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Screening and Selecting Building Materials and Products Based on Their Emissions of Volatile Organic Compounds (VOCs)

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ABSTRACT: The cost of emissions tests and other factors have discouraged nearly all but the largest product manufacturers from obtaining emissions data. Emissions data, where available, require toxicologic evaluation before design professionals and other potential purchasers can use them. The absence of health effects information at the low exposures likely to occur from normal indoor uses of most products and materials increases the uncertainty in any such evaluation. The complex mixture emitted by most products poses an additional interpretation problem.

A simple screening procedure to identify potentially problematic products has been developed, and preliminary experience indicates it may be suitable for screening or comparing products during selection by design professionals and other consumers. Commercial specimens are tested for emissions in a small, controlled, dynamic test container over a 24-h period after initial screening by headspace analysis. The procedure allows identification of and quantification of dominant compounds that may then be reviewed for odor, irritancy, toxicity, and carcinogenicity. Only significant quantities of such substances likely to cause adverse effects are considered sufficient basis for rejecting a product. The screening procedure is relevant to the uses required for product selection and significantly less costly than current standard environmental chamber tests.

A relatively short-term test of emissions from office work stations using a large-scale chamber is also presented. This test is conducted at realistic building conditions. The six-day test duration is adequate to characterize emissions rates and provides data that can be used to both compare products and estimate expected concentrations in buildings.

Finally, procedures and criteria for evaluating the results of emissions tests with respect to the selection of products are discussed. With these procedures, measured and modeled concentrations are compared to published values for human toxicity, irritation, and odor and the existing data on indoor concentrations of volatile organic compounds (VOCs).

KEYWORDS: indoor air quality, volatile organic compounds, emissions testing, building materials, building design, environmental chamber

Various approaches are being used to evaluate emissions from indoor air pollutant sources such as building materials, furnishings, office and other equipment, and consumer products. The available evaluation methods include "paper" studies, bulk chemical analysis, environmental

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chamber testing of chemical emissions, subjective evaluations, and bioassays [*1*]. Table 1 lists examples of these approaches.

The results of these emissions evaluations are being put to a variety of uses. For example, they may be used for comparison of products, modeling of indoor air quality, and screening for product selection based on potential toxicological effects [*2–4*]. Table 2 lists various uses of emissions evaluations.

Increasing demands from building design professionals and facility operators for product specific information on potential indoor air quality (IAQ) impacts has increased the need and uses for actual chemical emissions data. Such information is used for product selection during the design or purchase process or for review of submittals by contractors and vendors during the construction or renovation process [*1–4*]. Since building materials represent between 30 and 60% of typical construction costs, the financial impact of design decisions is significant.

Barriers and Disincentives

There are several barriers (or disincentives) to the more widespread use of emissions data by design professionals and other potential users. The barriers include the difficulty of acquiring

TABLE 1—*Outline of various methods for evaluating emissions from sources of indoor air pollutants Adapted from Ref* 1.

- Paper Studies
  - Review sources of information on potential emissions
    - Material Safety Data Sheets (MSDSs)
    - Disclosures of product contents/components provided by manufacturers
    - Published studies and reports on emissions for the same or similar products
  - Review data on known volatile constituents
    - Boiling points or vapor pressures
    - Toxicity of volatile constituents
    - Threshold Limit Values (TLVs)
    - Carcinogenicity risk factors
    - California Proposition 65 listing
    - Irritant potency—ASTM E 981[a]
  - Assess material usage based on plans, specifications
    - Quantity used in building
    - Exposure of material to circulating air
    - Proximity of material to occupants
  - Estimate potential to cause IAQ problems
- Bulk chemical analysis to determine constituents/emissions
  - Solvent extraction
  - Vacuum extraction (NASA)
  - Thermal desorption
- Environmental Chamber Testing
  - Collect representative sample
  - Conduct chamber test
    - Identify individual VOC
    - Measure concentrations of TVOC and select VOC
  - Calculate emission rates
- Subjective evaluation of odor and air quality
  - Perceived air quality evaluation [*16,17*]
  - Air quality evaluation [*14,18*]
  - Clean glass jar test [*1*]
- Animal and human bioassays
  - ASTM E 981, Mouse studies of irritant potency
  - Animal bioassay for neurotoxicity
  - Human task performance or other testing for subacute neurotoxicity

[a]ASTM Test Method for Estimating Sensory Irritancyt of Airborne Chemicals (E 981).

