construction materials become available.

In addition, because of the lack of sufficient field data on the optimum length of time that occupancy should be delayed in new or newly remodeled buildings, the guidelines do not recommend regulation of delayed occupancy. Instead the guidelines encourage building flush outs for as long as economically feasible but not less than seven days. A pre-occupancy VOC testing is also advised as was discussed in Section 2.6. Further information on the development of occupancy schedules is presented also in Section 2.6.

3.2 Need to Establish an Ad Hoc Group of Building Professionals

The usefulness of the guidelines depends on the extent to which they are disseminated to those professionals who would apply them, as well as the ease with which they can be applied and the extent to which such professionals are convinced that following them is in their best interest. Therefore, every effort should be made to: (a) ensure that the guidelines are disseminated widely; (b) ensure that the guidelines are easy to apply; (c) provide additional training in support of the guidelines; and (d) demonstrate to possible users that it is in their interest and in the interest of their employers to follow the guidelines.

According to Section 426.10 of the California Health and Safety Code, copies of the guidelines are to be submitted to the California Department of General Services (CDGS) and the Building Standards Commission. It is recommended that CDGS disseminate the guidelines to all staff with responsibility in the areas of building design and construction, leasing, renovation, and operation. The CDHS will make copies of the guidelines available to professional associations of architects, mechanical engineers, interior and business designers, building owners and managers, stationary engineers, and others responsible for building design, renovation, construction, and operation in the private sector. The CDHS also will make copies of the guidelines available to the general public.

The guidelines as they are presented here have been developed and reviewed with the assistance of professionals in the design, construction, building management, and indoor air quality fields, as well as by suppliers of building and furnishing products, and other parties interested in indoor air quality in office buildings. (A complete list of all the reviewers is shown under Acknowledgments at the beginning of this document.) In order for the CDHS to substantiate the usefulness, procedures, validity, costs, and benefits of implementing the guidelines, it is recommended that an ad hoc committee of interested parties be convened. The composition of this committee should include:

a) health experts, such as physicians and toxicologists knowledgeable about VOCs;

b) architects, HVAC design engineers, and interior designers;

c) industrial hygienists and chemists knowledgeable about indoor VOCs;

d) representatives of other State agencies with interest or regulating authority in indoor air such as the California Energy Commission (CEC), the California Occupational Safety and Health Administration (Cal-OSHA), the California Air Resources Board (CARB), and the California Department of General Services (CDGS);

e) manufacturers of building construction materials and products as well as cleaning products;

f) builders and building subcontracting professionals;

g) building owners, building managers, and building engineers;

h) representatives of organized labor; and

i) building inspectors.

The above group should further review the guidelines, and should make recommendations for modifications to them, for further testing of them in the field, and for determining if, based on reasonable dissemination, the guidelines are being used.

In addition to the formation of the ad hoc committee, the CDHS also recommends that a public agency or an appropriate professional organization serve as a central repository for, and provide a regular updated listing of, emissions testing information and current product regulations. Thus, the central repository could provide building professionals with the most current information.

3.3 Building Bake-outs

The purpose of a **bake-out** is to "artificially age" building materials and products by accelerating emissions of residual solvents. A building bake-out involves elevating the temperature of an unoccupied, newly constructed or remodeled building to between 95 and 102°F (35 and 39°C) while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the bake-out. According to Girman et al. (1987), an increase from 74°F (23°C) to between 90 to 102°F (32 and 39°C) should increase diffusion of solvents through materials by approximately 10 percent and should increase the vapor pressure of solvents by approximately 200 percent.

Various researchers have conducted a number of field trials of bake-out in actual buildings (Girman, 1989; Girman et al., 1987, 1989, 1990; Offermann et al., 1993; Hicks et al., 1990). However, the results of these studies have been mixed. In some cases, concentrations of certain compounds were significantly reduced, while in other cases, concentrations either remained unaffected or increased after a bake-out. In one case, VOC concentrations were substantially decreased immediately after a bake-out but within two weeks returned to the concentrations measured prior to the bake-out (Offermann et al., 1993).

Based on current knowledge, the building bake-out procedure is neither recommended or discouraged. The problems often associated with this process include: (a) technical difficulties such as being able to raise significantly the temperature of all VOC sources while providing sufficient ventilation as is discussed in Appendix D; (b) its questionable effectiveness; (c) the potential of material damage due to elevated temperatures; and (d) the potential of VOC adsorption and subsequent re-emission by porous surfaces. The bake-out procedure can be used in some situations as long as the building owners and/or building professionals are aware of the limitations and risks associated with this technique. The technical aspects of building bake-outs are discussed in Appendix D.

Instead of the bake-out procedure, the guidelines recommend the following: (a) select low-VOC-impact products and materials; (b) develop a ventilation protocol during and after construction (a method known as building flush out); and (c) delay occupancy until VOC concentrations have been decreased to an acceptable level (see Section 2).

APPENDICES

APPENDIX A: California Health and Safety Code, Article 9.5, Section 426.10

ARTICLE 9.5
INDOOR ENVIRONMENTAL QUALITY

§ 426.10. Volatile organic compounds in newly constructed or remodeled office buildings; nonbinding guidelines

(a) The state department through its Indoor Air Quality Program shall develop nonbinding guidelines for the reduction of exposure to volatile organic compounds (VOC) from construction materials in newly constructed or remodeled office buildings. At a minimum, the state department shall consider all of the following:

(1) The type of building to which the guidelines shall apply.

(2) The methodology for identifying indoor sources of VOC.

(3) The bake-out procedures prior to occupancy for newly constructed buildings.

(4) The procedures for VOC reduction during and after major remodeling of occupied buildings.

(5) The need to establish mandatory regulations rather than nonbinding guidelines for the procedures to reduce VOC exposure in newly constructed buildings and during the remodeling of buildings and, in addition, the need for regulation regarding the occupancy of a newly constructed building or a building undergoing remodeling where VOC reduction is to be a consideration.

(6) The need to establish an ad hoc group of building construction material manufacturers, builders, building owners and managers, organized labor, sheetmetal contractors, plumbing contractors, mechanical engineers, architects, and building inspectors to advise the state department on procedures and costs related to implementing the proposed guidelines.

(b) The state department shall develop and submit the nonbinding guidelines to the Legislature, and file copies with the Department of General Services and the State Building Standards Commission, by January 1, 1992.

(c) The guidelines developed by the state department pursuant to this section shall be nonbinding and voluntary, and shall therefore, be exempt from the procedures for adoption of regulations, including the review and approval by the Office of Administrative Law, pursuant to Chapter 3.5 (commencing with Section 11340) of Part 1 of Division 3 of the Government Code.

(Added by Stats.1990, c. 1229 (A.B.3588), § 1.)

APPENDIX B: VOCs That May Be Emitted From Building Materials and Cleaning Products

Various VOCs are emitted from building materials and cleaning products. The following table covers only some of the common VOCs and their potential sources in building materials and cleaning products as reported by Levin (1989). (Note that the original list has been modified.) The intent of the list is to cover only some of the more common VOCs emitted from building materials and products. The designation of "potential sources" does not imply that a specific VOC will be found in all the products and materials listed. In addition, the listings of potential sources are not necessarily comprehensive. The VOCs are listed in alphabetical order and synonyms, where applicable, are given in parentheses.

Table B1. VOCs That May Be Emitted From Building Materials and Products and Their Potential Sources	
Chemical Name	**Potential Sources**
Acetic acid	Solvent for resins, caulks, sealants, glazing compounds, volatile oils
Acetone (2-Propanone)	Lacquer solvent
1-Amyl alcohol (Amyl alcohol; Pentyl alcohol; 1-Pentanol)	Solvent in organic synthesis
Benzaldehyde	Fiberboard, particleboard
Benzene	Adhesives, spot cleaners, alkyd paints, paint removers, particleboard, furniture waxes
2-Butanone (Methyl ethyl ketone)	Floor/wall coverings, fiberboard, caulking compounds, particleboard
n-Butyl acetate (Butyl acetate)	Floor lacquers.
Butyl acrylate (Butyl-2-propenoate)	Used in manufacture of polymers and resins for textile and leather finishes.
n-Butyl alcohol (1-Butanol)	Edge sealings, molding tapes, jointing compounds, cement flagstones, linoleum floor coverings, floor lacquers, industrial cleaners, paint removers
n-Butylbenzene	Solvent
Camphene	Occurs in many essential oils
Chlorobenzene	Solvent for paint, used in manufacture of phenol
Cyclohexane	Solvent for lacquers and resins, paint and varnish removers
Cyclohexanone	Solvent for many resins and waxes
Dibutylphthalate (Di-n-butyl phthalate)	Plasticizer
Diethylamine	Used in resins, dyes, and in manufacture of rubber
Dimethyl acetamide (N,N-Dimethyl acetamide)	Solvent for organic reactions
Dioxane (p-Dioxane; 1,4-Dioxane)	Solvent for many oils, waxes, dyes, cellulose acetate

Table B1 (continued)	
Chemical Name	**Potential Sources**
Dodecane (n-Dodecane)	Floor varnishes, floor/wall coverings
2-Ethoxyethanol (Cellosolve®; Ethylene glycol monoethyl ether)	Epoxy paints, latex paints, polyurethane varnishes
2-Ethoxyethyl acetate (Cellosolve® acetate; Ethylene glycol monoethyl ether acetate)	Floor lacquers, epoxy paints
Ethyl acetate	Vinyl floor coverings, solvent for varnishes and lacquers
Ethyl alcohol (Ethanol)	Fiberboard, solvents
Ethyl benzene	Floor/wall coverings, insulation foam, chipboard, caulking compounds, jointing compounds, fiberboard, adhesives, floor lacquers, grease cleaners
2-Ethyltoluene (o-Ethyltoluene)	Floor waxes
Formaldehyde (Methanal)	Major Sources: MDF, plywood, particleboard, ceiling panels, fiberboard, chipboard Minor Sources: Upholstery fabrics, latex-backed fabrics, fiberglass, fiberglass insulation in air ducts, urea formaldehyde foam insulation, wallpaper, caulking compounds, jointing compounds, floor and furniture varnishes, adhesives, floor lacquers, gypsum board
Heptane (n-Heptane)	Floor coverings, floor varnishes
Hexachlorobenzene	Fungicide
Hexanal	Polyurethane wood finish
Hexane (n-Hexane)	Chipboard, gypsum board, insulation board, floor coverings, wallpaper
Isobutyl acetate (2-Methylpropyl acetate)	Floor lacquers
Isobutyl alcohol (Isobutanol; 2-Methyl-1-propanol)	Edge sealings, molding tapes, jointing compounds, cement flagstone, linoleum floor coverings, floor lacquers
Isopropyl alcohol (Isopropanol; 2-Propanol)	Particleboard

Table B1 (continued)	
Chemical Name	**Potential Sources**
Isoquinolone	Used in synthesis of dyes and insecticides; rubber accelerator
d-Limonene	Paints, adhesives, chipboard, detergents, furniture polish
Methylene chloride (Methane dichloride; Dichloromethane)	Paint removers, aerosol paints, industrial solvents
Methyl isobutyl ketone (MIBK; 4-Methyl-2-pentanone)	Floor/wall coverings
2-Methylpentane (Isohexane)	Chipboard, gypsum board, insulation foam, floor coverings, wallpaper
Nonane (n-Nonane)	Wallpaper, caulking compounds, floor coverings, chipboard, adhesives, cement flagstone, jointing compounds, floor varnishes, floor waxes
Nonyl phenol isomers	Used in manufacture of lubricating oil additives, resins, plasticizers, and surface active agents
Pentachlorophenol (PCP)	Wood preservative, disinfectant, fungicide, paints, wallpaper, adhesives, textiles, wood finishes, floor shampoos
4-Phenylcyclohexene (4-PC; Cyclohexylbenzene)	Manufacturing by-product in carpets with SBR latex backing
α-Pinene	Cement flagstone, fiberboard, gypsum board, adhesives, insulation sheets, chipboard, wood
n-Propyl acetate	Plastics
Propylbenzenes (n-Propyl benzene)	Adhesives, floor/wall coverings, chipboard, paints, caulking compounds, insulation foam
Quinolone	Used in the manufacture of dyes; solvent for resins
Styrene (Vinyl benzene)	Insulation foam, jointing compounds, fiberboard, carpets with SBR latex backing
α-Terpinene (1-Methyl-4-isopropyl-1,3-cyclohexadiene)	Furniture polishes
Tetrachloroethylene (Perchloroethylene)	Widely used in the textile industry for dry cleaning, processing, and finishing of fabrics; used in metal degreasers, spot removers, adhesives, wood cleaners, and lubricants

Table B1 (continued)	
Chemical Name	**Potential Sources**
Tetrachlorophenol	Wood preservative
Toluene	Solvent-based adhesives, water-based adhesives, edge sealings, molding tapes, wallpaper, jointing compounds, floor coverings, vinyl coated wallpaper, caulking compounds, paints, chipboard, vinyl floor coverings
1,1,1-Trichloroethane (Methyl chloroform)	Cleaning fluids, water and stain repellents
Trichloroethylene (TCE)	Solvent for paints and varnishes
1,2,3-Trimethylbenzene	Floor/wall coverings, floor waxes
1,2,4-Trimethylbenzene	Floor/wall coverings, linoleum floor coverings, caulking compounds, vinyl coated wallpaper, jointing compounds, cement flagstone, floor varnishes, chipboard, floor waxes
1,3,5-Trimethylbenzene (Mesitylene)	Caulking compounds, floor/wall coverings, floor waxes
Undecane (n-Undecane)	Wallpaper, gypsum board, floor/wall coverings, joint compounds, chipboard, floor varnishes, paints, paint removers
Xylenes	Adhesives, jointing compounds, wallpaper, caulking compounds, floor coverings, floor lacquers, grease cleaners, varnishes

APPENDIX C: Survey of Product Labeling Programs

A few countries have instituted labeling programs for building materials and products. Following is a discussion of labeling programs from five countries, i.e., United States, Canada, Germany, Denmark, and Sweden.

C1 United States: Carpet and Rug Institute's Carpet Labeling Program

In the United States, the Carpet and Rug Institute (CRI) initiated a voluntary testing program in 1994 as a result of the USEPA's Carpet Policy Dialogue. The testing protocol is based on the ASTM Standard Guide D 5116 - 90 (ASTM, 1990a). The protocol is under consideration at the ASTM and may become a standard guide or method in the future. To qualify for the *CRI Indoor Air Quality Carpet Testing Program Label* the following maximum emission factors for new styrene butadiene rubber (SBR) latex-backed carpet samples collected at the time of manufacture must not be exceeded at 24 hr elapsed time after initiating a test (CRI, 1994a).

1. TVOCs: 500 $\mu g/m^2 \cdot hr$.
2. Styrene: 400 $\mu g/m^2 \cdot hr$.
3. 4-PC: 100 $\mu g/m^2 \cdot hr$.
4. Formaldehyde: 50 $\mu g/m^2 \cdot hr$.

C2 United States: Hardwood Plywood and Veneer Association's and National Particleboard Association's Formaldehyde Labeling Program

Tables C1 and C2 list the maximum allowable formaldehyde chamber concentrations under given loading factors as required by: (a) the United States Department of Housing and Urban Development (HUD); (b) the United States Hardwood Plywood and Veneer Association; and (c) the National Particleboard Association.

Table C1. United States Department of Housing and Urban Development (HUD) Guidelines for Formaldehyde $^{\alpha}$ (HUD, 1984; HPVA, 1994)

Product	Concentration (ppm)	Loading Factor $^{\beta}$ (ft^2/ft^3)
Plywood wall panels	0.2	0.29
Particleboard Industrial hardwood plywood panels	0.3	0.13

α Testing conditions are specified in *Large-Scale Test Method for Determining Formaldehyde Emissions From Wood Products, Large Chamber Method FTM 2-1983, NPA/HPMA for Manufactured Housing Components* and ASTM Standard E 1333 - 90: *Standard Test Method for Determining Formaldehyde Levels from Pressed Wood Products Under Defined Test Conditions Using a Large Chamber* (ASTM, 1990b).

β Ratio of surface area of formaldehyde-containing product to volume of chamber in which the product was tested.

Table C2. National Particleboard Association's Testing and Certification Program for Formaldehyde (Groah and Margosian, 1995)			
Product	**Standard**	**Concentration (ppm)**	**Loading Factor [α] (ft^2/ft^3)**
Industrial Particleboard	ANSI A208.1-1993	0.3	0.13
Particleboard Flooring	ANSI A208.1-1993	0.2	0.13
Particleboard Decking	HUD	0.3	0.13
MDF	ANSI A208.2-1994	0.3	0.08

α Ratio of surface area of formaldehyde-containing product to volume of chamber in which the product was tested.

C3 Canada: Canadian Carpet Institute's (CCI) Carpet Labeling Program

CCI has adopted the same carpet testing program as the United States-based CRI. However, research from the Public Works and Government Services of Canada indicated a strong correlation between occupant complaints and 4-PC concentrations. As a result, CCI is considering lowering the maximum allowable emission factor of 4-PC in their labeling program.

C4 Canada: "Ecologo" Program

This program rates residential and architectural coatings based on calculated (i.e., not measured) TVOC contents from product formulations as submitted by product manufacturers. Table C3 (see next page) lists the calculated maximum TVOC emissive content for various material groups that are allowed under this program.

C5 Canada: Ontario Building Environmental Performance Assessment Criteria (BEPAC)

This program was developed as an extension of the Building Research Establishment Environmental Assessment Method (BREEAM) used in the United Kingdom. The following materials and procedures are recommended for the control of VOCs (CMHC, 1994b):

a) Non-textile floor coverings in common areas;

b) Fusion-bonded, needle-punched, or other types of low emission carpet backings;

c) Installation of carpets without adhesives;

d) Water-based paints, low-odor solvent-based paints, and water-based (low toxicity) adhesives meeting the requirements of Ecologo, Green Cross (name has been changed to: Scientific Certification Systems), or Blue Angel programs (Ecologo and Blue Angel programs are described in Sections C4 and C6 of this appendix); and

e) Conducting a building bakeout/flashout at >27°C and 1.5 ACH at least one week prior to building occupancy.

Table C3. Specifications of the Canadian "Ecologo" Program (CMHC, 1994a)		
Material	**Type**	**TVOC Emissive Content (g/L)**
Paints	water-based	250 [α]
	solvent-based	380 [β]
Wood Finishes	water-based	300
	solvent-based	not eligible
Wood Stains	water-based	250
	solvent-based	not eligible
Adhesives	-	20
Caulks and Sealants	-	20

[α] 1989 guideline. Likely to be reduced to 200 g/L.
Typical current emissive contents (other than high-gloss enamel paints): 100-150 g/L. Typical emissive contents of high-gloss enamel paints: 250 g/L.