TABLE 2—*Potential uses of data on emissions of VOC* [1].

Manufacturers
Product development
Limit liability
Marketing
Designers (architects, engineers, interior designers)
Specification language
Product comparison and selection
Application: installation considerations, ventilation requirements
Design calculations
Conditioning requirements
Consumers and consumer advisors
Product comparison and selection
Application/installation/use considerations
Ventilation requirements
Researchers, consulting engineers, industrial hygienists
Air contaminant source identification
Source strength estimations
Exposure estimations
Regulators
Exposure estimations
Risk assessments
Pollution prevention
Regulatory initiatives, (for example, restrictions on use, product bans, and so forth)

emissions test data from manufacturers and vendors, the lack of standardized test procedures and consistent reporting formats, and the concurrent difficulty of interpreting reported emissions test data combined with the lack of relevent data on the toxicity or irritancy of products' emissions. These difficulties are compounded by the designers' reluctance to assume additional potential professional liability. Some of the major problems are discussed in more detail below.

1. Difficulty of Acquiring Emissions Test Data from Manufacturers and Vendors

Because the use of emissions data is relatively new, many individuals representing product manufacturers with whom design professionals and other potential customers may have direct contact have little or no knowledge or understanding of chemical emissions and emissions testing. It is not uncommon for marketing personnel to claim that their products are "inert" implying that the product does not emit volatile organic compounds (VOCs).

2. Lack of Standardized Test Procedures

A wide range of test methods have been used because of the lack of standardized procedures and the newness of the field. In some cases innovative approaches have been used. However, results from diverse tests usually cannot be compared [5]. There is also a general lack of knowledge about emissions testing among commercial laboratories that might be able to perform this service.

Some manufacturers have conducted or have contracted others to conduct emissions tests of their products. When data from such testing are submitted to design professionals, it is often not possible to evaluate the reliability of the data because of lack of information on the test specimens and the test procedures. Even where reasonably comparable test methods have been used, the data are diversely presented making comparisons difficult.

3. Difficulty of Evaluating the Potential Toxicity or Irritancy of Products' Emissions

Emissions data, where available, require toxicologic evaluation before design professionals and facility operators can use them. Such evaluations are costly and time consuming. In many cases, no clear conclusions can be reached because of the lack of relevant health effects data. This lack stems from an absence of health effects information on many chemical substances. The unavailability of health effects information at the low concentrations likely to occur from normal indoor uses of most products and materials increases the uncertainty of any such evaluations. The complex mixtures of chemicals emitted by many products and materials further exacerbates the problem because there are no procedures to estimate the combined effects of such mixtures.

4. Designers' Eluctance to Assume Additional Potential Professional Liability

Legal actions filed in connection with asbestos in buildings has led to an upheaval in the professional liability insurance industry. It is now difficult for design professional to obtain such insurance. Design professionals have also become cautious because of the numerous notorious lawsuits that have been filed against their colleagues. Therefore, many professionals prefer to avoid dealing with new environmental issues including emissions from building materials.

5. Insufficient Data

Presently available data on chemical emissions are insufficient to assist design professionals to make informed selections of products and materials. Far too few emissions tests results are available because of the lack of requirements for emissions testing, either by potential customers or by regulatory authorities. Testing to date has generally been done either by manufacturers who are seeking to improve their products by reducing emissions in order to create a marketing advantage or to reduce potential liabilities.

The rapidly changing and expanding product inventory resists comprehensive testing because of its size. The available number of products is so large that a widely distributed hardbound product catalogue used by design professionals occupies approximately three linear metres of shelf space. New products are constantly being developed, and old products are modified without any change in their labels or advertising that would alert a design professional to the change.

6. Emissions Testing Costs

The cost of tests has discouraged nearly all but the largest product manufacturers from testing their products. These costs have ranged form $1500 to $3500 per test for individual products to more than $10 000 for complete workstations in environmental chambers. Concerns about product liability and possible misuse of the data have also been expressed by some manufacturers. In practice, designers have only been successful in getting manufacturers to test their products if the dollar value of the material being specified is high. Court decisions related to asbestos suggest that ignorance does not protect manufacturers from liability and may alter the current financial disincentive. Emissions testing would be one way for manufacturers to assure themselves that their products had low impacts on indoor air quality.

Available Solutions: Test Methods

Numerous distinct emission test methods have been reported in the literature. The earliest emissions testing was done for NASA to evaluate products/materials being considered for construction use in spacecraft or for use by astronauts inside the vehicles [*6*]. Emissions testing for formaldehyde from pressed-wood products was first reported in 1974 [*7,8*]. The U.S. Department of Housing and Urban Development (HUD) later adopted regulations limiting emissions of formaldehyde from composite wood products used in manufactured housing and mobile homes [*9*]. That is the earliest regulatory action mandating emissions testing that we have found. The HUD regulations led to the development of ASTM Test Method for Determining Formaldehyde Levels from Wood Products Under Defined Test Conditions Using a Large Chamber (E 1333) [*10*]. More recently, the U.S. EPA's Carpet Policy Dialogue resulted in the creation of a testing program for carpets [*11*]. The Carpet and Rug Institute (CRI) has initiated a "Green Tag" labeling program based on industry-wide testing. ASTM Subcommittee D22.05 on Indoor Air is considering adopting a modified version of the CRI method as a standard practice. ASTM Standard Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products (D 5116) now establishes standard guidelines for conducting chemical emissions tests and should provide the basis for all product emissions testing [*12*].

Emission tests have been done using vessels ranging from small (approximately 0.03 L) to room-size environmental chambers including paint cans, ordinary rooms, and highly engineered environmental chambers. *In-situ* testing has been done using the Field and Laboratory Emissions Cell (FLEC), which collects surface emissions without disturbing the specimen. Sample analysis has varied from subjective odor evaluation to highly sensitive modern analytical chemistry [*1–5,12–14*]. Table 3 lists various emissions test and their primary applications.

Small-Scale Screening Test: Modest Proposal for a Practical Solution

Architects, engineers, interior designers, and other building design professionals need information on product emissions that is reliable and easily obtainable. In particular, there is a need to develop tests that can be conducted at reasonable cost and in a reasonable time period. Several different approaches are being used to encompass the range of materials and products that need to be tested.

Examples include a simple small chamber screening test for fabrics and composite wood products, other solid materials, and a room-size environmental chamber test for entire office work stations (free-standing partitions, work surface, and associated storage units). Neither of these presents any fundamentally new techniques or approaches but simply builds on what has been done before to provide relevant and useful information for building design professionals. Both tests are being used in current indoor air quality projects for which one author is a consultant. Many of the principles and practices described for these two tests may be adapted as required for other materials and products.

The small-chamber screening test described in Appendix A is being used to identify products that may emit significant quantities of toxic, irritating, or odorous compounds. Preliminary experience with the test by design professionals indicates that the test may be a useful tool to identify products that could potentially create a significant indoor air quality problem.

Since the test is not particularly expensive, it has not been too difficult to convince manufacturers that they should have the test conducted as a condition for final selection of their product as long as the dollar value of the potential sale is significant.