[β] Industry average: 400-450 g/L. Reformulation needed to meet standard.

C6 Germany: "Blue Angel" Environmental Labeling Program

This voluntary labeling program, established in 1977, now consists of approximately 75 product groups including not only building-related products but also consumer products (RAL, 1995). Environmental acceptability of a product is based on a number of factors such as chemical emissions, waste generation, recycling characteristics, associated noise, and use of hazardous substances. An independent Environmental Label Jury determines the criteria and compliance methods and makes final decisions on compliance. The German Institute of Quality and Assurance for Certification administers this program, and the Federal Environmental Agency supervises product testing and application review.

C7 Denmark: Labeling Program

A voluntary program titled "Danish Indoor Climate Labeling System of Building Materials" was initiated in 1994 (Wolkoff, 1994; CMHC, 1994b; Wolkoff and Nielsen, 1995a, 1995b; Nielsen and Wolkoff, 1995; Larsen et al., 1995a, 1995b). This program takes the approach of ranking materials according to the time required for emissions to reach concentrations below the odor and irritation thresholds. The maximum concentrations of selected VOCs are established at half the known odor and irritation thresholds, and the time to reach these concentrations is based on emission measurements or modeling.

C8 Sweden: Flooring Material Labeling Program

This is a voluntary program based on two "trade" standards titled *Measurement of Chemical Emission from Flooring Materials* and *Measurement of Chemical Emission from Smoothing Compounds* (GBR, 1992a, 1992b). Measurements are taken to establish emission factors for TVOCs according to method NT Build 358 (see Section G4 of Appendix G: Survey of Standard Testing Methods) at 4 and 26 week elapsed times. In the case of floor coverings, test samples consist of "newly manufactured, unlaid surface covering materials," whereas, in the case of smoothing compounds, samples are prepared "4 ± 1 week after [compound] production" by mixing the dry sample with water. TVOCs represent all organic compounds with boiling points between 50 and 260°C that are adsorbed on Tenax TA® and analyzed using a gas chromatograph equipped with a non-polar column and a flame ionization detector (FID). Formaldehyde and other selected compounds are also included. An "Emission Declaration" form is provided by each manufacturer indicating the product's emissions at 4 and 26 weeks.

The environmental labeling programs of other countries are described in a book titled *Environmental Labeling in OECD Countries* (OECD, 1991).

APPENDIX D: Technical Considerations During Building Bake-Outs

The following is a discussion of problems associated with building bake-outs that are based on the limited experience of CDHS researchers in applying the bake-out procedure in several buildings (as reported by Girman et al., 1987; 1989; and 1990).

1. Achieving bake-out temperatures: HVAC systems are sized for specific thermal and cooling loads which depend on the number of occupants, office equipment, ventilation rate, and outdoor conditions. Thus, attempting to use a building's HVAC system for a bake-out may be problematic. Increased temperatures may be achievable by modifying an HVAC system's temperature controls because most HVAC systems are slightly oversized. Additional heat sources also can be brought into a building (e.g., portable electric heaters), however, kerosene or other unvented combustion heaters should be avoided. A building's lights also can be used as additional heat sources. The final air temperature also will depend on outdoor conditions. If a bake-out is conducted in winter when outdoor temperatures are close to the "design" temperature, it may not be possible to achieve the desired bake-out temperatures. In addition, the fluctuation of a building's air temperature between day and night time must also be taken into consideration. Adjustment of window shades and curtains can maximize solar heat gain during the day and minimize heat loss during the night.

2. Ventilation during bake-out: A certain amount of mechanical ventilation must be provided during a bake-out to minimize adsorption of VOCs by porous materials. The need for increased ventilation must be balanced against the need to achieve and maintain high temperatures. Usually minimum outdoor air quantities are utilized during a bake-out (with maximum recirculation to ensure adequate air mixing throughout the area being baked-out), thereby minimizing the heating load due to ventilation, so that the highest possible indoor temperatures can be achieved. However, Tichenor et al. (1991) caution that a bake-out conducted with minimal ventilation may result in a re-distribution of VOCs from some building materials to others.

3. Duration of bake-out: Ideally a bake-out should be conducted over an extended period of time. However, financial constraints usually limit such a procedure to a few days. It is worth noting that, depending on the thermal mass of a building, it takes at least a day to achieve target air temperatures at the beginning of a bake-out and at least a day to decrease indoor temperatures to comfortable levels after the end of a bake-out. Thus, a total of four days must be allocated to allow two days or less of actual bake-out time.

4. Effectiveness of bake-out on various sources: According to Levin (1992b), a bake-out will not affect all VOC-emitting materials and products in the same manner. Thin materials, with large surface-to-volume ratios (i.e., a large fraction of the mass close to the surface such as paints, varnishes, and waxes), are more likely to be affected by a bake-out than thick materials, with small surface-to-volume ratios (i.e., only a small fraction of the mass close to the surface, such as particleboard).

   Another important parameter in determining the effectiveness of a bake-out is the temperature of the various materials during this procedure. Material temperatures depend on a material's thermal mass and on the duration of the bake-out (see Item 3 above), where the thermal mass of a material is determined by multiplying the specific heat of the material by its density. For example, to raise the temperature of a carpet and carpet adhesive sufficiently, the temperature of the sub-floor also must be increased due to the large thermal mass of the carpet assembly. Therefore, materials with large heat capacities are unlikely to be affected by bake-outs of short duration.

5. Cost of bake-outs: There are certain costs involved in a building bake-out besides energy costs. These costs include HVAC modifications, personnel involved with planning and execution of the bake-out, continuous monitoring and adjustment of building temperatures during the bake-out especially in cases when building emergency systems are overridden, etc. In addition, replacement cost of any building materials damaged as a result of the bake-out must be considered. For example Girman et al. (1990) reported that in one of five baked-out buildings there was some material damage consisting of buckled vinyl flooring in one room and a cracked window pane (out of a total of 225 double-glazed windows). The authors also reported that the building with the material damage was the one most extensively baked-out [this building was heated for 102 hr to temperatures up to 100°F (38°C).] The overall cost for this building bake-out was higher than that of the four other buildings, i.e., $\$0.23/ft^2$ ($\$2.5/m^2$), but negligible when compared to the cost of the building. Finally, the costs associated with delayed occupancy also must be considered.

6. Other issues: Some of the fire and safety alarms may have to be overridden during a bake-out. In addition, because during a bake-out a building operates well above design temperatures it is important to consider all the related legal and insurance issues. During a bake-out: (a) access to the building should be limited to HVAC maintenance/monitoring personnel; and (b) respirators capable of removing VOCs should be offered to those entering the building.

APPENDIX E: Survey of Existing Guidelines for VOCs (see also Appendix C)

E1 Guidelines for TVOCs

Listed below are guidelines for concentrations and emissions of VOCs as reported by various researchers and organizations. We caution readers that researchers, especially in the United States, strongly debate the applicability of such guidelines. However, we believe that readers should have all available information before making their own decisions. This document does not endorse or oppose any TVOC guidelines.

E1.1 European Guidelines on VOC Concentrations

Although standards for exposure to VOCs in non-industrial settings do not exist, a number of exposure limits have been recommended. The European Collaborative Action (ECA) Report No. 11 titled *Guidelines for Ventilation Requirements in Buildings* (CEC, 1992) lists the following TVOC concentration ranges as measured with a flame ionization detector calibrated to toluene [these recommendations are based on Mølhave's toxicological work on mucous membrane irritation (Mølhave, 1990)].

1. Comfort range: $<200\ \mu g/m^3$.
2. Multifactorial exposure range: 200 to 3,000 $\mu g/m^3$.
3. Discomfort range: 3,000 to 25,000 $\mu g/m^3$.
4. Toxic range: $>25{,}000\ \mu g/m^3$.

The same European report also lists a second method based on Seifert's work (Seifert, 1990). This method establishes TVOC guidelines based on the ten most prevalent compounds in each of seven chemical classes. The concentrations in each of these classes should be below the maximums listed below.

1. Alkanes: 100 $\mu g/m^3$.
2. Aromatic hydrocarbons: 50 $\mu g/m^3$.
3. Terpenes: 30 $\mu g/m^3$.
4. Halocarbons: 30 $\mu g/m^3$.
5. Esters: 20 $\mu g/m^3$.
6. Aldehydes and ketones (excluding formaldehyde): 20 $\mu g/m^3$.
7. Other: 50 $\mu g/m^3$.

The TVOC concentration is calculated by adding the totals from each class. Seifert gives a target TVOC concentration of 300 $\mu g/m^3$ which is the sum of the above listed target concentrations. The author also states that no individual compound concentration should exceed 50 percent of the guideline for its class or 10 percent of the TVOC target guideline concentration. However, Seifert states that "...the proposed target value is not based on toxicological considerations but - to the author's best judgement."

E1.2 Tucker's Classification of Low-Emitting Materials and Products

Tucker (1990) reported a classification scheme for determining whether or not materials and products are low-emitting. Tucker assumed that: (a) the maximum indoor concentration of organic vapors from any single source to be 500 $\mu g/m^3$; (b) the indoor air to be well mixed; and (c) the ventilation rate to be 0.5 ACH. The author suggested that the maximum emissions in his classification scheme be used only when predictive modeling for IAQ impact is not performed. Tucker's classification scheme is listed in Table E1.

Table E1. Classification of Low-Emitting Materials and Products (Tucker, 1990)	
Material or Product	**Maximum Emissions ($\mu g/m^2 \cdot hr$)**
Flooring materials	600
Flooring coatings	600
Wall materials	400
Wall coatings	400
Movable partitions	400
Office furniture	2,500 (μg/hr/workstation)

E1.3 State of Washington's Requirements

In 1989, the State of Washington developed indoor air quality specifications for new office buildings as part of the East Campus Plus program (Black et al. 1991a; State of Washington, 1989; *Building with Nature*, 1992). The specifications included, among other requirements, that product emissions from every building material or product should not result in indoor concentrations higher than the ones listed below "within 30 days of installation." (Each product's loading factor was based on a 900 ft^3 work station volume.) Test protocols for office furniture and office chairs specified six and four week-long environmental chamber testing periods respectively, in order to "...allow for mathematical modeling of product emission profiles over time" (State of Washington, 1989).

1. TVOCs: 500 $\mu g/m^3$.
2. Formaldehyde: 0.05 ppm.
3. 4-PC: 1 ppb.

In addition, the designer/builder was required to disclose in writing any interior design materials, furnishings, or finishes that contained any detectable amounts of compounds listed as carcinogens or reproductive toxins according to: (a) the list of chemical carcinogens as established by the International Agency for Research on Cancer; (b) the list of carcinogens of the National Toxicology Program; and (c) the list of reproductive toxins in the *Catalogue of Teratogenic Agents*.

This protocol also recommended that: (a) the building flush out period to begin 90 days before occupancy; (b) all VOC-emitting material, furniture excluded, to be installed at the beginning of the flush out period; (c) furniture could not be brought in the building earlier than 30 days after the start of the flush out; and (d) the designer/builder was encouraged to continue the flush out before occupancy by the owner.

Mason et al. (1995) reported on the TVOC measurements taken at the Natural Resources Building, which was part of the East Campus Plus building project. TVOC concentrations were reduced 30 to

60% 30 days after the flush out but did not decrease significantly through the 120-day sampling period (flush out ended at 90 days.) However, considerable reductions in TVOC concentrations were noticed at the 266-day sampling period (TVOC concentrations were 15 to 20% of those measured before the flush out.)

Although the East Campus Plus building project is now complete, the State of Washington as well as others continue to refer to the above specifications.

E2 Health Effects and Concentration Guidelines for Selected VOCs

Health effects and concentration guidelines are listed below for selected VOCs. The six VOCs discussed below were selected because: (a) they are common indoor air contaminants; (b) they are listed by the CARB as toxic air contaminants (CARB, 1993b); and (c) they have significant adverse health effects. The selected VOCs are discussed below in alphabetical order: benzene, formaldehyde, methylene chloride, styrene, tetrachloroethylene, and toluene. An identification number known as the **Chemical Abstracts Service (CAS) Registry Number** is also listed for each chemical.

E2.1 Benzene (CAS # 71-43-2)

E2.1.1 Sources

Benzene belongs to the chemical class of aromatic hydrocarbons. It is a constituent of environmental tobacco smoke, automobile exhaust, glues, paints, furniture wax, and detergents. The use of benzene has been discouraged due to its toxicity.

E2.1.2 Exposure Route

The primary route of exposure to benzene is inhalation or ingestion. Skin contact results in defatting and increased absorption of this and other chemicals.

E2.1.3 Health Effects

Information about the health effects of benzene comes from animal and human studies. The range of reported health effects includes death (usually from exposure to high concentrations during exertion with subsequent collapse from heart failure), anesthesia (at concentrations >3000 ppm), intoxication (headache, euphoria, nausea, and giddiness), mild irritation of eyes and mucous membranes, respiratory inflammation, and eye hemorrhage (if systemic poisoning occurs). Major concerns of systemic toxicity of benzene are aplastic anemia and acute myelogenous leukemia, which usually result from chronic exposures but which also may occur after acute exposures (ATSDR, 1993a). Benzene is a known human carcinogen and is listed as such under California Proposition 65 (1994). Benzene also has been identified as a Toxic Air Contaminant by the CARB (1993b) based on its carcinogenicity.

The odor of benzene is characterized as "aromatic/sweet/solvent" (AIHA, 1989). The lowest reported odor detection thresholds are 0.36 ppm (Devos et al., 1990) and 0.78 ppm (AIHA, 1989).

Table E2 lists the short-term exposure thresholds for benzene.

Table E2. Short-Term Exposure Thresholds For Benzene		
Health Effect	**Benzene Concentration** [α]	**Comments and References**
Olfactory threshold	See Table E9	
Discomfort / mild effect	0.24 ppm (0.78 mg/m^3) [β]	Transient changes in immune function tests may occur above this concentration (OEHHA, 1995)
Disability or serious effect	1.0 ppm (3.24 mg/m^3) [β]	Developing fetus may be harmed above this concentration (OEHHA, 1995)
Immediately dangerous to life and health (IDLH)	3,000 ppm (9,700 mg/m^3)	NIOSH (1994)

[α] Conversion factors for benzene at room air temperature and 1 atm. pressure:
1 ppm = 3.24 mg/m^3; 1 mg/m^3 = 0.31 ppm.

[β] Interim number.

E2.2 Formaldehyde (CAS # 50-00-0)

E2.2.1 Sources

Formaldehyde belongs to the chemical class of aldehydes, several of which are found in indoor air. Formaldehyde has been of special concern as an indoor air pollutant because of the number of products in which it occurs and the adverse health effects associated with exposure to formaldehyde. Indoor sources of formaldehyde include building materials, particularly pressed wood products (e.g., plywood, MDF, and particleboard), insulation materials (e.g., urea-formaldehyde foam insulation), adhesives, durable-press and flame resistant textiles, combustion appliances, and environmental tobacco smoke. Formaldehyde has been associated with about 4 percent of the building-related illness incidents that NIOSH has investigated (Samet et al., 1988).

E2.2.2 Exposure Route

The primary route of exposure to formaldehyde in the indoor environment is through inhalation. Skin contact with products containing formaldehyde, such as adhesives, results in a localized effect. Uptake into the body and bloodstream from skin exposures is low. Eye exposures similarly have a localized effect.

E2.2.3 Health Effects

Information about the health effects of formaldehyde comes largely from animal studies and from human occupational exposure assessments. The range of health effects observed includes: (a) odor and irritation effects; (b) broader systemic effects; and c) potential carcinogenic effects.

Formaldehyde is a primary upper respiratory tract irritant and its odor is characterized as "pungent" (AIHA, 1989). The lowest listed odor detection threshold is 0.03 ppm (Devos et al., 1990; AIHA, 1989). Devos et al. (1990) reported the mean detection threshold of seven published studies to be 0.87 ppm. Symptoms of eye, nose, and throat irritation, such as tearing, running nose, and a burning sensation in these areas, are relatively common with formaldehyde exposure. People vary widely in their sensitivities to formaldehyde and may respond differently to formaldehyde exposure.

Formaldehyde vapor can irritate the skin directly. Allergic responses (contact dermatitis) also can develop with skin exposure, but the degree of exposure required to cause this is uncertain. Some individuals occupationally exposed to formaldehyde have developed asthma. Chronic lung disease may occur in people exposed to high concentrations of formaldehyde (> 10 mg/m^3).

People with known residential exposures to formaldehyde have reported neuropsychological symptoms, including headache, fatigue, memory and concentration difficulty, and emotional changes. Studies have shown chemical and physical changes in the nervous systems of experimental animals exposed to formaldehyde. Effects of formaldehyde on reproduction, including menstrual disorders, adverse pregnancy outcomes and complications, and low-birth-weight babies have been suggested. However, the human epidemiologic evidence is presently too limited to draw final conclusions.

Formaldehyde is classified as a probable human carcinogen based on sufficient evidence in animal studies. Formaldehyde is very soluble in water and as a result is absorbed readily by the mucous membranes of the upper respiratory tract. Cancer of the nasal cavity has been shown to develop in animals exposed to formaldehyde. Formaldehyde is listed as a California Proposition 65 (1994) carcinogen and as a Toxic Air Contaminant by the CARB (1993b) based potential carcinogenicity.

Table E3 lists some effects of short-term formaldehyde exposure in humans.

Table E3. Short-Term Exposure Thresholds For Formaldehyde

Health Effect	Formaldehyde Concentration $^{\alpha}$	Comments and References
Olfactory threshold	See Table E9	
Discomfort / mild effect	0.14 ppm (0.17 mg/m^3) $^{\beta}$	Eye irritation (OEHHA, 1995)
Disability or serious effect	10 ppm (12 mg/m^3) $^{\beta}$	Tearing eyes (OEHHA, 1995)
Immediately dangerous to life and health (IDLH)	20 ppm (24 mg/m^3)	NIOSH (1994)

$^{\alpha}$ Conversion factors for formaldehyde at room air temperature and 1 atm. pressure:
1 ppm = 1.24 mg/m^3;
1 mg/m^3 = 0.815 ppm.

$^{\beta}$ Interim number.

E2.2.4 Guidelines for Formaldehyde

The following organizations have issued guidelines for formaldehyde.

1. The California Department of Health Services recommends 0.05 ppm as an "indoor air concentration guideline" for homes (CARB, 1991).

2. The California Air Resources Board recommends for homes an "action level" of 0.10 ppm (0.12 mg/m^3) and a "target level" of 0.05 ppm (0.06 mg/m^3) or lower (CARB, 1991).

3. The United States Department of Housing and Urban Development (HUD, 1984) recommends for manufactured homes that chamber formaldehyde concentrations for plywood wall panels should not exceed 0.2 ppm and for particleboard 0.3 ppm. In addition, HUD recommends that indoor formaldehyde concentrations of manufactured homes from all sources including plywood and particleboard should not exceed 0.4 ppm.