The test consists of an initial headspace sample that is qualitatively analyzed by gas chromatography-mass spectrometry (GC-MS) to identify very volatile compounds that might be emitted during the first hours of product installation or application. Then a chamber test with a small sample of material is conducted at standard conditions collected at average times of 3, 6, and 24 h after initiating the test. The multiple air samples for TVOC allow verification that emissions are constant or declining over the test period. The 24-h air sample is also

TABLE 3—*Methods used for determining emission factors and rates.*

Sampling Method	Primary Use	Advantages/Disadvantages
Vacuum extraction	Identification of volatile constituents.	More complete chemical profile; may distort profile of extracted compounds that would not be emitted at significant rates at normal atmospheric pressures.
Solvent extraction or bulk digestion	Identification of soluble constituents; measurement of bulk concentrations.	Will not identify compounds that are not soluble in the chosen solvent.
Headspace sampling	Identification of emission; semiquantitative analysis of emissions.	Requires less sophisticated equipment. Does not provide quantitatively reliable results.
Dynamic testing using small containers	Qualitative and quantitative analysis of emissions under controlled conditions.	Requires sophisticated control of environmental conditions in test vessel. Enables determination of quantitative information on emissions. May be more economical than environmental test chambers while producing similar results.
Small environmental chamber testing	Qualitative and quantitative analysis of emissions under conditions simulating indoor environment.	Allows careful control of chamber environment. Can be used for extended time tests. Usually requires testing a small specimen, often cut from a larger section of the product of interest. Costly to construct and operate, but less costly than full-size environmental chambers.
Room-size chamber testing	Qualitative and quantitative analysis of emissions from large assemblies (e.g., furnishings, composite wood panels) and from use of consumable products (e.g., application of paints, adhesives) under conditions similating indoor environments.	Allows testing of full-size material or product components or sheets of materials. More closely simulates "real" world conditions. Large costs for equipment, operation of chamber, space required for chamber.
FLEC (field and laboratory emissions chamber)	In-situ qualitative and quantitative analysis of emissions from surfaces.	Portable: allows in-place testing of emissions from surfaces. Non-destructive. Requires sophisticated equipment.

analyzed by GC-MS to identify and quantify individual volatile organic compounds (VOCs). Two samples are also collected to determine formaldehyde emissions. Only significant emission rates of TVOC, individual VOCs, or formaldehyde are considered to be sufficient basis for rejecting a product.

The 24-h test duration is both practical and consistent with the objective of the test, which is to identify products that emit significant quantities of compounds. (Limited experience indicates that as little as 6 h may be sufficient for some materials). Also, if several brands or types of the same material are being compared, these materials will typically have similar emissions profiles so that valid comparisons can be made at 24 h. Finally, very volatile compounds and many surface-sorbed compounds are emitted rapidly under the conditions of the test; therefore, the compounds emitted at 24 h are probably primarily indicative of the compounds diffusing out of the material. However, this assumption needs to be assessed for each type of material.

Expansion of the use of the screening test will require identification of the critical test variables for each type or class of product (for example, carpet, fibrous insulation, ceiling tiles, and so forth). Once there is agreement about standardized product-specific test conditions, it should be possible to establish reasonably achievable emission guidelines that can then be used as the basis for evaluating individual products.

Environmental Chamber Test for Office Work Stations

A four-day test of a complete office work station in a room-size environmental chamber is described in Appendix B. The test is intended to provide accurate results for the purposes of comparing competitive products and identifying those that have unacceptably high emissions. The office workstation test is conducted at realistic building conditions with respect to ventilation rate, air mixing and velocities, temperature, and humidity. Seven samples for TVOC are periodically collected over the 96-h test period. Samples for the identification and quantification of individual VOCs and for the analysis of formaldehyde are collected at 4, 24, and 96 h. Because of the conditions and length of the test, the results may be used in a mass-balance model with loading values and building data to calculate reasonably reliable estimates of building concentrations.

Tests of office work stations and of residential furniture conducted for longer time periods of approximately three weeks and three months, respectively, in room-size environmental chambers have not substantially improved the usefulness of the results compared to the four-day test [*13*]. In the case of the three-week office work station tests, the emissions of TVOC declined sharply during the first 24 h and then steadily but less sharply during the next six days. The decay in emissions during the following two weeks was reasonably predictable based on the data from the first week [*13*]. Therefore, the four-day test duration recommended here appears to be sufficient.