4. The World Health Organization (WHO) guideline is 0.082 ppm (WHO, 1987b).

5. The California Environmental Protection Agency, the Office of Environmental Health Hazard Assessment (OEHHA) in a draft document lists an acute 1-hr exposure concentration of 0.14 ppm (0.17 mg/m^3), based on early symptoms of eye irritation. This draft is presently undergoing public review (OEHHA, 1995).

E2.3 Methylene Chloride (CAS # 75-9-2)

E2.3.1 Sources

Methylene chloride or dichloromethane is a chlorinated solvent. It is commonly used as an industrial solvent and paint remover, in aerosol products, and in some spray paints. Indoor air concentrations during the use of paint removers containing methylene chloride in non-occupational settings have averaged 460 to 2980 mg/m^3 in an unventilated room (WHO, 1987b). Methylene chloride is a common indoor air contaminant. It is also measurable in ambient air as a result of industrial and end product uses, with background concentrations usually less than 1 ppb (3.5 $\mu g/m^3$).

E2.3.2 Exposure Route

Methylene chloride is absorbed well by inhalation and the oral route if ingested. Skin absorption is generally minor.

E2.3.3 Health Effects

Absorbed methylene chloride may be broken down into other chemicals in the body, including carbon monoxide, or may be released unchanged. The health effects of methylene chloride have been determined largely from animal studies although some studies of occupational exposures have been done. Relatively little is known about potential health effects of long-term, low-level exposures to methylene chloride, such as those that occur in non-occupational or environmental settings.

The odor of methylene chloride is characterized as "sweet" (AIHA, 1989). The lowest reported odor detection thresholds are 1.2 ppm (AIHA, 1989) and 10 ppm (Devos et al., 1990). Carbon monoxide is formed during the breakdown of methylene chloride in the body. Carbon monoxide binds to hemoglobin in the blood, forming carboxyhemoglobin, and destroys the ability of the bound hemoglobin to carry oxygen to the tissues. This carboxyhemoglobin may form in addition to that formed from other carbon monoxide sources, such as cigarette smoke and automotive exhaust, causing an added stress to the body. The WHO suggests that a 24-hr exposure to methylene chloride not exceed 3 mg/m^3 to limit the corresponding carboxyhemoglobin formation to less than 0.1 percent in the body (WHO, 1987b).

Methylene chloride affects the nervous system. Brief human exposures of 1 to 2 hr or less to 300 ppm methylene chloride can temporarily affect vision and hearing. Higher exposures may affect reaction time and steadiness, and long-term exposures to very high concentrations (500 to 1000 ppm) can cause permanent neurologic damage. The Agency for Toxic Substances and Disease Registry (ATSDR) has recommended a short-term inhalation Minimum Risk Level (MRL) of 0.4 ppm, based on human evidence for nervous system toxicity (ATSDR, 1993b). Short-term exposures to methylene chloride at or below this concentration are not believed to be a concern with respect to non-cancer health effects in the general population. The OEHHA in a draft document (OEHHA, 1995) lists an acute, 1-hr exposure concentration of 24 ppm (83 mg/m^3) based on subtle impairment of the central nervous system.

Exposures to methylene chloride have been shown to cause liver and kidney damage in animal studies. The lowest exposure level at which liver and kidney toxicity have been seen in animal studies is 25 ppm for approximately 3 mo. Human studies are limited regarding potential effects of methylene chloride on the liver or kidney. The ATSDR has developed an inhalation MRL for intermediate exposures (2 wk to 1 yr) of 0.03 ppm based on animal studies. No longer-term inhalation MRL has been developed.

Methylene chloride has been shown to cause cancer in animal studies and it is classified as a probable human carcinogen based on sufficient animal evidence. Methylene chloride also is listed as a California Proposition 65 (1994) carcinogen and as a Toxic Air Contaminant by the CARB (1993b) based on its cancer-causing potential. Increases in lung and liver cancer, benign mammary tumors, salivary gland cancer, and leukemia have been seen in animal studies. Long-term follow up of chemical factory workers exposed to methylene chloride suggests a possible association with liver and biliary tract cancers (USEPA, 1995). The latter human evidence is not conclusive at this time.

Table E4 lists a summary of health effects from short-term exposure to methylene chloride.

Table E4. Short-Term Exposure Thresholds For Methylene Chloride

Health Effect	Methylene Chloride Concentration $^{\alpha}$	Comments and References
Olfactory threshold	See Table E9	
Discomfort / mild effect	24 ppm (83 mg/m^3) $^{\beta}$	Subtle central nervous system impairment (OEHHA, 1995)
Disability or serious effect	No threshold established	OEHHA (1995)
Immediately dangerous to life and health (IDLH)	2300 ppm (7980 mg/m^3)	NIOSH (1994)

α Conversion factors for methylene chloride at room air temperature and 1 atm. pressure:
1 ppm = 3.47 mg/m^3;
1 mg/m^3 = 0.28 ppm.

β Interim number.

E2.4 Styrene (CAS # 100-42-5)

E2.4.1 Sources

Styrene belongs to the chemical class of aromatic hydrocarbons. It is a constituent of automobile exhaust, environmental tobacco smoke, building materials, and consumer products (e.g., polystyrene used in packaging, toys, housewares, and appliances may contain small amounts of unlinked styrene).

E2.4.2 Exposure Route

The primary route of exposure to styrene is by inhalation. It can be absorbed readily by the skin into the body.

E2.4.3 Health Effects

Information about the health effects of styrene come from animal and human studies. The range of reported health effects include respiratory inflammation or asthma, intoxication (depression, difficulty concentrating, headache, euphoria, nausea, and giddiness), irritation of eyes and mucous membranes, and neurological damage (ATSDR, 1992a). The neurological damage associated with styrene exposure includes slowing in sensory nerves and central nervous system depression (Cherry and Gautrin, 1990). There is no direct evidence for human reproductive or developmental toxicity from styrene exposure. Styrene has been identified as a Toxic Air Contaminant by the CARB (1993b).

The odor of styrene is characterized as "sharp/sweet" (AIHA, 1989). The lowest reported odor detection thresholds are 4.7 ppb (AIHA, 1989) and 52 ppb (Devos et al., 1990).

Table E5 lists a summary of health effects from short-term exposure to styrene.

Table E5. Short-Term Exposure Thresholds For Styrene

Health Effect	Styrene Concentration $^{\alpha}$	Comments and References
Olfactory threshold	See Table E9	
Discomfort / mild effect	5.1 ppm (21.4 mg/m^3) $^{\beta}$	OEHHA (1995)
Disability or serious effect	No threshold established	OEHHA (1995)
Immediately dangerous to life and health (IDLH)	No threshold established	

α Conversion factors for styrene at room air temperature and 1 atm. pressure:
1 ppm = 4.2 mg/m^3;
1 mg/m^3 = 0.24 ppm.

β Interim number.

E2.4.4 Guidelines for Styrene

An acute toxicity exposure concentration of 5.1 ppm has been recommended for styrene, based on lack of human eye and throat irritation symptoms below 51 ppm and allowing for a 10-fold margin of safety for individual variation (OEHHA, 1995).

E2.5 Tetrachloroethylene (perchloroethylene or ethylene tetrachloride) (CAS # 127-18-4)

E2.5.1 Sources

Tetrachloroethylene is a VOC which is also known as perchloroethylene (PCE) and ethylene tetrachloride. It is commonly used as a dry-cleaning solvent and as a metal degreaser. Tetrachloroethylene is used in building materials and various consumer products including spot removers, lubricants, adhesives, and wood cleaners (ATSDR, 1992b). Tetrachloroethylene has been measured in the indoor air of homes, new and occupied office buildings, and ambient air. Indoor air concentrations have been measured up to 250 $\mu g/m^3$ (35 ppb) (WHO, 1987b).

E2.5.2 Exposure Route

Tetrachloroethylene is absorbed well by the inhalation route and the oral route if ingested. Absorption through the skin is relatively low.

E2.5.3 Health Effects

Much of what is known about the health effects of tetrachloroethylene comes from animal studies and some occupational studies. Most of these studies involve relatively high exposures to tetrachloroethylene. Less is known about the health effects of low-level, long-term exposures to tetrachloroethylene.

The odor of tetrachloroethylene is characterized as "etherish" (AIHA, 1989). The lowest reported odor detection threshold is 2 ppm (AIHA, 1989) and 3 ppm (Devos et al., 1990). Once absorbed into the body, the liver is a main target organ for the toxic effects of tetrachloroethylene. The central nervous system and the kidney also can be affected. Short-term exposures to tetrachloroethylene concentrations of 200 ppm or higher cause liver toxicity in animal studies. Symptoms of eye and respiratory irritation have been observed in humans briefly exposed (< 2 hr) to between 100 and 200 ppm tetrachloroethylene. Central nervous system effects of tetrachloroethylene, depending on concentration, include changes in mood, behavior, or coordination and anesthetic effects. The ATSDR has established a short-term inhalation MRL for tetrachloroethylene of 0.6 ppm for the general population, based on central nervous system depression in adults exposed to 100 ppm for the equivalent of a work week. Short-term exposures to concentrations at or below this number are not believed to cause adverse non-cancer health effects for the general population. The OEHHA, in a draft document (OEHHA, 1995), lists an acute, 1-hr exposure concentration of 1.7 ppm (12 mg/m^3), based on loss of normal coordination and irritant effects.

Longer exposures to tetrachloroethylene at lower concentrations can also have adverse effects. Liver toxicity was seen in mice exposed by inhalation to 9 ppm tetrachloroethylene for a month. The ATSDR established an intermediate-duration (2 wk to 1 yr), inhalation MRL of 0.009 ppm for the general population based on this study. Occupational exposures at 12 ppm for 4 to 5 mo have been associated with impaired perception, attention, and intellectual skills. Mild kidney damage has been associated with long-term occupational exposures to 10 ppm tetrachloroethylene. Although not conclusive, some epidemiological studies suggest an association between occupational exposures to tetrachloroethylene and adverse reproductive effects, primarily menstrual disorders and spontaneous abortions.

Tetrachloroethylene is listed as a carcinogen under California's Proposition 65 (1994) and as a Toxic Air Contaminant by the CARB (1993b) based on its carcinogenicity. Tetrachloroethylene has been shown to cause liver cancer and leukemia in animal studies, by both oral and inhalation exposures, and is considered to be a potential human carcinogen based on animal data. Some human epidemiological studies of dry cleaning workers also suggest an association between exposure to solvents, including tetrachloroethylene, and increased cancer risk. Table E6 lists a summary of health effects from short-term exposure to tetrachloroethylene.

Table E6. Short-Term Exposure Thresholds For Tetrachloroethylene

Health Effect	Tetrachloroethylene Concentration $^{\alpha}$	Comments and References
Olfactory threshold	See Table E9	
Discomfort / mild effect	No threshold established	
Disability or serious effect	1.7 ppm (12 mg/m^3) $^{\beta}$	Loss of coordination, headache, eye, nose, and throat irritation, and light headiness (OEHHA, 1995)
Immediately dangerous to life and health (IDLH)	150 ppm (1017 mg/m^3)	NIOSH (1994)

$^{\alpha}$ Conversion factors for tetrachloroethylene at room air temperature and 1 atm. pressure:
1 ppm = 6.78 mg/m^3;
1 mg/m^3 = 0.15 ppm.

$^{\beta}$ Interim number.

E2.6 Toluene (CAS # 108-88-3)

E2.6.1 Sources

Toluene belongs to the chemical class of aromatic hydrocarbons. Toluene is present in gasoline, automobile exhaust, environmental tobacco smoke, paints, fingernail polishes, glues, and building materials.

E2.6.2 Exposure Route

The primary route of exposure to toluene is by inhalation. It can also cross the skin into the body. Toluene, like other organic hydrocarbon solvents, can dissolve the skin's natural protective oils, and prolonged or frequent contact may cause irritation or cracking of the skin.

E2.6.3 Health Effects

Information about the health effects of toluene come from animal and human studies. The range of health effects reported include intoxication (i.e., headache, nausea, difficulty concentrating, euphoria, and giddiness followed by depression), respiratory inflammation, worsening of asthma, irritation of eyes and mucous membranes, and neurological damage. Toluene may cause changes in the heart leading to abnormal heart rhythms or death. The neurological damage associated with toluene exposure may include alteration in a person's balance, speech, hearing, muscle control, memory, and thinking abilities. Kidney function may be affected, but generally returns to normal after cessation of exposure. Animals exposed to toluene have demonstrated effects on the liver, kidneys, and lungs.

The odor of toluene is characterized as "sour/burnt" (AIHA, 1989). The lowest reported odor detection thresholds are 0.021 ppm (AIHA, 1989) and 0.11 ppm (Devos et al., 1990). Exposure of unborn animals to toluene resulted in harm when high concentrations were breathed by the mothers. Women who abused toluene throughout their pregnancy (e.g., by "sniffing" glue or paint) have delivered children with birth defects and delayed development. However, it is not known if toluene can affect pregnancy or other reproductive function at concentrations normally found in indoor air.

Schmid et al. (1985) and Bauchinger et al. (1982) reported chromosomal damage in workers with prolonged exposures to toluene concentrations between 200 and 300 ppm. Chromosomes contain information that tells a person's body cells how to function and form new cells. The long-term effects of chromosome damage are not known, but may include increased risk of cancer. No other evidence has been published to suggest that toluene by itself causes cancer. Studies that suggest that toluene is a carcinogen may be due to the use of commercial products contaminated with small amounts of benzene, a known carcinogen. Toluene has been identified as a Toxic Air Contaminant by the CARB (1993b).

Table E7 summarizes the nervous system effects of toluene and the acute toxicity exposure levels for 1-hr exposure to toluene.

Table E7. Short-Term Exposure Thresholds For Toluene

Health Effect	Toluene Concentration $^{\alpha}$	Comments and References
Olfactory threshold	See Table E9	
Discomfort / mild effect	9.8 ppm (37 mg/m^3) $^{\beta}$	OEHHA (1995)
Disability or serious effect	12.3 ppm (46 mg/m^3)	Exposure above this concentration may harm a developing fetus (OEHHA, 1995)
Immediately dangerous to life and health (IDLH)	2000 ppm (7500 mg/m^3)	NIOSH (1994)

$^{\alpha}$ Conversion factors for toluene at room air temperature and 1 atm. pressure:
1 ppm = 3.75 mg/m^3; 1 mg/m^3 = 0.27 ppm.

$^{\beta}$ Interim number.

E2.6.4 Guidelines for Toluene

An acute toxicity exposure concentration of 9.8 ppm (37 mg/m^3) has been recommended for toluene (OEHHA, 1995). This recommendation is based on studies showing perceived impaired reaction time, headache, dizziness, intoxication symptoms, and slight eye and nose irritation in 16 healthy males exposed to 100 ppm of toluene over a 6-hr period, with no reported symptoms at a concentration of 40 ppm over a 6-hr period. The results of these studies were extrapolated to a 1-hr exposure period allowing for a ten-fold margin of safety for individual variation (OEHHA, 1995).

E3 Sources of Information on Carcinogenicity and Reproductive Toxicity of VOCs

There are several sources listing information on the carcinogenicity and reproductive toxicity of VOCs. Some of these sources are listed below.

1. In California, the OEHHA has been designated by the Governor to publish at least annually a list of chemicals "...known to the State to cause cancer or reproductive toxicity" (California Proposition 65, 1994). Publication of this list is required by the Safe Drinking Water and Toxic Enforcement Act of 1986.

2. Also in California, the CARB has developed a list of Toxic Air Contaminants as mandated under Chapter 3.5 of the California Heath and Safety Code. A number of these contaminants have been determined by the CARB's Scientific Review Panel to be carcinogenic (CARB, 1993b). For those contaminants designated as carcinogenic, the CARB has developed various control measures to reduce emissions outdoors.

3. The Working Group on the Evaluation of Carcinogenic Risks to Humans of the International Agency for Research on Cancer (IARC) publishes, in the form of monograms, critical reviews of data on the carcinogenicity of agents to which humans are likely to be exposed. The Working Group evaluates these data and decides whether on not sufficient data exist on carcinogenicity for humans and animals. The Working Group then lists each agent's carcinogenic potential to humans. The Working Group lists the carcinogenic potential of each agent in Group 1, 2A, 2B, or 3. **Group 1** agents are considered human carcinogens based on sufficient evidence in humans; **Group 2A** agents are listed as probable human carcinogens based on limited evidence in humans and sufficient evidence in animals; **Group 2B** agents are listed as possible human carcinogens based on inadequate evidence in humans but sufficient evidence in animals, or limited evidence in humans without sufficient evidence in animals; and **Group 3** agents are not classifiable as human carcinogens.

Some of the chemicals listed under Proposition 65 and by the IARC are VOCs emitted from building materials and are likely to be found in office environments. Table E8 (see next page) lists some of these chemicals. The reader is cautioned that the intent of the following table is to cover the most common carcinogenic VOCs emitted by building materials and products and not to list all possible indoor carcinogens emitted by building materials and products or other sources. Note that all the chemicals shown on Table E8 are listed also as Toxic Air Contaminants by the CARB (CARB, 1993b).

E4 Sensory Effects of VOCs

Humans are able to detect both odor and irritant effects of many VOCs. However, these two effects cannot be easily differentiated by most humans. A number of indicators or substitute measures may be used to estimate or predict the odor and irritation potency of VOCs as discussed below. The reader is cautioned that the mere presence of a chemical with odor or irritation potential does not imply adverse health effects. Other factors that must be considered are concentration, proximity of occupants to VOC-emitting sources, and duration of exposure as discussed in Section 2.2.1.

Table E8. VOCs Emitted By Building Materials Known or Suspected To Be Human Carcinogens or Reproductive Toxicants				
Chemical Name	Listed as Carcinogen			Listed as Reproductive Toxicant
	California Prop. 65 $^{\alpha}$	CARB $^{\beta}$	IARC Group $^{\gamma}$	California Prop. 65 $^{\delta}$
Benzene $^{\epsilon}$	Yes	Yes	1	No
Carbon tetrachloride (Tetrachloromethane)	Yes	Yes	2B	No
Dioxane (p-Dioxane; 1,4-Dioxane)	Yes	No $^{\zeta}$	2B	No
Formaldehyde (Methanal) $^{\eta}$	Yes	Yes	2A	No
Methylene chloride $^{\theta}$ (Methane chloride; Dichloromethane)	Yes	Yes	2B	No
Styrene (Vinyl benzene) $^{\iota}$	(oxide) Yes	No $^{\zeta}$	2B	No
Tetrachloroethylene $^{\kappa}$ (Perchloroethylene; 1,1,2,2-Tetrachloroethylene)	Yes	Yes	2B	No
Toluene $^{\lambda}$	No	No $^{\zeta}$	3	Yes
Trichloroethylene (TCE)	Yes	Yes	3	No

$^{\alpha}$ Chemical known to the State of California to cause cancer (California Proposition 65, 1994);
$^{\beta}$ Chemical listed in the CARB's Toxic Air Contaminant List and determined by the Scientific Review Panel to be carcinogenic (CARB, 1993b);
$^{\gamma}$ Chemical listed by the IARC as: Group 1 ("human carcinogen"); Group 2A ("probable human carcinogen"); Group 2B ("possible human carcinogen"); and Group 3 ("not classifiable human carcinogen") (IARC, 1987, 1989);
$^{\delta}$ Chemical known to the State of California to cause reproductive toxicity (California Proposition 65, 1994);
$^{\epsilon}$ See Section E2.1 of Appendix E for a detailed discussion of this chemical;
$^{\zeta}$ Chemical listed in the CARB's Toxic Air Contaminant List (CARB, 1993b);
$^{\eta}$ See Section E2.2 of Appendix E for a detailed discussion of this chemical;
$^{\theta}$ See Section E2.3 of Appendix E for a detailed discussion of this chemical;
$^{\iota}$ See Section E2.4 of Appendix E for a detailed discussion of this chemical;
$^{\kappa}$ See Section E2.5 of Appendix E for a detailed discussion of this chemical;
$^{\lambda}$ See Section E2.6 of Appendix E for a detailed discussion of this chemical.

E4.1 Odor

The most common index for measuring the presence of an odorous chemical is the odor threshold. There are two types of odor thresholds: the **detection** and **recognition** thresholds. These thresholds are the lowest concentrations of an odorous chemical at which a specified percentage, usually 50 percent, of a panel of at least six judges "detects a stimulus as being different from odor-free blanks" (i.e., detection threshold) or ascribes "a definite character to the odor" (i.e., recognition threshold) (AIHA, 1989).

Reported odor threshold data vary considerably, sometimes as much as four orders of magnitude for the same chemical. Reasons for this variability include differences in experimental methodologies and in human olfactory responses. The two most widely used odor threshold references are AIHA (1989) and Devos et al. (1990).

AIHA (1989) lists detection and recognition threshold values for 182 chemicals that have established threshold limit values (TLVs). AIHA critiqued multiple studies, and only data from those studies that met AIHA's threshold determination criteria were used to calculate geometric mean detection and recognition thresholds for the 182 chemicals. AIHA (1989) also lists odor thresholds from all individual studies, highlighting those used for the calculation of the geometric mean values.

Similarly, Devos et al. (1990) compiled a list of standardized human olfactory (i.e., odor) thresholds for 529 chemicals. Each standardized threshold is presented as a weighted average of data from published studies for each chemical. Odor thresholds from individual studies are also included for comparison to the weighted average.

Table E9 lists detection odor thresholds from the above references for the VOCs listed in Appendix B. Differences exceeding one order of magnitude exist between the two references for some VOCs. This discrepancy illustrates the variability of existing odor threshold data. The lowest odor threshold listed in Table E9 is for 1,3,5-trimethylbenzene (i.e., 2.2 ppb). Other VOCs with low odor thresholds include 1,2,4-trimethylbenzene (i.e., 2.4 ppb), butyl acrylate (i.e., 2.6 ppb), and ethyl benzene (i.e., 2.9 ppb). Note that many of the listed compounds have odor thresholds significantly higher than typical indoor concentrations.

E4.2 Irritation

Most skin and eye irritation information is obtained from tests using rabbits. The **Draize** procedure specifies the experimental methodologies for the skin and eye irritation tests. Both of these tests are relatively simple to conduct. The Draize procedure can adequately identify most of the moderate to severe human eye or skin irritants, but the procedure often fails to detect mild or subtle irritation. The Draize assessment of severity of different eye or skin effects is based on a subjective grading system which, as in the case of odor thresholds, is one of the main sources of discrepancy among data reported by various researchers. Skin and eye irritation information for humans is available for some chemicals.

Two of the most widely used sources for irritation information are NIOSH (1994) and Sax and Lewis (1989). The irritation data listed in both references are based on Draize tests in rabbits and on human exposure data where available. Table E9 lists irritation characteristics for the VOCs presented in Appendix B. All VOCs listed in Table E9 have irritation information available, and 85 percent of these compounds exhibit some type of irritation. Among the VOCs that are listed as irritants, over 90 percent cause eye irritation, over 95 percent cause skin irritation, and over 85 percent cause both types of irritation.

Table E9. Odor Thresholds and Irritation Characteristics for VOCs Known or Suspected of Being Emitted From Building Materials and Cleaning Products						
Chemical Name	**CAS #**	**Odor Threshold**		**Irritant Characteristics**		
		AIHA[α]	**Devos et al.**[β]	**Irritant (+/-)**[γ]	**Type of Irritation**	**Ref.**
Acetic acid	64-19-7	0.074 ppm	0.14 ppm	+	Eye, skin, nose	1
					Severe eye and skin	2
Acetone (2-Propanone)	67-64-1	62 ppm	14 ppm	+	Eye, nose, throat	1
					Skin, severe eye	2
1-Amyl alcohol (Amyl alcohol; Pentyl alcohol; 1-Pentanol)	71-41-0	Not listed	0.47 ppm	+	Eye, upper resp., severe skin and eye	2
Benzaldehyde	100-52-7	Not listed	0.04 ppm	+	Skin	2
Benzene[ε]	71-43-2	61 ppm	3.6 ppm	+	Eye, skin, nose	1
					Severe eye, skin	2
2-Butanone (Methyl ethyl ketone)	78-93-3	16 ppm	7.8 ppm	+	Eye, skin, nose	1
				-		2
n-Butyl acetate (Butyl acetate)	123-86-4	0.31 ppm	0.19 ppm	+	Eye, skin, upper resp. system	1
					Skin, severe eye	2
Butyl acrylate (Butyl-2-propenoate)	141-32-2	None accepted	2.6 ppb	+	Eye, skin, upper resp. system	1
					Skin and eye	2

Table E9 (continued)						
Chemical Name	CAS #	Odor Threshold		Irritant Characteristics		
		AIHA[α]	Devos et al.[β]	Irritant (+/-)[γ]	Type of Irritation	Ref.
n-Butyl alcohol (1-Butanol)	71-36-3	1.2 ppm	Not listed	+	Eye, nose, throat	1
					Skin, severe eye	2
n-Butylbenzene	104-51-8	Not listed		-		2
Camphene	79-92-5	Not listed		-		2
Chlorobenzene	108-90-7	1.3 ppm	0.74 ppm	+	Eye, skin, nose	1
					"Slight irritant"	2
Cyclohexane	110-83-8	780 ppm	22 ppm	+	Eye, skin, resp. system	1
					Skin	2
Cyclohexanone	108-94-1	3.5 ppm	0.71 ppm	+	Eye, skin, mucous membrane	1
					Skin, severe eye irritant	2
Dibutylphthalate (Di-n-butyl phthalate)	84-74-2	Not listed		+	Eye, upper resp. system	1
				-		2
Diethylamine	109-89-7	0.053 ppm	0.19 ppm	+	Eye, skin, resp. system	1
					Skin, severe eye irritant	2
Dimethyl acetamide (N,N-Dimethyl acetamide)	127-19-5	Not listed	48 ppm	+	Skin	1, 2

Table E9 (continued)						
Chemical Name	CAS #	Odor Threshold		Irritant Characteristics		
		AIHA[α]	Devos et al.[β]	Irritant (+/-)[γ]	Type of Irritation	Ref.
Dioxane (p-Dioxane; 1,4-Dioxane)	123-91-1	12 ppm	5.5 ppm	+	Eye, skin, nose, throat	1
					Eye, skin	2
Dodecane (n-Dodecane)	112-40-3	Not listed	2.0 ppm	-		2
				+	Mucous membrane by analogy[δ]	4
2-Ethoxyethanol (Cellosolve®, Ethylene glycol monoethyl ether)	110-80-5	2.7 ppm	1.2 ppm	+	Eye, resp. system	1
					Eye, skin	2
2-Ethoxyethyl acetate (Cellosolve® acetate, Ethylene glycol monoethyl ether acetate)	111-15-9	0.060 ppm	0.18 ppm	+	Eye, nose	1
					Skin, eye	2
Ethyl acetate	141-78-6	18 ppm	2.6 ppm	+	Eye, skin, nose, throat	1
					Eye	2
Ethyl alcohol (Ethanol)	64-17-5	180 ppm	29 ppm	+	Eye, skin, nose	1
					Eye, severe skin	2
				-		4
Ethyl benzene	100-41-4	See footnote λ	2.9 ppb	+	Eye, skin, mucous membrane	1
					Eye, skin	2

Table E9 (continued)						
Chemical Name	CAS #	Odor Threshold		Irritant Characteristics		
		AIHA[α]	Devos et al.[β]	Irritant (+/-)[γ]	Type of Irritation	Ref.
2-Ethyltoluene (o-Ethyltoluene)	611-14-3	Not listed		-		2
				+	Mucous membrane by analogy[δ]	4
Formaldehyde[ζ] (Methanal)	50-00-0	See footnote λ	0.87 ppm	+	Eye, nose, throat, resp. system	1
					Eye, skin	2
Heptane (n-Heptane)	142-82-5	230 ppm	9.8 ppm	-		1, 2
Hexachlorobenzene	118-74-1	Not listed		-		2
Hexanal	66-25-1	Not listed	14 ppb	+	Eye, skin	2
Hexane (n-Hexane)	110-54-3	See footnote λ	22 ppm	+	Eye, nose	1
					Eye, resp. tract	2
Isobutyl acetate (2-Methylpropyl acetate)	110-19-0	1.1 ppm	Not listed	+	Eye, skin, upper resp. system	1
					Skin, eye	2
Isobutyl alcohol (Isobutanol; 2-Methyl-1-propanol)	78-83-1	3.6 ppm	0.83 ppm	+	Eye, throat	1
					Severe skin and eye	2
Isopropyl alcohol (Isopropanol; 2-Propanol)	67-63-0	43 ppm	10 ppm	+	Eye, nose, throat	1
					Eye, skin	2
Isoquinolone	119-65-3	Not listed		+	Severe skin and eye	2

Table E9 (continued)						
Chemical Name	CAS #	Odor Threshold		**Irritant Characteristics**		
		AIHA[α]	**Devos et al.**[β]	**Irritant (+/-)**[γ]	**Type of Irritation**	**Ref.**
d-Limonene	5989-27-5	Not listed	0.44 ppm	-		2
Methylene chloride[η] (Methane dichloride; Dichloromethane)	75-09-02	See footnote λ	28 ppm	+	Eye, skin	1
					Eye, severe skin	2
Methyl isobutyl ketone (MIBK; 4-Methyl-2-pentanone)	108-10-1	0.88 ppm	Not listed	+	Eye, skin, mucous membrane	1
				+	Very irritating to eye, skin, and mucous membrane	2
2-Methylpentane (Isohexane)	107-83-5	Not listed		+	Eye	2
Nonane (n-Nonane)	111-84-2	See footnote λ	1.3 ppm	+	Eye, skin, nose, throat	1
					Resp. tract	2
Nonyl phenol isomers	25154-52-3	Not listed		+	Severe skin and eye	2
Pentachlorophenol (PCP)	87-86-5	Not listed		+	Eye, nose, throat	1
					Skin	2
4-Phenylcyclohexene (4-PC; Cyclohexylbenzene)	827-52-1	Not listed		-		2
α-Pinene	80-56-8	Not listed	0.69 ppm	+	Eye, mucous membrane, severe skin	2

Table E9 (continued)						
Chemical Name	CAS #	Odor Threshold		Irritant Characteristics		
		AIHA[α]	Devos et al.[β]	Irritant (+/-)[γ]	Type of Irritation	Ref
n-Propyl acetate	109-60-4	0.18 ppm	0.58 ppm	+	Eye, nose, throat	1
					Skin	2
Propylbenzenes (n-Propylbenzene)	103-65-1	Not listed		-		2
Quinoline	91-22-5	Not listed	15 ppb	+	Skin, severe eye	2
Styrene[θ] (Vinyl benzene)	100-42-5	0.14 ppm	0.14 ppm	+	Eye, nose, resp. system	1
					Skin, eye	2
α-Terpinene (1-Methyl-4-isopropyl-1,3-cyclohexadiene)	99-86-5	Not listed		-		2
Tetrachloroethylene[ι] (Perchloroethylene)	127-18-4	47 ppm	6.2 ppm	+	Eye, nose, throat	1
					Eye, severe skin	2
Tetrachlorophenol	25167-83-3	Not listed				2
Toluene[κ]	108-88-3	1.6 ppm	1.6 ppm	+	Eye, nose	1
					Skin, eye	2
1,1,1-Trichloroethane (Methyl chloroform)	71-55-6	390 ppm	22 ppm	+	Eye, skin	1
					Skin, severe eye	2
Trichloroethylene (TCE)	79-01-6	82 ppm	4.9 ppm	+	Eye, skin	1
					Eye, severe skin	2

Table E9 (continued)						
Chemical Name	CAS #	Odor Threshold		Irritant Characteristics		
		AIHA[α]	Devos et al.[β]	Irritant (+/-)[γ]	Type of Irritation	Ref
1,2,3-Trimethylbenzene	526-73-8	Not listed		+	Eye, skin, nose, throat, resp. system	1
				-		2
1,2,4-Trimethylbenzene	95-63-6	2.4 ppb	0.15 ppm	+	Eye, skin, nose, throat, resp. system	1
				-		2
1,3,5-Trimethylbenzene (Mesitylene)	108-67-8	2.2 ppb	0.23 ppm	+	Eye, skin, nose, throat, resp. system	1
				-		2
Undecane (n-Undecane)	1120-21-4	Not listed	1.2 ppm	-		2
				+	Mucous membrane by analogy[δ]	4
m-Xylene (1,3-Dimethylbenzene)	108-38-3	0.62 ppm	0.32 ppm	+	Eye, skin, nose, throat	1
					Severe skin	2
o-Xylene (1,2-Dimethylbenzene)	95-47-6	5.4 ppm	0.85 ppm	+	Eye, skin, nose, throat	1
				-		2
p-Xylene (1,4-Dimethylbenzene)	106-42-3	2.1 ppm	0.49 ppm	+	Eye, skin, nose, throat	1
				-		2

α Reference: AIHA. 1989. *Odor Thresholds for Chemicals with Established Occupational Health Standards*. Akron, Ohio: American Industrial Hygiene Association; Concentrations listed are detection thresholds;

β Reference: Devos, M.; Patte, F.; Rouault, J.; Laffort P.; and Van Gemert, L.J., Editors. 1990. *Standardized Human Olfactory Thresholds*. New York, New York: Oxford University Press;

γ +: mention of irritant effect in references; -: no mention of irritant effects in references;

δ By analogy to chemically similar compounds;

ε See Section E2.1 of Appendix E for a detailed discussion of this chemical;

ζ See Section E2.2 of Appendix E for a detailed discussion of this chemical;
η See Section E2.3 of Appendix E for a detailed discussion of this chemical;
θ See Section E2.4 of Appendix E for a detailed discussion of this chemical;
ι See Section E2.5 of Appendix E for a detailed discussion of this chemical;
κ See Section E2.6 of Appendix E for a detailed discussion of this chemical;
λ None of the literature critiqued by AIHA met the odor threshold determination criteria.

References used to obtain irritant characteristics for Table E9 (numbers correspond to the last column of Table E9)

1. NIOSH. 1994. *NIOSH Pocket Guide to Chemical Hazards*, United States Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 94-116. Available from the U.S. Government Printing Office, Superintendent of Documents, Washington, DC (stock no. 017-033-00473-1) and the National Technical Information Service, Springfield, VA (stock no. PB95-100368).

2. Sax, N. I; and Lewis, J., Sr. 1989. *Dangerous Properties of Industrial Materials*. New York, New York: Van Nostrand Reinhold.

3. Clayton, G.D.; and Clayton, F.E., Editors. 1981. *Patty's Industrial Hygiene and Toxicology. Third Revised Edition. Volume 2A: Toxicology*. New York, New York: John Wiley & Sons, Inc.

4. Mølhave, L. 1982. "Indoor Air Pollution Due to Organic Gases and Vapours of Solvents in Building Materials." *Environ Int.* 8:117-127.

APPENDIX F: Sample Language for Contract Documents

Following is a sample of contract language used by the USEPA for their New Headquarters Project to specify indoor air quality requirements for office furniture systems. This contract does **not** represent official USEPA policy and it was developed for their New Headquarters furniture contract **only**. The contract language was developed with the cooperation of several furniture manufactures. Several manufacturers responded to the document when it was sent out for bid, and a furniture manufacturer was selected. Only the manufacturer that was selected was required to provide the information specified in this contract. We caution readers that the expense of the emissions testing specified in this sample contract is considerable (in the case of the USEPA contract this cost was about $20,000) and that only a limited number of laboratories are capable of performing it. In addition, no standard testing methods exist for contacting chamber tests, quantifying TVOCs, or for specifying duration of a test. This document does not endorse or oppose the language listed below. Lettering and numbering of the text is that of the original document.

APPENDIX B:

EMISSIONS TESTING REQUIREMENTS - EPA's NEW HEADQUARTERS PROJECT: FURNITURE PROCUREMENT

I. INTRODUCTION

EPA is committed to providing their employees with a healthful, productive workplace. Providing good indoor air quality is central component of this commitment. Good indoor air quality is influenced by several integral factors:

1. *Good HVAC system design/construction/maintenance*
2. *Adequate ventilation with fresh air*
3. *Adequate filtration*
4. *Appropriate management of construction/remodeling work*
5. *Source management*

The careful selection of materials is an important component of any source management strategy. Evaluating Volatile Organic Compound (VOC) emissions can improve building material/furnishing decision making.

II. EMISSION TESTING

There are no federal regulations governing VOC emissions from building materials. However, product manufacturers have begun to focus on limiting emissions of selected chemicals and have established testing programs for their products. Guidance for small chamber testing has been established (ASTM D 5116-90) and is being used by a number of product manufacturers to test their products in chambers.

In addition, the State of Washington in 1990 established emissions testing requirements for vendors interested in bidding on the State's furniture contract. This procurement required independent large chamber testing of an entire system under standardized test conditions. Emission levels for TVOC's, formaldehyde and particulates were measured.

EPA's New Headquarters Project intends to establish an environmental large chamber testing protocol for emissions testing of workstations to be procured under this contract. A brief outline of the anticipated requirements is included below for your information.