Options for Evaluation of Results of Emission Tests

Once the emissions data are obtained, they must be evaluated for the purposes of product selection, acceptance, or comparison. Several approaches have been used.

State of Washington Office Buildings Program [*13*]

This program developed a set of requirements for the State of Washington that established target concentrations or concentration limits under defined test conditions. Values were established for formaldehyde, TVOC, and particulate matter. The emission tests results are to be used in a mass-balance model to estimate concentrations, and selection or acceptance is supposed to be dependent upon concentrations remaining below the specified limits. In the "design-build" program now being used for the State of Washington office buildings, final acceptance of the building is contingent upon air sampling in the completed building that demonstrates that concentrations are below the target values. This may not be a totally realistic and workable approach since the occupant activities can substantially contribute to contaminant concentrations in occupied buildings. It is also extremely impractical to consider rejection of a building after construction is completed and furnishings are installed.

Danish Indoor Climate Labeling System of Building Materials

In Denmark, a new labeling program is being developed based on the use of emission tests and an IAQ model to predict the time it will take for concentrations to reach a specified fraction (50%) of the thresholds for irritation or odor perception [*14*]. So far this system has been pilot tested with paints, sealants, and carpets. The Danish Confederation of Industries is preparing standard test protocols for various types of materials. Private laboratories are being accredited to perform the analysis, and a labeling board has been established.

CRI Labeling Program

The Carpet and Rug Institute has established a labeling program for its members that sets standards for emissions of styrene, 4-phenylcyclohexene, TVOC, and formaldehyde from carpets. The tests are conducted over 24 h in small-scale chambers. Product lines whose emissions are below the established levels are allowed to display the CRI "green tag" label.

Procedures and Criteria for Evaluating Results of Emission Tests

Appendix C presents some procedures and criteria for evaluating the results of emissions tests. These procedures have been developed in connection with recent construction projects in California and elsewhere. They primarily focus on the process of evaluation. However, in some cases (for example, formaldehyde and some carcinogens) there are established guidelines or limit values that can be used as appropriate.

The screening tests described in Appendices A and B are intended primarily to identify potential problems. If a significant emission rate of a particular compounds(s) of concern is found, the manufacturer is advised of the results and encouraged to conduct (or contract for) more extensive testing that might include a longer test period. If these results still show that the compound(s) is emitted at significant rates, the manufacturer is advised of the problem and encouraged to modify the product. Where particular compounds of concern are not identified, products may be compared based on their TVOC emissions. If a product emits substantially more TVOC than other products suitable for the same construction or furnishing use, the recommendation is made not to specify that product.

Several major manufacturers of office work stations were willing to test their products and provide the test results for evaluation. Therefore, it was possible to make direct comparisons of these products. In the tests that have been conducted so far, very low emissions were observed, and no products were recommended to be rejected except one. This was a mock up not manufactured by the normal process that includes an oven finish to set plastic materials that presumably eliminates much of the VOC emissions. This product will be retested when a normal production-manufactured specimen is available.

Conclusions and Recommendations

The screening tests presented here are intended to be practical methods of obtaining data on emissions of VOCs for several types of products and materials used in building interiors. These data can be evaluated with respect to the potential of the tested products to cause an adverse indoor air quality impact. These evaluations are made with reference to a few existing guidelines and to the relevant literature on health effects and typical indoor concentrations of individual constituents. The interpreted data are then used by design professionals as one of their criteria in the process of selecting and specifying products and materials for building projects. The carpet industry has already established a voluntary, industry-wide testing and labeling program. Our experience shows that if the dollar value of the potential sale is large enough then other manufacturers are often willing to test their products. When the tests are reasonable with respect to time and costs, it is likely that more widespread testing will be conducted in response to requests for emissions data.