IIIA. ***EPA's NEW HEADQUARTERS PROJECT SPECIFICATIONS FOR SYSTEMS FURNITURE***

The EPA New Headquarters Project intends to establish emission standards for all workstations to be included under this contract. Testing protocols will be identified which will allow for standardized large chamber testing of a single composite workstation. This workstation is not a prototype for this procurement. It will include typical componentry to be used in a number of workstations which are being standardized to meet EPA's specific New Headquarters requirements. Testing for the following parameters will be undertaken:

- *TVOC's*[1] — *<0.5 mg/m^3*
- *Formaldehyde* — *<0.05 ppm*
- *Total Aldehydes* — *<0.1 ppm*
- *4-PC (as an odorant)* — *below the limits of detection*[2]

[1]*NOTE: TVOC's represents the sum of volatile organic compounds (VOC's) that can be analyzed and measured by the specified analytical method, and are calibrated referenced to toluene (by introducing known quantities of toluene onto a sorbent trap and introducing it into the analytical system exactly as a sample analysis would be).*

[2]*NOTE: The limit of detection is defined as the amount of the material (analyte) that can be distinguished from background, i.e., below the limits of detection means less than the quantitation limit of the analytical technique.*

IIIB. In addition, and subsequent to this testing, EPA reserves the right to undertake small chamber testing, in accordance with ASTM D 5116-90, for items such as panel fabric (which could change over the period of the contract) and other components including new items which become available during the period of the contract.

IIIC. EPA also reserves the right to undertake discretionary testing of complete workstations at their own cost throughout the period of the contract. This is intended to ensure that the selected vendor's product continues to meet the established test standard. Should testing described in IIIB and IIIC produce results which exceed the accepted emissions standards, the vendor will be responsible for correction of the problem at his own cost.

IV. ***TEST PROTOCOLS***

Environmental large chamber test protocols will use selected conditions representative of anticipated conditions at the new EPA headquarters complex. They will include the ventilation rate (ACH), product loading (m^2/m^3), (product loading is the ratio of the test specimen area to the chamber volume), humidity, and temperature. The environmental chamber testing will be conducted to the extent practicable in accordance with the guidance established for small chamber environmental testing (ASTM D 5116-90) and any up-dates to that document in place at the test date, together with modifications necessary to meet the requirements of large chamber testing.

Vendors who choose to submit a proposal for the forthcoming RFP, will be responsible for submitting the composite workstation components to the selected laboratory. Packaging of the componentry must be in accordance with the established protocol, details of which will be available to interested vendors. Schedule for delivery will be strictly enforced to ensure that the workstation components come directly from manufacturer's production line to the laboratory holding area, where they will be allowed to acclimatize for 24 hours prior to being assembled in the test chamber.

V. *DURATION OF TEST & DOCUMENTATION*

EPA believes that essential information can be gained by testing this composite workstation under the controlled conditions noted above for a maximum of seven days (168 hours). This period of time will allow for the identification of TVOCs, formaldehyde, total aldehydes, and 4-PC.

During this period sample collection for analysis of TVOCs, formaldehyde, total aldehydes and 4-PC will be made, starting at one hour after installation and continued at pre-determined intervals throughout the 168 hours of the test period.

Sample collection will be fully documented by lab personnel. A representative from the manufacturer may be present at the sample collection if desired.

VI. *COSTS*

All costs associated with the testing of the workstation will be borne by the manufacturer. (with the exception of any possible tests conducted by the EPA as noted above in section IIIC.) The costs include, but are not limited to, packaging of the componentry, transportation, assembly, all costs associated with laboratory procedures and lab time, disassembly, and transportation back to manufacturer.

Note: It is anticipated that laboratory costs will be substantially lessened due to the reduction in time from the more typical thirty-nine (39) days test period to seven (7) days. However, no cost data are available at the moment.

VII. *COMPOSITE WORKSTATION*

A Plan and an axonometric drawing of the composite workstation for the EPA procurement are included, together with a list of typical components required for the workstation (See Appendix C). All manufacturers wishing to submit an RFP in response to the forthcoming solicitation must be prepared to deliver a workstation for testing which meets these basic requirements. Only minor variations in dimensions and scope will be accepted. The workstaion will remain the property of each manufacturer, and can be returned at vendor's expense on completion of the testing.

APPENDIX D:

ENVIRONMENTAL CHAMBER TESTING FOR FURNITURE, QUALITY ASSURANCE EMISSIONS TESTING PROCEDURES - EPA's New Headquarters Project

PART 1 - GENERAL

1.0 WORK INCLUDED

An indoor pollutant source management plan which will provide assurance that minimum pollutant emission rate standards for components and finish materials are met by applying uniform testing controls and procedures.

2.0 PRODUCT(S) INCLUDED

Product shall include a single, easily assembled, composite workstation, incorporating panels, components and related modular units, as developed for this protocol and which meets the requirements of EPA's New Headquarters Project. See Appendix C of the Requote for workstation layout and itemized list of componentry.

Fabric(s) shall be excluded from this testing procedure, and may be tested separately in accordance with ASTM Standard D5116-90.

PART 2 - PROTOCOL FOR SHIPPING FURNITURE TO CHAMBER TESTING LABORATORIES

3.0 SELECTION PROCESS

The furniture selected for testing should be taken directly off the production line. It should be representative of and treated no differently (including temperature and air flow) from other similar types of furniture. The furniture should be randomly selected. Neither the first nor the last piece in a production batch should be selected. The furniture should not be selected based on any physical attribute that distinguishes it from the other furniture in the batch. The furniture will be selected in the presence of an EPA official or his or her representative.

3.1 PACKAGE PROTOCOL

The furniture should be shrink-wrapped directly off the production line, consistent with the Manufacturer's standard practice. An unused sample of the packing material must be included with each shipment.

3.2 SHIPPING & LABELING

The furniture should be shipped to arrive at the chamber testing laboratory within 48 hours of manufacture. Each piece should be labeled (see example below) with the date, and time of manufacture and shipping to enable the testing laboratory to place the furniture in the chamber at the appropriate time.

SAMPLE FURNITURE LABEL

Date and Time of Manufacture:
Date and Time of Shipping:
Shipping Company:
Furniture Company:
Furniture Description (e.g., Make and Model):
Signature of Furniture Company Employee:

Because the workstation must be placed in the chamber within 48 hours of arrival at the chamber testing laboratory, the manufacturer should coordinate the schedule for arrival of all pieces of the workstation with the chamber testing laboratory.

PART 3 - EXECUTION

4.0 TARGET POLLUTANT EMISSION RATES

The target emission standards are defined as those "emission rates" of pollutants emanating from the product of concern which will not produce building air concentrations greater than the following:

(a)	*Formaldehyde*	*< 0.05 ppm*
(b)	*TVOC's*	*< 0.5 mg/m*^{3}
(c)	*Total Aldehydes*	*< 0.1 ppm*
(d)	*4-PC (as an odorant)*	*below the limits of detection*

The pollutant specification compliance is based on an outside air rate of 1.0 A.C.H. The loading rate is 1 full workstation per 25.7 m^3*. A workstation is defined in 2.0 above.*

5.0 TEST PROTOCOLS

The environmental chamber testing will be conducted to the extent practicable in accordance with the guidelines established for small chamber environmental testing (ASTM D 5116-90) and any updates to that document in place at the test date, together with modifications necessary to meet the requirements of large chamber environmental testing.

All data shall be made available for review by EPA's New Headquarters planning staff and their consultants.

Specific requirements for this protocol include, but are not limited to the following parameters, in addition to those noted above.

(a) *The tests shall be conducted in a chamber capable of accommodating the entire workstation as specified by EPA (See Appendix C). The range of chamber sizes which may be used is 21 to 29 m^3. The volume of air that flows through the chamber will be at a constant volume of 25.7 m^3/hr.*

(b) *The environmental chamber will be constructed of inert, smooth surfaces such as stainless steel or glass and will assure that formaldehyde at the level of 0.05 ppm and representative volatile organics at the level of 10 ug/m^3 are not irreversibly retained on the interior of the surfaces. Quality control data must be submitted showing that recovery rates of 85-115% are possible for formaldehyde, toluene, and decane at these levels, as per the recoveries specified by the analytical method.*

(c) *The air within the chamber will be free of any obstructions or contamination such as internally mounted fan(s), humidifiers, or refrigeration coils. A fan with an external mounting may be used to keep the chamber air well mixed. The internal air will only come in contact with inert chamber walls, a fan with an external mounting, the air diffusion system and sampling ports.*

(d) *Internal air velocity within the chamber will be reproducibly maintained at a level in the range of 0.05 to 0.1 m/sec. (10 to 20 fpm).*

(e) *Internal chamber air will be well mixed and comply with 5% of the theoretical well-mixed model.*

(f) *Clean air will be generated and used as the supply air to the chamber. It is necessary that the supply air backgrounds be sufficiently low to achieve statistically meaningful analytical measurements at the level anticipated. Purified air will be supplied to the chamber with background concentrations not exceeding 0.002 ppm formaldehyde, and 2 ug/m^3 of total volatile organics with no individual organic exceeding this level. The ambient air (background) in the chamber should also not exceed these levels. Using gas chromatographic thermal desorption/mass spectrometric technique, the ambient air in the chamber will be sampled just prior to loading.*

(g) *The chamber operation will be maintained with strict and reproducible operating parameters of 1.0 $\pm$ 0.05 A.C.H., 25^o $\pm$ 2^o C and 50% $\pm$ 5% relative humidity. These parameters shall be monitored continuously throughout the test, and shall be included in the final report.*

(h) *The chamber will be operated under slight positive pressure relative to atmospheric pressure.*

(i) *The test protocol will include evaluation of pollutant emissions over a nominal one (1) week, 7 day period ($\pm$ four (4) hours) to allow for mathematical modeling of the product emission profiles over time. Operational and QC procedures will be adequate to maintain sample integrity over the entire test period.*

(j) *Off-the-line products (workstation components) are to arrive at the testing laboratory with 48 hours of the testing date. The materials are to remain in their packaged state until immediately prior to loading into the environmental chamber. (The product selection, packaging, and shipping protocols are described in Part 2, items 3.0-3.2.) The components are to be unpacked immediately prior to assembly and set-up in the environmental chamber. Care must be taken during assembly by the installers, in concert with the laboratory personnel, not to introduce any contamination into the chamber. The testing facility must have a QC procedure to minimize this concern. Testing of the pollutant levels must begin following one (1) hour of complete installation and enclosure in the environmental chamber.*

(k) *Emission rates are to be determined from the environmental chamber measurements.*

(l) *Dynamic analytical measurements will be made using methods sensitive and reproducible at the level in the low ppb range and other volatile organics. Appropriate standard and recovery data will be obtained for the classes of compounds and the concentration ranges found to substantiate the accuracy and precision of the analytical methods used.*

(m) *Analysis of air samples for formaldehyde, TVOC's (total volatile organic compounds), total aldehydes, and 4 phenycyclohexene are to be reported separately.*

(n) *Quality control data on the chamber operational parameters as mentioned in Section 5.0, Test Protocols, items (a) through (f) above must be submitted with the final analytical data, as well as supporting documentation for the accuracy and precision of the analytical measurements. A statistically valid number of analytical measurements must be made for interpretative reasons, and external quality control audits must be incorporated into the overall measurements program.*

5.1 SAMPLE COLLECTION AND ANALYSIS

(a) *Timing for sample collection for analysis for formaldehyde, TVOC's, total aldehydes and 4-PC; 1 hour after workstation assembly and enclosure in the chamber, and then at 4, 24, 72, 120, and 168 hours thereafter.*

(b) *Air samples are to be analyzed and measured utilizing the specified analytic method and are to be calibrated referenced to toluene or other suitable analytical standards. (Air samples to be collected on multi-sorbent trap and analyzed by gas-chromatography-mass spectroscopy.)*

5.2 AIR EXCHANGE RATE

Air exchange rate in chamber: 1.0 air changes per hour (ACH) of clean air for a 25.7 m^3 *chamber, or an equivalent ACH for a different size chamber (see Section 5.0, Test Protocols, item (a) for acceptable sizes). Air flow through chamber: use a one-pass system using clean purified air as referenced in 5.0 (f).*

5.3 AIR VELOCITY

Air velocity within the chamber will simulate the building environment. Velocity as described in 5.0 (d) is required and must be verified upon completion of chamber test. Mixing shall be provided for by careful location of inlets and outlets for air supply and circulation. The report or the tests shall include a description of the airflow in the chamber. The report or the tests shall include a distribution of the air flow in the chamber and the determination of distribution patterns, mixing and local velocity at the surfaces of the test specimen. Local velocity shall be measured 1 cm. from specimen surfaces at no less than five representative locations.

5.4 QUALITY ASSURANCE/QUALITY CONTROL

Report of test must include complete description of the test system, analysis and results. All Quality Assurance/Quality Control (QA/QC) procedures must be reported.

5.5 REPRESENTATION AT TESTING LABORATORY

As its own cost, the manufacturer may choose to have a company representative present during the sample collection and analysis. This will be an observatory role. All work connected with the testing will be handled by lab personnel.

PART 4 - ADDITIONAL TESTING

6.0 MANUFACTURER RESPONSIBILITY

If, after installation of the product, a strong odor is detected, EPA may request a random sample/component of the workstation be retested. The manufacturer shall bear responsibility for retesting the suspect component in an appropriately sized chamber test to verify the system meets the emissions testing requirements for EPA's New Headquarters Project. If the suspect component does not meet the specified requirements, the Manufacturer shall replace the component throughout with one which does meet the emissions testing requirements for EPA's New Headquarters Project, at no cost to EPA.

6.1 EPA's TESTING OPTION

At any time during the manufacture of componentry designated for the new EPA Headquarters Project, and/or during installation or thereafter, EPA reserved the right to undertake discretionary testing of individual components and/or a complete workstation (excluding fabric) at their own cost. Should such testing produce results which exceed the accepted emission standards as established by this protocol, the manufacturer shall be responsible for replacing the components or workstations throughout the project with replacement(s) which meet the emissions testing requirements for EPA's New Headquarters Project, at no cost to EPA.

ENVIRONMENTAL CHAMBER TESTING FOR FURNITURE - EPA's New Headquarters Project

ADDENDUM TO REQUOTE: SYSTEMS FURNITURE

Ref: Appendices B, C, and D

Attached, please find the name, address, and contact personnel together with fax and telephone numbers for the three (3) testing laboratories EPA has identified as acceptable for the independent large chamber testing of vendors' systems furniture. The systems furniture will include all items described in Appendix C together with essential hardware, etc., necessary to assemble the composite workstation. Testing will be undertaken in accordance with the protocol outlined in Appendix D of the Requote.

Please note that the time allowed for shipping the furniture from the factory to the testing laboratory is 48 hours. However, the holding time at the laboratory, prior to assembly in the test chamber has been increased from 24 hours (as described in Appendix B) to 48 hours.

Vendors may select any of the three laboratories listed. Other independent laboratories may also be acceptable to EPA. Should a vendor wish to utilize a laboratory other than those listed, the name, contact person, and telephone number should be submitted in writing to Mr. Jeffrey L. Davidson at EPA's Safety, Health and Environmental Management Division for approval prior to proceeding with any such arrangements.

The tentative schedule for testing the systems furniture has been set for mid-November, 1995. However, final arrangements will have to be made by the vendor(s) after the technical and cost review process is complete, and an actual date can be established for the total testing process.

APPENDIX G: Survey of Testing Methods for VOCs

Several standard guides, practices, and methods exist for testing building materials. In addition, a number of proposed standards and guidelines are being considered both in the United States (under the direction of the ASTM) and in Europe [under the framework of the European Collaborative Action (ECA): Indoor Air Quality and its Impact on Man].

G1 American Society for Testing and Materials (ASTM)

a) ASTM D 3960 - 93: *Standard Practice for Determining Volatile Organic Compound Content of Paints and Related Coatings*;

b) ASTM D 5116 - 90: *Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products*;

c) ASTM E 1333 - 90: *Standard Test Method for Determining Formaldehyde Levels from Pressed Wood Products Under Defined Test Conditions Using a Large Chamber*; and

d) ASTM D 3614 - 90: *Guide for Laboratories Engaged in Sampling and Analysis of Atmospheres and Emissions*.

G2 Canadian General Standards Board (CGSB)

CAN/CGSB-51.23-92: *Spray-applied rigid polyurethane cellular thermal insulation*.

G3 Commission of the European Community (CEC)

a) EUR 13593-1991: *Guideline for the Characterization of Volatile Organic Compounds Emitted from Indoor Materials and Products Using Small Test Chambers*; and

b) EUR 12196-1989: *Formaldehyde Emission from Wood Based Materials: Guideline for the Establishment of Steady State Concentrations in Test Chambers*.

G4 Nordic Countries: Nordtest Methods (NT)

NT Build 358: *Building Materials: Emissions of Volatile Compounds, Field and Laboratory Emission Cell (FLEC)*. This method is also described in Wolkoff et al. (1991) and Gustafsson and Jonsson (1993),

G5 Swedish National Testing and Research Institute and Swedish National Flooring Trade Association

The standards listed below are described in Gustafsson and Jonsson (1993):

a) *Trade Standard: Measurement of Chemical Emission from Flooring Materials*; and

b) *Trade Standard: Measurement of Chemical Emission from Smoothing Compounds*.

APPENDIX H: California Regulations for Architectural Coatings and Consumer Products

In California, architects, contractors, building owners and managers must comply with three product-related regulatory programs when building, renovating, and maintaining buildings. These programs effectively limit emissions of reactive organic gases from architectural coatings and consumer products. Reactive organic gases are VOCs that are photochemically reactive and contribute to the formation of ground level ozone (smog). (The complete definition of reactive VOCs is shown in the glossary at the end of this document.) These programs are important components of the California Air Resources Board's (CARB's) mission to protect public health from the adverse effects of air pollutants.

Architectural coatings regulations limit VOC content in coatings such as paints, varnishes, and wood preservatives. These regulations have been adopted by a number of local air pollution control districts (APCDs) and air quality management districts (AQMDs) in California, with oversight by the CARB. Two other regulations limit VOC content in products sold throughout California, and are managed by the CARB: (a) the Aerosol Coatings Products Regulation limits VOC emissions in a variety of aerosol coating products such as aerosol paints, wood stains, and clear coating products; and (b) the Consumer Products Regulation limits VOC content in several types of consumer products, which include both household products and certain products commonly used in institutional and industrial maintenance or operations. A side benefit of these regulations may be reduced VOC levels in indoor air when regulated products are used inside building structures.

H1 Architectural Coatings

Architectural coatings are coatings applied to stationary structures and their appurtenances, to mobile homes, to pavements, or to curbs. These products include both water-based and solvent-based coatings such as flat or higher gloss paints, lacquers, varnishes, metallic pigmented coatings, primers, sealers, concrete curing compounds, and below ground wood preservatives. Architectural coatings are a source of VOC emissions to both indoor and outdoor environments.

Architectural coatings in many regions of California now have lower VOC contents than coatings that are available in other parts of the United States. In 1989, the CARB developed a suggested control measure (SCM) on architectural coatings for possible adoption by the APCDs and AQMDs (ARB-CAPCOA, 1989). The SCM, which was based primarily on previous model rules, presents proposed standards stipulating the allowable content, by weight, of total VOCs for each type of coating (see Table H1). Regulations based on the SCM and previous model rules have been adopted by 16 of the 34 districts in California.

In districts where there is an architectural coatings regulation, it is illegal to solicit the use of, or to sell, non-complying coatings. For example, clients in districts where architectural coating rules have been adopted may not request the use of non-complying coatings by their architect, contractor, or building manager. Before selecting products to be used in building or renovating a particular building, architects, contractors, and building managers should consult the local APCD or AQMD if they have any questions about compliance with local architectural coating regulations (see Section K6 of Appendix K for a list of California's air pollution control districts). In particular, contractors and others should check with the local APCD or AQMD if they are purchasing coating supplies from outside the district in which the building project is located.

Based on 1990 data, the CARB estimates that 39,100 tons of VOCs are released into the air each year from architectural coatings (CARB, 1994b). Although about three-quarters of all coating sales in California are water-based paints, solvent-based coatings produce more than twice the amount of VOC emissions as water-based coatings. Solvent-based coatings produce an estimated 26,181 tons of VOCs per year. The CARB estimates that adoption of the SCM by the districts would achieve a reduction of 4,841 to 7,887 tons of VOCs per year from solvent-based coatings (CARB, 1994b).

H2 Aerosol Paints

Aerosol coating products such as paints, stains, and clear coatings packaged in disposable cans emit a significant amount of VOCs to the air during use. The CARB estimates that 30 tons of VOCs per day are emitted to the air from these products (CARB, 1995a). The CARB is required by Section 41712 of the California Health and Safety Code to develop regulations controlling emissions of VOCs from aerosol coating products.

The CARB adopted a regulation, which became effective on January 8, 1996, that reduces VOC content in aerosol coating products. This regulation sets VOC standards for a variety of aerosol paint products, such as flat and glossy paints, primers, metallic coatings, wood stains, clear coatings, and other coatings (CARB, 1995a). There are two tiers of this regulation, the first effective January 8, 1996, and the second effective December 31, 1999. By each effective date, manufacturers must produce aerosol products for sale in California that comply with maximum allowable VOC content limits (see Table H2). Suppliers may continue to sell the older non-complying aerosol products for 18 months after each effective date.

CARB staff projected a 12 percent reduction (about a 3 tons per day reduction) in VOC emissions from the adoption of the first tier of this regulation (CARB, 1995a). However, the recent exemption of acetone as a reactive VOC has significantly reduced this estimate. CARB staff project reductions of about 60 percent (about an 18 tons per day reduction) when the second tier standards become effective (ibid). This regulation is effective statewide, with the exception of the Bay Area Air Quality Management District (BAAQMD), which adopted an aerosol paint rule in 1990.

H3 Consumer Products

The CARB adopted a regulation to limit the amount of VOCs in selected consumer product categories in 1990 (Phase I), and amended the regulation to include additional products in 1992 (Phase II). These categories include detergents, cleaning compounds, polishes, floor finishes, disinfectants, sanitizers, and certain insecticides that are likely to be used in building cleaning and maintenance activities before and after construction. Such products sold in California must adhere to the maximum allowable VOC limits shown in Table H3.

For further information on regulations pertaining to architectural coatings, aerosol coating products, and consumer products, interested parties may call the CARB at (916) 322-2990.

H4 References

Section K8.3 of Appendix K lists all the publications referenced here and presents a brief summary of the contents of each publication. Exact citations are also provided in the References section at the end of this document.

Table H1. Selected Architectural Coating Standards [α] From California's Suggested Control Measure (ARB-CAPCOA, 1989)		
Coating Category		**Maximum Allowable Grams of Reactive VOCs per Liter**
Below ground wood preservatives		350
Bond breakers		350
Clear wood finishes	Lacquer	680
	Sanding sealers	350
	Varnish	350
Concrete curing compounds		350
Dry fog coatings		400
Fire-retardant coatings	Clear	650
	Pigmented	350
Form-release compounds		250
Graphic arts (sign) coatings		500
Magnesite cement coatings		450
Mastic texture coatings		300
Metallic pigmented coatings		500
Multi-color coatings		420
Opaque stains		350
Opaque wood preservatives		350
Pre-treatment wash primers		420
Primers, sealers and undercoaters		350
Semi-transparent stains		350
Semi-transparent and clear wood preservatives		350
Shellac	Clear	730
	Pigmented	550
Waterproofing sealers		400

[α] This is a partial listing of standards presented in *ARB-CAPCOA Suggested Control Measure for Architectural Coatings* (ARB-CAPCOA, 1989). The suggested control measure is a model rule developed by the CARB. Each district may adopt all, part, or none of these standards, or may adopt different rules. The reader is encouraged to consult with their local air pollution control districts for specific architectural coating standards.

Table H2. Selected Aerosol Coating Standards [α] in California (CARB, 1995b)				
Aerosol Coating Category			Maximum Allowable Percent of Reactive VOCs by Weight	
			Effective 1/8/96	Effective 12/31/99
General coatings	Clear coatings		67	40
	Flat paint products		60	30
	Fluorescent coatings		75	45
	Metallic coatings		80	50
	Nonflat paint products		65	30
	Primers		60	30
Specialty Coatings	Glass coatings		95	80
	Shellac Sealers	Clear	88	70
		Pigmented	75	60
	Slip-resistant coatings		80	70
	Spatter/Multicolor coatings		80	60
	Vinyl/fabric/leather/ polycarbonates		95	70
	Webbing/veil coatings		90	70
	Weld-through primers		75	60
	Wood stains		95	75
	Wood touch-up/repair/restoration		95	75

[α] Adopted January 8, 1996 with the exception of the Bay Area Air Quality Management District which adopted a similar rule in 1990.

Table H3. Selected Consumer Product Standards in California (CARB, 1993a)			
Product Category		Percent of Reactive VOCs by Weight	
		Current [α]	Future
Air Fresheners	Single phase aerosols	30	
	Double phase aerosols	30	
	Liquids/pump sprays	18	
	Solids/gels	3	
	Dual purpose air fresheners/disinfectant aerosols	60	
Bathroom & Tile Cleaners	Aerosols	7	
	All other forms	5	
Floor Polishes/Waxes	Products for flexible flooring materials	7	
	Products for nonresilient flooring	10	
	Wood floor wax	90	
Furniture Maintenance Products	Aerosols	25	
	All other forms except solid or paste forms	7	
General purpose cleaners		10	
Glass Cleaners	Aerosols	12	
	All other forms	6	
Dusting Aids	Aerosol	35	25 (1/1/97)
	All other forms	7	
Fabric protectants		75	60 (1/1/97)
Household Adhesives	Aerosol	75	25 (1/1/97)
	Contact	80	
	Construction & panel	40	
	General purpose	10	
Insecticides	Crawling bug	40	20 (1/1/98)
	Flying bug	35	
	Foggers	45	

[α] As of 5/31/96

APPENDIX I: Estimating Indoor Concentrations From Emission Factors

I1 Using Mass Balance Equations to Predict Indoor VOC Concentrations

In theory, prediction of pollutant concentrations in indoor environments using mathematical models has an attractive advantage: estimations of occupant exposure to various indoor pollutants can be made prior to building construction and based on emission data of the building materials, building ventilation rates, and the sink effects of some of these materials. In addition, the effectiveness of various control strategies, such as increased ventilation, can be estimated and their costs justified to building owners at least based on simple theoretical terms.

In practice, the use of such models is problematic. Mathematical models are based on mass balance equations for each pollutant. A mass balance equation simply states that the rate of change of the mass of a pollutant in an indoor environment is equal to the difference between the pollutant mass entering the indoor environment and the total pollutant mass exiting that environment. However, the mass balance modeling approach is complicated because all terms of a mass balance equation are time and space dependent. For example, the VOC emission rate of a building material may vary with time; indoor VOC concentrations may not be distributed uniformly throughout a building; airflow rates into a building or a space may vary with time, such as in the case of VAV systems; and the removal rate of VOCs may vary with time, such as in the case of a porous surface with its absorptivity varying according to the amount of pollutant load. It is beyond the scope of the guidelines presented in this document to discuss complex mathematical models. Instead, the interested reader is referred to: (a) the USEPA Indoor Air Quality Model as described in Sparks et al. (1989, 1991), Sparks and Tucker (1990), and Owen et al. (1989); and to the NSIT model as described in Walton (1994).

Simple equations can be derived from complex mass balance models after a number of assumptions are made. These simple equations can be used for estimating ranges of VOC concentrations. Such assumptions include:

a) VOC emission rates are constant;

b) airflow rates do not vary with time;

c) there are no VOC removal mechanisms other than ventilation (i.e., no filtration, no adsorption onto surfaces, and no chemical decomposition); and

d) perfect mixing.

I1.1 A Simplified Mass Balance Equation for Calculating Indoor VOC Concentrations

One of the simplest forms of a mass balance equation is the steady-state equation. A steady-state equation is applicable only when the concentration of a pollutant in an indoor environment has reached steady-state conditions (i.e., concentrations are no longer time dependent). Nielsen et al. (1994) recommended the following first order mass-balance equation for calculating indoor concentrations of VOCs emitted from building materials and products:

$$C_{ss} = \frac{EF \cdot A}{N \cdot V} \qquad \text{(I1)}$$

where:

C_{ss} = calculated equilibrium concentration of a chemical compound in the indoor air ($\mu g/m^3$)
N = air change rate, (ACH or 1/h)
V = volume of the indoor environment (m^3)
EF = emission factor of the chemical compound from the material or product ($\mu g/m^2 \cdot hr$)
A = area of the material or product in the indoor environment (m^2).

The ratio A/V is termed a material's **loading factor or ratio**. The loading factor can be calculated using Equation I2.

$$L = \frac{A_m}{A_f \cdot H} \qquad \text{(I2)}$$

where:

L = loading factor (m^2/m^3)
A_m = area of installed material (m^2)
A_f = floor area of indoor space where material is installed (m^2)
H = ceiling height of indoor space where material is installed (m)

Equation I1 can be rewritten using the above definition of the loading factor:

$$C_{ss} = \frac{EF}{N} \cdot L \qquad \text{(I3)}$$

Equation I3 simply states that the indoor concentration of a given chemical compound is equal to its source strength (expressed in $\mu g/m^2 \cdot hr$) multiplied by the loading factor of the material emitting the chemical compound (expressed in m^2/m^3), and divided by the building ventilation rate (expressed in 1/hr).

Equation I3 can be used to estimate indoor concentrations of VOCs based on emission factors of building materials and products, loading factors, and building ventilation rates. The estimated indoor concentrations can be used to select building materials and products by comparing these concentrations to the guidelines listed in Appendix E. Calculation of indoor concentrations of VOCs is made only for the purpose of selecting building materials and products and not for precise prediction of indoor concentrations after a building has been constructed. This is because some of the assumptions associated with the steady-state equation do not hold true in the "real" world.

When comparing calculated VOC concentrations with health-based VOC guidelines, it is important to recognize that emission factors of installed materials may be different from the factors measured in chamber tests due to differences in environmental conditions, manufacturing processes, or age.

I2 Examples of Application of the Steady-State Equation

The following examples illustrate the application of Equation I3 in estimating indoor concentrations from emission factors.

I2.1 Example 1: Application of the Steady-State Equation in the Selection of a Carpet

Carpets are considered "dry" products emitting VOCs at moderate to low rates for weeks or months after manufacturing and installation.

Table I1 lists TVOC emissions factors for four carpet samples.

Table I1. TVOC Emission Factors Of Four Carpet Samples ($\mu g/m^2 \cdot hr$) [α]

Carpet	Description of Backing			Age [β]	TVOC Emission Factor ($\mu g/m^2 \cdot hr$)	
	Primary	Secondary	Adhesive		24 hr	168 hr
1a	Polypropylene	Polypropylene	SBS latex	2 wks	213	71
1b	Polypropylene	Polypropylene	SBS latex	5 wks	178	51
2	Polypropylene	Polyurethane	not specified by the manufacturer	2 wks	83	33
3	Polypropylene	Polyvinyl chloride	not specified by the manufacturer	3 wks	602	192
4	Polypropylene	Polypropylene	SBR latex	2 wks	399	94

[α] Reference: Hodgson et al. (1993).

[β] Storage age (i.e., not installed age); samples were kept in Tedlar® bags from the time of manufacture until they were tested; decreases in emissions during storage were minimal.

The CRI's maximum allowable TVOC emission factor for carpets is currently 500 $\mu g/m^2 \cdot hr$ at 24 hr after manufacture (see Appendix C). In addition as shown in Table E1 (Appendix E), Tucker's maximum emission factor for flooring materials is 600 $\mu g/m^2 \cdot hr$. All carpet samples meet the recommended factors except for Carpet Sample 3 at 24 hr. However, the reader is reminded that: (a) TVOC measurements have high uncertainties due to variations in the mixture of compounds; and (b) there can be differences of two or more times in TVOC results depending on the measurement and analysis methods.

To calculate TVOC concentrations, we first assume 100 percent floor area coverage (i.e., $A_m = A_f$) and a ceiling height of 2.5 m ($\sim$8 ft). Then from Equation I2, we calculate the loading factor to be 0.4 m^2/m^3. Using Equation I3, we can calculate the resulting C_{ss} for various ventilation rates. Table I2 shows the results of these calculations.

The above calculated TVOC concentrations can be compared to those listed in Appendix E (Section E1). If we consider the State of Washington's (Section E1.3) TVOC guideline of 500 $\mu g/m^3$ and assume that no adhesive or padding will be used during carpet installation, then we conclude that all carpet samples meet this recommendation with Carpet Sample 2 having the lowest TVOC concentrations. It is noted that the indoor TVOC concentration of Carpet Sample 3 at 24 hr and at the low ventilation rate (i.e., 0.5 ACH) is only slightly below this recommendation. However increasing the ventilation rate to 1.0 ACH lowers this concentration by 50%.

Table I2. Calculated Indoor TVOC Concentrations ($\mu g/m^3$) of Four Carpet Samples Based on a Loading Factor of 0.4 m^2/m^3						
Carpet	ACH = 0.5		ACH = 1.0		ACH = 4.0	
	24 hr	168 hr	24 hr	168 hr	24 hr	168 hr
1a	170	57	85	28	21	7.1
1b	140	41	71	20	18	5.1
2	66	26	33	13	8.3	3.3
3	480	150	240	77	60	19
4	320	75	160	38	40	9.4

The above example illustrates the following:

a) the lower the TVOC emission factors the lower the indoor TVOC concentrations; and

b) increased ventilation rates result in decreased estimated indoor TVOC concentrations.

I2.2 Example 2: Application of the Steady-State Equation in the Selection of a Carpet Adhesive

Adhesives are considered "wet" products that typically emit solvents and other chemicals at relatively high rates for a few hours or days after installation.

Table I3 lists emissions data for three different carpet adhesives tested at 24 and 144 hr (i.e., six days) in an environmental chamber. Note that the adhesives were tested individually and not as part of a complete carpet system consisting of carpet, cushion, glue, etc. Adhesives tested individually may not behave the same as in a complete carpet system.

Table I3. TVOC Emission Factors Of Three Adhesives ($\mu g/m^2 \cdot hr$) $^{\alpha}$			
Adhesive	Description	TVOC Emission Factor ($\mu g/m^2 \cdot hr$)	
		24 hr	144 hr
1	Multipurpose latex adhesive	99,000	17,200
2	Multipurpose latex adhesive	76,000	3,950
3	Synthetic, "low-VOC" adhesive	698	76

α Reference: Black et al., 1991b

It is worth noting that although at 24 hr the emission factor of Adhesives 1 and 2 differ only by about 23 percent, at 144 hr their emission factors differ by a factor of four. This observation illustrates the difference in the long-term emission rates of various adhesives and the importance of using long-term emission data for product comparison and selection. It is also worth noting that Adhesive 3 had a 100-

fold lower emission factor than the other two adhesives. If we use Tucker's maximum emission factor of 600 $\mu g/m^2 \cdot hr$ for flooring materials (Table E1 of Appendix E), then we should consider the emission factor of the complete carpet assembly (i.e., carpet and padding). Adhesives 1 and 2 exceed the 600 $\mu g/m^2$ maximum emission factor at 144 hr even without accounting for emissions from the carpet or the padding. Even the low-emitting Adhesive 3 exceeds this maximum at 24 hr, but drops well below it at 144 hr.

Table I4 shows the resulting indoor VOC concentrations calculated using Equation I3 for various ventilation rates.

Table I4. Calculated Indoor TVOC Concentrations ($\mu g/m^3$) of Three Adhesives Based on a Loading Factor of $0.4 m^2/m^3$

Adhesive	ACH = 0.5		ACH = 1.0		ACH = 4.0	
	24 hr	144 hr	24 hr	144 hr	24 hr	144 hr
1	79,000	14,000	40,000	6,900	9,900	1,700
2	61,000	3,200	31,000	1,600	7,600	400
3	560	61	280	30	70	7.6

Using the State of Washington's (Section E1.3 of Appendix E) of 500 $\mu g/m^3$ we conclude that: (a) Adhesives 1 and 2 do not meet this recommendation at ventilation rates of 0.5, 1.0, or 4.0 ACH with the exception of Adhesive 2 at 4.0 ACH and 144 hr; and (b) Adhesive 3 meets this recommendation under all conditions except at 0.5 ACH and 24 hr.

The above example demonstrate again the points outlined at the end of Section I2.1 (Example 1), i.e., that indoor VOC concentrations can be reduced by selecting building materials with low VOC emission rates and by increasing building ventilation rates.

APPENDIX J: California's Minimum Ventilation Standard

California Code of Regulations, Title 8: Industrial Relations, Section 5142:
Mechanically Driven Heating, Ventilating and Air Conditioning (HVAC) Systems to Provide Minimum Ventilation

(a) Operation:

(1) The HVAC system shall be maintained and operated to provide at least the quantity of outdoor air required by the State Building Standards Code, Title 24, Part 2, California Administrative Code, in effect at the time the building permit was issued.

(2) The HVAC system shall be operated continuously during working hours except:

(A) during scheduled maintenance and emergency repairs;

(B) during periods not exceeding a total of 90 hours per calendar year when a serving electric utility by contractual arrangement requests its customers to decrease electrical power demand; or

(C) during periods for which the employer can demonstrate that the quantity of outdoor air supplied by nonmechanical means meets the outdoor air supply rate required by (a)(1) of this section. The employer must have available a record of calculations and/or measurements substantiating that the required outdoor air supply rate is satisfied by infiltration and/or by a nonmechanically driven outdoor air supply system.