Other innovative approaches may be developed for specific materials to address the issue of VOC emissions. For example, it may be possible to predict emissions for some materials using physically-based models and a few simply measured parameters [*15*].

The quality of any widespread testing will largely be a function of the degree to which the methods become standardized and those standards are followed. The technical competence of the testing organizations will also be a significant factor. At present, it is not clear how the testing market will develop. Testing may be concentrated in a few specialized organizations or there may be a proliferation of testing laboratories. The standardization of the process of the interpretation of the results is another critical factor. This process will undoubtedly be impacted by the legal system. Design professionals may possibly be assuming more liability by making these kinds of judgments about the acceptability of products.

Ultimately, the utility of emissions testing of products and materials will depend on the development of more knowledge about the potential health effects of relatively low concentrations of VOCs and of mixtures of compounds.

APPENDIX A

Small-Scale Screening Test to Identify and Measure Emissions of VOCs from Solid Materials

This test is applicable to solid materials that can be represented by relatively small-sized specimens. The test is used to screen a material specimen for emissions of volatile organic compounds (VOCs), total VOCs (TVOC), and formaldehyde at standardized environmental conditions in a small-volume chamber over a period of 24 h.

Test Specimen

The history of the material, including the manufacturing date, storage conditions, and storage duration, should be documented. A representative specimen of the material is wrapped in two layers of heavy aluminum foil. The specimen is shipped by air to the testing laboratory.

Specimen Handling and Headspace Screening

The laboratory removes the packaging and transfers the specimen to a Tedlar bag, which is sealed so that it contains no more than ~1-L of headspace air. The specimen is stored at room conditions for one to a maximum of seven days. Before chamber testing, a sample of headspace air (~100 cm^3) is withdrawn from the Tedlar bag for qualitative analysis of VOCs.

Chamber Testing

A test specimen is cut from the sample. For sheet materials, such as flooring, wall panels, and fabric, the specimen dimensions are typically 15 by 15 cm. The specimen is immediately placed on a wire screen in the approximate center of the chamber, and the test is initiated.

TABLE A1—*Parameters for the VOC emissions screening test.*

Parameter	Value
Chamber volume, m^3	0.010
Inlet flow rate, m^3 h^{-1}	0.06 ± 0.0012
Typical specimen size, m^2	0.0225
Loading ratio	2.25
Average temperature (range), °C	23 (22–24)
Atmosphere	dry N_2

The stainless-steel chamber with a volume of 10-L is ventilated with dry nitrogen. (Alternately, it may be desirable to use humidified nitrogen at 45 to 50% relative humidity.) The environmental parameters for the test are summarized in Table A1. The inlet flow rate and the chamber temperature are kept constant and recorded throughout the test. The relatively high loading ratio allows larger specimen sizes to be used in a small chamber. The high ventilation rate means that the chamber will approach steady-state conditions quickly.

Gas exiting the chamber is sampled for VOCs and formaldehyde. The sampling schedule is designed to be practically accomplished within normal working hours. Samples for VOCs are collected on multisorbent tubes at average times of 3, 6, and 24 h after starting the test. Appropriate gas volumes are selected based on the results for the headspace sample. Samples for formaldehyde are collected over the 3–6 h interval and at an average time of 24 h. These samples (typically 50 L) are collected on DNPH-coated cartridges. The total sampling flow rates are less than the total flow rate of gas exiting the chamber. A blank test lasting 3 h is used to determine background concentrations of the analytes. The laboratory's standard operating procedure should specify that chamber blanks be collected at a reasonable frequency. TVOC and formaldehyde concentrations in the blank chamber samples should be less than 20 and 2 $\mu g\ m^{-3}$, respectively.