(b) Inspection and Maintenance:

(1) The HVAC system shall be inspected at least annually, and problems found during these inspections shall be corrected within a reasonable time.

(2) Inspections and maintenance of the HVAC system shall be documented in writing. The employer shall record the name of the individual(s) inspecting and/or maintaining the system, the date of the inspection and/or maintenance, and the specific findings and actions taken. The employer shall ensure that such records are retained for at least five years.

(3) The employer shall make all records required by this section available for examination and copying, within 48 hours of a request, to any authorized representative of the Division (as defined in Section 3207), to any employee of the employer affected by this section, and to any designated representative of said employee of the employer affected by this section.

NOTE: Authority cited: Section 142.3, Labor Code. Reference: Section 142.3, Labor Code.

HISTORY:

1. New section filed 1-8-87; effective thirtieth day thereafter (Register 87, No. 2). For history of former section, see Register 75, No. 29.

APPENDIX K: Information Resources

K1 Building Management Associations

Association of Physical Plant
Administrators of Universities and
Colleges
1446 Duke Street
Alexandria, VA 22314-3492
(703) 684-1446

Business Council on Indoor Air
2000 L Street, N.W., Suite 730
Washington, DC 20036
(202) 775-5887

Building Owners and Managers
Association
1201 New York Avenue, N.W., Suite 300
Washington, DC 20003
(202) 408-2662

Building Owners and Managers
Association of California
c/o Mr. Les Spahnn
Time - Noack - Kelly - Spahnn
770 L Street - Suite 960
Sacramento, CA 95814
(916) 442-4584

Institute of Real Estate Management
430 North Michigan Avenue
Chicago, IL 60611
(312) 661-1930

International Council of Shopping Centers
1199 North Fairfax Street, Suite 204
Alexandria, VA 22314
(703) 549-7404

International Facilities Management
Association
1 East Greenway Plaza, 11th Floor
Houston, TX 77046
(713) 623-4362

National Apartment Association
1111 14th Street, N.W., Suite 900
Washington, DC 20005
(202) 842-4050

National Association of Industrial
and Office Parks
1215 Jefferson Davis Highway, Suite 100
Arlington, VA 22202
(703) 979-3400

K2 Professional and Standard-Setting Organizations

Air and Waste Management Association (A&WMA)
P. O. Box 2861
Pittsburgh, PA 15230
(412) 232-3444

Air-Conditioning and Refrigeration Institute (ARI)
1501 Wilson Boulevard, Suite 600
Arlington, VA 22209
(703) 524-8800

American Conference of Governmental Industrial Hygienists (ACGIH)
Kemper Woods Center
1330 Kemper Meadow Drive
Cincinnati, OH 45240
(513) 742-2020

American Industrial Hygiene Association (AIHA)
2700 Prospect Avenue, Suite 250
Fairfax, VA 22031
(703) 849-8888

American Institute of Architects (AIA)
1735 New York Avenue, N.W.
Washington, DC 20006
(202) 626-7300

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE)
1791 Tullie Circle, N.E.
Atlanta, GA 30329
(404) 636-8400

American Society for Testing and Materials (ASTM)
Subcommittee D22
1916 Race Street
Philadelphia, PA 19103
(215) 299-5524

American Society of Safety Engineers (ASSE)
1800 E. Oakton Street
Des Plaines, IL 60018-2187
(708) 692-4121

Association of Energy Engineers (AEE)
4025 Pleasantdale Road, Suite 420
Atlanta, GA 30340
(404) 447-5083

National Asbestos Council (NAC)/ The Environmental Information Association
1777 Northeast Expressway, Suite 150
Atlanta, GA 30329
(404) 633-2622

National Conference of States on Building Codes and Standards, Inc. (NCSBCS)
505 Huntmar Park Drive, Suite 210
Herndon, VA 22070
(703) 437-0100

National Society of Professional Engineers (NSPE)
1420 King Street
Alexandria, VA 22314
(703) 684-2810

K3 Product Manufacturers

Adhesive and Sealant Council
1627 K Street, N.W., Suite 1000
Washington, DC 20006
(202) 452-1500

American Plywood Association/
Technical Services Division (APA)
P.O. Box 11700
Tacoma, WA 98411
(206) 565-6600

Asbestos Information Association
1745 Jefferson Davis Highway, Room 509
Arlington, VA 22202
(703) 412-1150

Association of Home Appliance
Manufacturers (AHAM)
20 N. Wacker Drive
Chicago, IL 60606
(312) 984-5800

Association of Wall and Ceiling Industries
307 E. Annandale Road, Suite 200
Falls Church, VA 22042
(703) 534-8300

Carpet Cushion Council
P.O. Box 546
Riverside, CT 06878
(203) 637-1312

Carpet and Rug Institute (CRI)
P.O. Box 2048
Dalton, GA 30722
(706) 278-3176

Chemical Specialties Manufacturers
Association
1913 Eye "I" Street, N.W.
Washington, DC 20006
(202) 872-8110

Foundation of Wall and Ceiling Industries
(FWCI)
307 E. Annandale Road, Suite 200
Falls Church, VA 22042
(703) 534-8300

Gas Appliance Manufacturers Association,
Inc. (GAMA)
1901 North Moore Street, Suite 1100
Arlington, VA 22209
(703) 525-9565

Hardwood Plywood and Veneer
Association
P.O. Box 2789
1825 Michael Faraday Drive
Reston, VA 22090-5350
(703) 435-2900

Lead Industries Association (LIA)
295 Madison Avenue, 19th Floor
New York, NY 10017
(212) 578-4750

Manufactured Housing Institute (MHI)
1745 Jefferson Davis Highway, Suite 511
Arlington, VA 22202
(703) 979-6620

National Air Filtration Association
(NAFA)
1518 K Street, N.W., Suite 503
Washington, DC 20005
(202) 628-5328

National Association of Home Builders
(NAHB)
Indoor Air Quality Committee
1201 15th Street, N.W.
Washington, DC 20005
(202) 822-0200

National Paint and Coatings Association
1500 Rhode Island Avenue, N.W.
Washington, DC 20005-5597
(202) 462-6272

National Particleboard Association
18928 Premiere Court
Gaithersburg, MD 20879
(301) 670-0604

North American Insulation Manufacturers
   Association (NAIMA)
44 Canal Center Plaza, Suite 310
Alexandria, VA 22314
   (703) 684-0474

Sealant, Waterproofing and Restoration
   Institute (SWRI)
3101 Broadway, Suite 585
Kansas City, MO 64111
   (816) 561-8230

Swedish National Flooring Trade
   Association (GBR)
P. O. Box 4604
S11691 Stockholm
Sweden

Synthetic Organic Chemical
   Manufacturers Association
1330 Connecticut Avenue, N.W.,
Suite 300
Washington, DC 20036-1791
   (202) 659-0060

K4 Building Service Associations

American Consulting Engineers Council
1015 15th Street, N.W., Suite 802
Washington, DC 20005
(202) 347-7474

Associated Air Balance Council (AABC)
1518 K Street, N.W., Suite 503
Washington, DC 20005
(202) 737-0202

Association of Specialists in Cleaning and Restoration International
10830 Annapolis Junction Rd., Suite 312
Annapolis Junction, MD 20701
(301) 604-4411

National Air Duct Cleaners Association (NADCA)
1518 K Street, NW, Suite 503
Washington, DC 20005
(202) 737-2926

National Association of Power Engineers
5693 Colombia Pike, Suite 100
Falls Church, VA 22041
(703) 845-7059

National Energy Management Institute
Sacramento Regional Office
4441 Auburn Boulevard, Suite O
Sacramento, CA 95814
Headquarters:
601 North Fairfax Street, Suite 160
Alexandria, VA 22314

National Environmental Balancing Bureau
1385 Piccard Drive
Rockville, MD 20850
(301) 977-3698

National Lead Abatement Council (NLAC)
105 Campus Drive
Princeton, NJ 08543
(609) 520-1133

National Pest Control Association
8100 Oak Street
Dunn Loring, VA 20027
(703) 573-8330

National Roofing Contractors Association
O'Hare International Center
10255 W. Higgins Road, Suite 600
Rosemont, IL 60018-5607

Sheet Metal and Air-Conditioning Contractors National Association
4201 Lafayette Center Drive
Chantilly, VA 22021-1209
(703) 803-2980

U.S. Green Building Council
808 17th St., N.W., Suite 200
Washington, DC 20006
(202) 785-7809

K5 Environmental Health Organizations

American Academy of Allergy and Immunology
611 East Wells Street
Milwaukee, WI 53202
(414) 272-6071

American Academy of Environmental Engineers (AAEE)
130 Holiday Court, #100
Annapolis, MD 21401
(301) 261-8958

American Cancer Society (ACS)/ National Headquarters
1599 Clifton Road, N.E.
Atlanta, GA 30329
(404) 320-3333

American College of Allergy and Immunology
85 W. Algonquin Road, Suite 550
Arlington Heights, IL 60005
(708) 427-1200

American Lung Association
1740 Broadway
New York, NY 10019
(212) 315-8700

American Medical Association (AMA)/Council On Scientific Affairs
535 North State Street
Chicago, IL 60610
(312) 464-5000

American Public Health Association (APHA)
1015 15th Street, N.W., 3rd Floor
Washington, DC 20005
(202) 789-5600

Association of State and Territorial Health Officials (ASTHO)
415 2nd Street, N.E., Suite 200
Washington, DC 20002
(202) 546-5400

Asthma and Allergy Foundation of America
1125 15th Street, N.W., Suite 502
Washington, DC 20005
(202) 466-7643

Coalition On Smoking and Health (CSH)
1150 Connecticut Avenue, N.W., Suite 820
Washington, DC 20036
(202) 452-1184

Environmental Health Network
P. O. Box 1155
Larkspur, CA 94977
(415) 541-5075

National Association of Environmental Professionals (NAEP)
5165 MacArthur Boulevard, N.W.
Washington, DC 20016
(202) 966-1500

National Center for Environmental Health Strategies
1100 Rural Avenue
Voorhees, NJ 08043
(609) 429-5358

National Coalition On Indoor Air Quality (NCIAQ)
1518 K Street, N.W., Suite 503
Washington, DC 20005
(202) 628-5336

National Environmental Development Association/Total Indoor Environmental Quality Coalition (NEDA/TIEQ)
1440 New York Avenue, N.W., Suite 300
Washington, DC 20005
(202) 638-1200

National Environmental Health
Association
720 South Colorado Boulevard
South Tower Suite 970
Denver, CO 80222
(303) 756-9090

National Foundation for the Chemically
Hypersensitive
P. O. Box 9
Wrightsville Beach, NC 28480
(919) 270-9441

National Safety Council (NSC)
1121 Spring Lake Drive
Itasca, IL 60143-3201
(708) 285-1121

Occupational Health Foundation
1126 16th Street, N.W.
Washington, DC 20036
(202) 887-1988 or (202) 842-7840

Public Health Foundation
1220 L Street, N.W., Suite 350
Washington, DC 20005
(202) 898-5600

K6 California Air Pollution Control Districts (as of February 1, 1996)

Amador County APCD
500 Argonaut Lane
Jackson, CA 95642-2310
APCO - Noel Bonderson (209) 223-6406
Inspector - Jim Harris
FAX: (209) 223-6260

Bay Area AQMD
939 Ellis Street
San Francisco, CA 94109

APCO - Milton Feldstein	(415) 771-6000
	749-4970
Deputy APCO - Peter Hess	749-4971
Deputy APCO - Jan Bush	749-4943
Enforcement - Jim Guthrie	749-4792
Fiscal/Admin - Steve Hill	749-4673
Legal - John Powell	749-4920
Permits - John Swanson	749-4735
Tech. Services - Ellen Garvey	749-4730
Plan./Research - Tom Perardi	749-4667
Public Info. - Teresa Lee	749-4900
FAX:	(415) 928-8560

Butte County AQMD
9287 Midway, Suite 1A
Durham, CA 95938
APCO - Larry Olde (916) 891-2882
FAX: (916) 891-2878

Calaveras County APCD
Government Center
891 Mountain Ranch Rd.
San Andreas, CA 95249
APCO - Jearl Howard (209) 754-6404
Deputy APCO - Lakhmir Grewal
FAX: (209) 754-6521

Colusa County APCD
100 Sunrise Blvd. #F
Colusa, CA 95932
APCO - Harry Krug (916) 458-0590
FAX: (916) 458-5000

El Dorado County APCD
2850 Fairlane Ct, Bldg. C
Placerville, CA 95667
APCO - Ron Duncan (916) 621-5300
Program Mgr. - Dennis Otani
(916) 621-6662
FAX: (916) 626-7130

Feather River AQMD
938 14th Street
Marysville, CA 95901
APCO - Ken Corbin (916) 634-7659
FAX: (916) 634-7660

Glenn County APCD
P.O. Box 351 (720 N. Colusa St.)
Willows, CA 95988
APCO - Ed Romano (916) 934-6500
Technical - Kevin Tokunaga,
Rick Steward
FAX: (916) 934-6503

Great Basin Unified APCD
157 Short Street, Suite 6
Bishop, CA 93514
APCO - Dr. Ellen Hardebeck
(619) 872-8211
Deputy APCO - Duane Ono
FAX: (619) 872-6109

Imperial County APCD
150 South 9th Street
El Centro, CA 92243-2801
AQCO - Stephen Birdsall (619) 339-4314
Deputy AQCO - Jeannette Bryant
(619) 339-4606
Deputy AQCO - Gaspar Torres
FAX: (619) 353-9420

Kern County APCD
2700 "M" Street, Suite 290
Bakersfield, CA 93301
APCO - Thomas Paxson, P.E.
(805) 862-5250
FAX: (805) 862-5251

Lake County AQMD
883 Lakeport Blvd.
Lakeport, CA 95453
APCO - Robert L. Reynolds
(707) 263-7000
(707) 263-3225
FAX: (707) 263-0421

Lassen County APCD
175 Russell Avenue
Susanville, CA 96130
APCO - Kenneth R. Smith (916) 251-8110 Ext. 110
FAX: (916) 257-6515

Mariposa County APCD
P.O. Box 2039 (4988 Eleventh St.)
Mariposa, CA 95338
APCO - Ed Johnson (209) 966-5151
FAX: (209) 742-5024

Mendocino County APCD
Courthouse (306 E. Gobi St.)
Ukiah, CA 95482
APCO - David Faulkner (707) 463-4354
FAX: (707) 463-5707

Modoc County APCD
202 West 4th Street
Alturas, CA 96101
APCO - Les Wright (916) 233-6419
Technician - John E. Kelly (916) 667-2713
FAX: (916) 233-5542

Mojave Desert AQMD
15428 Civic Drive, Suite 200
Victorville, CA 92392
APCO - Chuck Fryxell (619) 245-1661
Division Chief - Eldon Heaston
Planning - Christian Ihenacho
Monitoring - Bob Ramirez
Toxics - Vacant
Division Chief - Edlon Heaston (Acting)
Engineering - Chris Collins
Compliance - Dough McCauley
Public Information - Don Blakemore
Administration - Scott Duncan
FAX: (619) 245-2699

Monterey Bay Unified APCD
24580 Silver Cloud Ct.
Monterey, CA 93940
APCO - Doug Quetin (408) 647-9411
District Counsel - David Schott
Engineering - Fred Thoits
Planning/Aid Monitoring - Janet Brennan
Public Affairs Officer - Tom Manheim
Enforcement - Ed Kendig, Esq.
Source Testing - Larry Borelli
Administrative Services - Bill Fergus
FAX: (408) 647-8501

North Coast Unified AQMD
2389 Myrtle Avenue
Eureka, CA 95501
APCO - Wayne Morgan (707) 443-3093
Engineering - Bob Clark
FAX: (707) 443-3099

Northern Sierra AQMD
P.O. Box 2509
200 Litton Dr., Suite 320
Grass Valley, CA 95945
APCO - Rod Hill (916) 274-9360
FAX: (916) 274-7546

Northern Sonoma County APCD
109 North Street
Healdsburg, CA 95448
APCO - Barbara Lee (707) 433-5911
FAX: (707) 433-4823

Placer County APCD
DeWitt Center
11464 "B" Avenue
Auburn, CA 95603
APCO - Richard Johnson (916) 889-7130
FAX: (916) 889-7107

Sacramento Metro AQMD
8411 Jackson Rd.
Sacramento, CA 95826

APCO - Norman D. Covell	(916) 386-6183
Rules - Nancy Ormandy	(916) 386-6606
Field Operations - Eric Munz	(916) 386-6617
Permitting - Bruce Nixon	(916) 386-6623
Prog. Coord. - Brigette Tollstrup	(916) 386-6672
Strategic Planning - Karen Wilson	(916) 386-6667
Public Information - Kerry Shearer	(916) 386-6180
Mobile Sources - Tim Taylor	(916) 386-7042
Special Projects - Vacant	
Administration - Lashelle Carlyse	(916) 386-7004
FAX:	(916) 386-6650

San Diego County APCD
9150 Chesapeake Drive
San Diego, CA 92123-1096

APCO - Richard J. Sommerville	(619) 694-3300
Secretary - Nancy Torregrossa	(619) 694-3302
Deputy Directors	
Richard J. Smith	(619) 694-3303
Morris Dye	(619) 694-3303
Administrative - Linda Fox	(619) 694-3306
Compliance - Teresa Morris	(619) 694-3342
Mon./Tech. Services - Judith Lake	(619) 694-3351
Engineering - Michael Lake	(619) 694-3313
Air Resources & Strategy Development - Vacant	
Public Information - Bob Goggin	(619) 694-3332
FAX:	(619) 694-2730

San Joaquin Valley Unified APCD
1999 Tuolumne, Ste. 200
Fresno, CA 93721-1638

APCO - David L. Crow	(209) 497-1000
Deputy APCO - Mark Boese	
Planning - Robert Dowell	
Permitting - Sayed Sadredin	
Compliance - Bob Kard	
District Counsel - Philip M. Jay	
Administrative Services - Roger McCoy	
Public Information/Education - Josette Bello	
FAX:	(209) 233-2057

Bakersfield Office (805) 861-3682
2700 M Street, Ste. 275
Bakersfield, CA 93301-2370
FAX: (805) 861-2060

Modesto Office (209) 545-7000
4230 Kiernan Avenue, Ste. 130
Modesto, CA 95356-9321
FAX: (209) 545-8652

San Luis Obispo County APCD
2156 Sierra Way, Suite B
San Luis Obispo, CA 93401

APCO - Robert W. Carr	(805) 781-5912
Planning - Larry Allen	
Public Information - Kathy Wolff	
Engineering - David Dixon	
Compliance - Karen Brooks	
Monitoring/Technical Services - Paul Allen	
Toxics - Tom Roemer	
FAX:	(805) 781-1035

Santa Barbara County APCD
26 Castilian Dr., Suite B-23
Goleta, CA 93117

APCO - Doug Allard	(805) 961-8800
Technology & Env. Assessment - Kathy Milway	
Administrative Services - John Nicholas	
Engineering - Peter Cantle	
Regulatory Compliance - Terry Dressler	
FAX:	(805) 961-8801

Shasta County AQMD
1640 West Street
Redding, CA 96001
APCO - Michael Kussow (916) 225-5674
FAX: (916) 225-5237

Siskiyou County APCD
525 So. Foothill Drive
Yreka, CA 96097
APCO - James R. Massey (916) 842-8029
Program Manager - Patrick Griffin
FAX: (916) 842-6690

South Coast AQMD
21865 E. Copley Drive
Diamond Bar, CA 91765 (909) 396-2000
Executive Officer - James M. Lents
Stationary Sources Rules & Compliance
P. Leyden, W. Fray
Planning & Technology Advancement
B. Wallerstein
Chief Scientist - Vacant
Public Advisor - La Ronda Bowen
Technical Support Services - Nick Nikkila
Government Affairs/Media - Tom Eichorn
Fiscal - Rick Pearce
Counsel - Peter Greenwald
Chief Prosecutor - Vacant
FAX: (909) 396-3340

Tehama County APCD
P.O. Box 38 (1750 Walnut Street)
Red Bluff, CA 96080
APCO - Heidi W. Hill
Assistant APCO -
Gary Bovee (916) 527-3717
FAX: (916) 529-1049

Tuolumne County APCD
2 South Green Street
Sonora, CA 95370
APCO -
Gerald A. Benincasa (916) 533-5693
Deputy APCO - Mike Waugh
FAX: (209) 533-5520

Ventura County APCD
669 County Square Dr., 2nd Floor
Ventura, CA 93003
APCO -
Richard H. Baldwin (805) 645-1440
Deputy APCO - Bill Mount (805) 645-1430
Enforcement - Keith Duval (805) 645-1410
Eng/Permits - Karl Krause (805) 645-1420
Rule - Mike Villegas (805) 645-1412
Monitoring - Doug Tubbs (805) 645-2809
Planning - Scott Johnson (805) 645-1491
Fiscal - Henry Solis (805) 645-1416
FAX: (805) 645-1444

Yolo/Solano AQMD
1947 Galileo Ct., Ste. 103
Davis, CA 95616
APCO - Ken Selover (916) 757-3675
Compliance -
Annette Carruthers (916) 757-3659
Planning - Carl Vandagriff (916) 757-3668
Engineering -
Steve Speckert (916) 757-3655
Board Clerk -
Eleanora Bailey (916) 757-3657
FAX: (916) 757-3670

K7 California Public Agencies and Organizations That Can Assist People with Indoor Air Quality Concerns

A directory compiled by the California Interagency Working Group on Indoor Air Quality and published by the California Department of Health Services lists names, addresses, telephone numbers, and brief descriptions of California agencies and organizations that can assist people with indoor air quality concerns. The *California Indoor Air Quality Assistance Directory* can be obtained free of charge by writing or calling to the following address:

California Indoor Air Quality Section
Environmental Health Laboratory Branch
Department of Health Services
2151 Berkeley Way, Room 334
Berkeley, CA 94704-1011
(510) 540-2469
Fax: (510) 540-3022

A list of private firms that offer indoor air quality services in California is also available free of charge at the above address.

K8 Publications and Written Material on Indoor Air Quality

K8.1 List of USEPA's publications

The following USEPA publication, which is a good reference for building owners and facility managers, is available for purchase:

USEPA. 1991. *Building Air Quality: A Guide for Building Owners and Facility Managers*, United States Environmental Protection Agency, EPA/400/1-91/033, Washington, DC. Available from the United States Printing Office, Superintendent of Documents, Mail Stop: SSOP, Washington, DC 20402-9328 (ISBN 0-16-035919-8)

Other publications listed below are available from the USEPA's Indoor Air Quality Information Clearinghouse free of charge from the following address:

Indoor Air Quality Information Clearinghouse
United States Environmental Protection Agency
P.O. Box 37133
Washington, DC 20013-7133
(800) 438-4318 or (202) 484-1307
Fax: (202) 484-1510

List of USEPA's publications:

USEPA. 1990. *Ventilation and Air Quality in Offices*, Fact Sheet No. 3, United States Environmental Protection Agency, 402-F-94-003, Washington, DC.

USEPA. 1991. *Indoor Air Facts: Sick Building Syndrome*, Fact Sheet No. 4 (revised), United States Environmental Protection Agency, 402-F-94-004, Washington, DC.

USEPA. 1992. *Carpet and Indoor Air Quality*, Fact Sheet, United States Environmental Protection Agency, Washington, DC.

USEPA. 1993. *The Inside Story: A Guide to Indoor Air Quality*, United States Environmental Protection Agency, EPA 402-K-93-007, Washington, DC.

USEPA. 1993. *Targeting Indoor Air Pollution: EPA's Approach and Progress*, United States Environmental Protection Agency, EPA 400-R-92-012, Washington, DC.

USEPA. 1993. *Current Federal Indoor Air Quality Activities*, United States Environmental Protection Agency, EPA 402/K-93/033, Washington, DC.

K8.2 List of National Institute of Standards and Technology Publications:

Dols, W.S.; Persily, A.K.; and Nabinger, S.J. 1995. *Indoor Air Quality Commissioning of a New Office Building*. Gaithersburg, MD: National Institute of Standards & Technology, NISTIR 5586.

K8.3 List of the CARB's publications:

1. Indoor Air Quality-Related:

   CARB. 1991. *Indoor Air Quality Guideline No. 1: Formaldehyde in the Home*. Sacramento, California: California Air Resources Board, Research Division.

2. Architectural Coatings-Related:

   a) ARB-CAPCOA. 1989. *ARB-CAPCOA Suggested Control Measure For Architectural Coatings - Technical Support Document*. Sacramento, California: California Air Resources Board (Stationary Source Division) and California Air Pollution Control Officers Association. July, 1989.

   This document recommends limits for VOCs which may be adopted by APCDs and AQMDs. The VOC limits are presented by different categories of architectural coatings. The document includes new and revised definitions of categories of architectural coatings.

   b) CARB. 1994a. *Summary of California's Coating Rules by Air Pollution Control Districts and Air Quality Management Districts*. Sacramento, California: California Air Resources Board, Stationary Source Division, Solvents Control Section. March, 1994.

   This document presents descriptions of different coating rules, and indicates the air pollution control districts/air quality management districts in which rules have been adopted. This document does not present specific VOC limits.

   c) CARB 1994b. *Survey of Emissions from Solvent Use. Volume 1: Aerosol Paints. Volume 2: Architectural Coatings*. Contract No. A132-086, Final Report to ARB submitted by Battelle. Sacramento, California: Air Resources Board. September, 1994.

   Volume 1: Aerosol Paints
   This volume presents results of a survey conducted by ARB of companies that sold aerosol coating products in California. (Note that the survey data were analyzed by Battelle.) The

report presents statistics on sales of aerosol paints, VOC content (percent by weight) and estimated VOC emissions by coating category. It also presents a summary of the BAAQMD rule (Regulation 8, Rule 49, adopted in 1990) that regulates VOC content in hand-held aerosol paint products, with a copy of the BAAQMD rule included in the appendices.

Volume 2: Architectural Coatings
This volume presents results from a survey of architectural coatings manufacturers who sold architectural and industrial maintenance coatings in California in 1990. This report includes sales in gallons of different architectural coatings by type, estimated emissions of VOCs by coating type, estimates of emission reductions due to 1989 ARB-CAPCOA Suggested Control Measure 1992 standards relative to the 1990 emissions, and a comparison of 1990 survey results with earlier CARB surveys.

3. Aerosol Coating Products-Related:

a) CARB. 1995a. *Initial Statement of Reasons for a Proposed Statewide Regulation to Reduce Volatile Organic Compound Emissions from Aerosol Coating Products and Amendments to the Alternative Control Plan for Consumer Products*. Sacramento, California: California Air Resources Board, Solvents Control Section, Stationary Source Division. January, 1995.

This document presents the CARB staff's proposed regulation (adopted 1/8/96) to reduce emissions of VOCs from aerosol paints. It also presents the technical support document prepared by the CARB staff, which includes a summary of the legislation, technical background information, environmental and economic impacts, and VOC emissions by product category.

b) CARB. 1995b. "Regulation for Reducing Volatile Organic Compound Emissions from Aerosol Coating Products." *Health and Safety Code*, Sections 39002, 39600, and 40000, and 41712.

This regulation presents VOC limits by aerosol paint product categories, and regulatory definitions.

4. Consumer Products-Related:

a) CARB. 1993a. *Regulation for Reducing Volatile Organic Compound Emissions From Consumer Products And Antiperspirants And Deodorants*. Sacramento, California: State of California, Air Resources Board. Effective: January 6, 1993.

This document presents two regulations, Article 1 (Antiperspirants and Deodorants, Sections 94500-94506.5) and Article 2 (Consumer Products, Sections 94507-94517) of Title 17, California Code of Regulations, Division 3, Chapter 1, Subchapter 8.5. These regulations include a table of standards specifying VOC limits (percent by weight) for different product categories; this table also presents the dates these limits are effective.

b) CARB. 1994c. *Proposed Alternative Control Plan Regulation for Consumer Products, Staff Report*. Sacramento, California: California Air Resources Board, Stationary Source Division. August, 1994.

This document presents a detailed description of the Alternative Control Plan (ACP), a voluntary program which enlists manufacturers to limit VOCs in consumer products.

K9 Irritation/Toxicity Information Sources

The following are sources of information on chemical irritants and toxicants.

1. Integrated Risk Information System (IRIS): on line.

2. Health Effects Assessment Sensory Table (HEAST): available from the National Technical Information Service (NTIS).

3. Registry of Toxic Effects of Chemical Substances (RTECS): available from NIOSH.

4. Sax and Lewis (1989 or most recent edition) Dangerous Properties of Industrial Materials: available from Van Nostrand Reinhold publishing company.

5. Toxicological profiles of approximately 120 hazardous substances found at National Priorities List (NPL) sites. Toxicological profiles are developed by the Agency for Toxic Substances and Disease Registry (ATSDR) and are available from NTIS, 5285 Prt Royal Road, Springfield, Virginia 22161 (Phone: 800-553-6847 or 703-487-4650.) A number of draft toxicological profiles are available for public comment from: Division of Toxicology, ATSDR, 1600 Clifton Road NE, Mail Stop E-29, Atlanta, Georgia 30333.

6. Hazardous Substance Data Bank (HSDB): available from the National Library of Medicine.

ACRONYMS AND SELECTED GLOSSARY

ACGIH American Conference of Governmental Industrial Hygienists.

ACH air change rate per hour; the number of times that outdoor air completely replaces the volume of air in a building per hour.

A/E Architectural/Engineering.

APCD air pollution control district

AQMD air quality management district

ASHRAE American Society of Heating, Refrigerating and Air-Conditioning Engineers.

ASTM American Society for Testing and Materials.

ATSDR Agency for Toxic Substances and Disease Registry.

BAAQMD Bay Area Air Quality Management District

building construction materials construction materials and products, major furnishings, and those cleaning and maintenance materials and products, the use of which are directly associated with the building materials selected.

building bake-out process designed to "artificially age" building materials and products by elevating the temperature of an unoccupied, newly constructed or remodeled building while supplying a fixed amount of ventilation, and flushing out the building with the maximum possible ventilation after completion of the bake-out.

building commissioning see HVAC commissioning.

building flush-out process during which a building is continuously (i.e., 24 hr per day) ventilated for several days or weeks at the maximum possible outdoor air rate.

Cal-OSHA California Occupational Safety and Health Administration.

CARB California Air Resources Board.

CAS # chemical abstracts service registry number.

CCI Canadian Carpet Institute.

CCR California Code of Regulations.

CDGS California Department of General Services.

CDHS California Department of Health Services.

CEC California Energy Commission; Commission of the European Communities.

CFM cubic foot per minute (ft^3/min); [1 CFM = 0.47 Liters/second (L/s)].

CFR Code of Federal Regulations.

CRI (United States) Carpet and Rug Institute .

dry products building materials characterized by slowly decreasing VOC emissions (e.g., floor coverings and composite wood products).

ECA European Collaborative Action.

emission rate mass of an individual volatile organic compound or mass of total measured volatile organic compounds emitted from a material per unit of time; emission rate unit is $\mu g/hr$; emission rate equals the emission factor times the sample's area.

emission factor mass of an individual volatile organic compound or mass of total measured volatile organic compounds emitted from a material per unit area of material or product per unit of time; emission factor unit is $\mu g/m^2 \cdot hr$.

FID flame ionization detector.

FLEC field and laboratory emission cell.

ft^3/min cubic foot per minute (CFM); (1 ft^3/min= 0.47 L/s).

GC gas chromatography or gas chromatograph.

headspace testing testing method that involves placing a product sample (e.g., a section from a carpet roll, a piece of plywood, etc.) in a closed container for a pre-determined period of time and then sampling the air in the "head space" above the sample in the container.

HEPA high efficiency particulate air (filter).

HUD (United States) Department of Housing and Urban Development.

HVAC heating, ventilating, and air conditioning.

HVAC commissioning process that ensures that the performance of an HVAC system meets design parameters.

IAQ indoor air quality.

IARC International Agency for Research on Cancer.

in. H_2O inch of water (a pressure unit); 1 in. H_2O (60°F) = 248.8 Pa.

loading factor (of a material or product) the ratio of the surface area of a material divided by the volume of the space where it is installed or tested.

low-VOC-impact building material or product building material or product that when installed in a building results in minimal or reduced exposure of occupants to VOCs that are emitted from the material or product.

material conditioning: a process during which materials are placed in a dry, well ventilated area for a period of time varying from a few days to a few weeks, depending on the decay characteristics of the material being conditioned, until emission rates have been reduced to a pre-determined acceptable level.

MDF medium density fiberboard.

mo month.

MRL Minimum Risk Level.

MS mass spectrometry or mass spectrometer.

MSDS Material Safety Data Sheet.

ng nanogram.

NIOSH (United States) National Institute for Occupational Safety and Health.

no-VOC-emitting product product that does not emit reactive VOCs that may participate in atmospheric photochemical reactions but that may emit other VOCs; also referred to a "zero"-VOC emitting product.

NTIS (United States) National Technical Information Service.

O_3 Ozone.

OEHHA (California Environmental Protection Agency) Office of Environmental Health Hazard Assessment.

OSHA (United States) Occupational Safety and Health Administration.

Pa Pascal (a pressure unit); 1 Pa = 1/248.8 in. H_2O.

4-PC 4-phenylcyclohexene.

PEL permissible exposure limit

ppb part per billion; 10^{-9}; unit of measure of air concentration of a gas or vapor.

porous material or product porous building material that has a large surface areas due to its rough or textured surface characteristics; porous materials act as VOC sinks (see VOC sinks), i.e., secondary sources of chemical compounds to which they were exposed and which they trapped; examples of porous materials include textiles, carpets, and insulation.

ppm part per million; 10^{-6}; unit of measure of air concentration of a gas or vapor.

RTECS registry of toxic effects of chemical substances.

SBR styrene butadiene rubber.

SBS sick building syndrome; situation in which building occupants experience symptoms, such as nose, eye, and throat irritation, sneezing, stuffy or running nose, fatigue or lethargy, headache, dizziness, nausea, irritability, and forgetfulness, and which the occupants associate with the building.

SCM suggested control measure.

sink effect see VOC sink.

TCE Trichloroethylene.

TLV threshold limit value.

TVOCs total volatile organic compounds; sum of air concentrations of individual VOCs

USEPA United States Environmental Protection Agency.

VAV variable air volume; a type of HVAC system that varies the volume of supply air depending on thermal requirements.

ventilation (dilution) process of supplying "contaminant-free" air to a space and of removing an equal volume of indoor air from this space by natural or mechanical means; the supplied air may or may not be conditioned.

ventilation (local exhaust) process of removing VOCs and other contaminants near their sources by direct exhaust to the outside.

VOC volatile organic compound typically sampled by adsorption on a solid sorbent that has a sufficiently high vapor pressure to exist as a gas or vapor at ambient temperatures, i.e., with lower boiling point limit between 50 and 100 °C and an upper limit between 240 and 260°C (this definition is based on the methods used to sample VOCs); however formaldehyde and some other compounds are included for convenience although they do not have boiling points between 50 and 260°C.

VOC (reactive) volatile organic compound; the USEPA (1983), the ASTM (1993), and the CARB (1993a) list the following operative (i.e., not physical) definition: *any organic compound that participates in atmospheric photochemical reactions, i.e., any compound containing at least one atom of carbon, except methane, carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, ammonium carbonate, 1,1,1-trichloroethane, methylene chloride, trichlorofluoromethane (CFC-11), dichlorodifluoromethane (CFC-12), chlorodifluoromethane (HCFC-22), trifluoromethane (HFC-23), 1,1,1-trichloro-2,2,2-trifluoroethane (CFC-113), 1-chloro-1,1-difluoro-2-chloro-2,2-difluoroethane (CFC-114), chloropentafluoroethane (CFC-115), 2,2-dichloro-1,1,1-trifluoroethane (HCFC-123), 1,1,1,2-tetrafluoroethane (HFC-134a), 1,1-dichloro-1-fluoroethane (HCFC-141b), 1-chloro-1,1-difluoroethane (HCFC-142b), 2-chloro-1,1,1,2-tetrafluoroethane (HCFC-124),* *pentafluoroethane (HFC-125), 1,1,2,2-tetrafluoroethane (HFC-134), 1,1,1-trifluoroethane (HFC-143a), 1,1-difluoroethane (HFC-152a), and the following classes of perflurocarbons: (A) cyclic, branched, or linear, completely fluorinated alkanes; (B) cyclic, branched, or linear, completely fluorinated ethers with no unsaturations; (C) cyclic, branched, or linear, completely fluorinated tertiary amines with no unsaturations; and (D) sulfur-containing perfluorocarbons with no unsaturations and with the sulfur bonds only to carbon and fluorine.*

VOC sink material that adsorbs VOCs; a VOC sink typically adsorbs VOCs when air concentrations are high and re-emits them when air concentrations decrease.

wet product building material with high solvent content characterized by relatively high VOC emissions during and immediately after installation followed by much lower emissions (e.g., paints and adhesives).

WHO World Health Organization.

zero-VOC emitting product see **no-VOC-emitting product**

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