Chamber and headspace samples for VOCs are analyzed by thermal desorption/gas chromatography/mass spectrometry. The compounds comprising most of the mass in the headspace and 24-h chamber samples are identified. If possible, identifications are confirmed by the analysis of standards. All samples are analyzed for TVOC by the total-ion-current (TIC) method using an average response factor for common hydrocarbons to calculate the mass [*19*]. The uncertainty in this method is estimated to be ~30 to 40%. The major compounds and other compounds of interest in the 24-h sample are quantified using calibrations prepared using pure standards. Both DNPH-coated cartridges are analyzed for formaldehyde by high-performance liquid chromatography.

Data Analysis and Reporting

Lists of VOCs identified in the headspace and 24-h chamber samples are provided along with labeled chromatograms. The headspace sample may show the presence of very volatile compounds that typically dissipate rapidly during dynamic chamber testing. The potential impacts of these very volatile compounds may be limited to a relatively short period during installation of the material. The 24-h sample is better representative of the emissions that may be of importance to the health and comfort of building occupants after the material is installed.

Concentrations of individually quantified VOCs, TVOC, and formaldehyde are determined. Then, the 24-h quasi steady-state source strengths ($\mu g\ h^{-1}$) are calculated for these analytes using the following equation

$$S = Q(C - C_0)$$

where Q is the volumetric flow rate ($m^3\ h^{-1}$) through the chamber, C is the average chamber concentration for the sampling interval ($\mu g\ m^{-3}$), and C_0 is the chamber blank concentration ($\mu g\ m^{-3}$). A quasi steady-state emission rate ($\mu g\ m^{-2}\ h^{-1}$) is calculated by dividing the source strength by the specimen size (m^2). The use of steady-state assumption introduces unknown amounts of error into the estimates of source strengths and emission rates.

The TVOC concentrations are evaluated to determine if emission rates are steady or declining over the duration of the test. Increasing or erratic TVOC concentrations may be indicative of problems with the test that should be investigated. Both the chamber concentrations and the emission rates of the quantified analytes are reported along with a detailed narrative description of the methods.

APPENDIX B

Environmental Chamber Test to Measure Emission of VOCs from Office Work Stations

This test is applicable to large specimens that require testing of component assemblies or large sheets of material that cannot be accommodated in small to medium sized environmental chambers. The test is used to screen a complete work station specimen for emissions of volatile organic compounds (VOCs), total VOCs (TVOC), and formaldehyde at standardized environmental conditions over a period of 96 h.

Test Specimen Acquisition and Handling

The history of the specimen work station components, including the manufacturing dates, storage conditions, and storage duration, should be documented. The specimens are wrapped in polyethylene and shipped directly to the testing laboratory taking care not to expose the specimens to extreme heat or cold. The laboratory removes the packaging and transfers the specimens directly to the environmental chamber that has been pre-conditioned for the test.

The test is conducted, to the extent practicable, following the guidelines of ASTM D 5116. The specifications for the test are as follows:

1. The test is conducted in an environmental chamber capable of accommodating the entire work station as specified by the architect. The environmental chamber is fully capable of controlling inlet air flow rate, air velocity, temperature, and humidity, and each of these parameters is monitored continuously throughout the test with the results included in the report.
2. The test specimens are packaged at the manufacturing location immediately after the final stage of the manufacturing process in the normal manner for shipping to an installation site. This package is then placed in an air tight package and delivered to the test facility without storage or other delays.
3. The air flow through chamber is no less than 5 or a maximum of 6 air changes per hour of recirculated plus clean air. The chamber ventilation rate is 1.0 air changes per hour (ACH) of clean air. Mixing is provided by the locations of the inlets and outlets for air supply and circulation. Fans can be used in the chamber to improve air mixing. Local air velocities are measured 1 cm from the specimen surfaces at no less than five representative locations. Air velocity measurements are also made at 0.3 and 1.2 m above the floor at the locations and conditions as follows:

1. The center of the space.
2. 0.3 m out from each chamber wall at the center of each wall.
3. 0.3 m out from each side of the work station at the center of each side. Air velocities in the chamber are maintained between 0.075 and 0.125 m/s to simulate a building environment.
4. The test chamber temperature is 23°C ± C 1°C. Relative humidity is 50% ± 5%.
5. The duration of test is 96 h, or more, at the manufacturer's option.
6. Air samples are analyzed for TVOC, individual VOCs and formaldehyde (or total aldehydes, with formaldehyde reported separately).
7. Sample collection and analysis.
   a. Air samples for VOCs and TVOC are collected on a multi-sorbent sampler. Formaldehyde is collected on DNPH cartridges.
   b. At 4-, 24-, and 96-h, samples are collected for analysis for individual VOCs and formaldehyde.
   c. TVOC samples are collected at 4, 6, 24, 36, 48, 72, and 96 h. TVOC is quantified using an FID calibrated with toluene.
   d. VOC samples are analyzed by GC-MS. Where possible, 95% of the total VOCs collected are identified. Dominant compounds are quantified.

Data Analysis and Test Report

Data analysis is similar to that for the 24-h chamber test described in Appendix A. The 96-h quasi steady-state source strengths are calculated and used in the evaluation of the product specimens by procedures and criteria described in Appendix C. The test report includes complete descriptions of the test system, all analyses, and results. All QA/QC procedures are also reported.

APPENDIX C

Procedures and Criteria for Evaluating Results of Emissions Tests

VOCs emitted by a product and identified as toxins, odorants, or irritants are evaluated in terms of published thresholds for those effects or by other relevant guidelines if available. The quasi steady-state source strengths ($\mu g\ m^{-2}\ h^{-1}$) are converted to concentrations (mg/m^3) by multiplying them by the loading ratio (m^2/m^3) and dividing by a standardized ventilation rate (h^{-1}) chosen by consideration of the building design ventilation rate.

VOCs identified as carcinogens, teratogens, and mutagens are evaluated to determine if significant concentrations will occur in building air. "Significant concentrations" are determined by comparing test chamber concentrations to building concentrations of these compounds reported in the literature. Identified compounds appearing on the California "Proposition 65" list are assessed in terms of the requirements of the relevant laws and regulations of the State of California [*20,21*].

1. Toxicity, Irritation, and Odor Evaluation References

The following references are used as guides to evaluating toxicity, irritation, and odor:

(a) *Air Quality Guidelines for Europe, World Health Organization, Regional Office for Europe* [22] provides guideline values for 19 substances based on effects other than cancer or odor/annoyance.
(b) Threshold limit values (TLVs) published by the American Conference of Governmental Industrial Hygienists for several hundred compounds that are intended to protect occupationally exposed workers primarily in industrial environments.
(c) California Office of Health Hazard Assessment (OEHHA) unit risk factors for cancer, and "Noncancer Acceptable Exposure Levels (Chronic)," and "Noncancer Acceptable Exposure Levels (Acute)." Guidelines developed by Cal OEHAA are used to assess carcinogenic risk [23]. These are, generally, identical to those used by the U.S. EPA and documented in the Integrated Risk Information System (IRIS) available from the National Technical Information System (NTIS) [24]. The noncancer values are generally derived from TLVs, information in the IRIS database, or other sources, and they have been subjected to peer review before being adopted by the State of California.
(d) Devos et al., *Standardized Human Olfactory Thresholds,* [25] have compiled and standardized odor threshold values for about 500 compounds using the major published sources.

2. Formaldehyde References

(a) The World Health Organization (WHO) Regional Office for Europe, and many other authorities and government organizations have identified formaldehyde as a carcinogen in experimental animals but have not identified it as a human carcinogen [22]. International Agency for Research on Cancer (IARC) has classified it as a Group 2B carcinogen. The U.S. EPA has identified it as a probable human carcinogen. California has identified it on its Proposition 65 list as a human carcinogen. Numerous governmental and international bodies including the WHO *Air Quality Guidelines for Europe* have established a guideline of 0.1 mg/m^3 (0.083 ppm) [22–24].
(b) California: The California Air Resources Board (CARB) and the California Department of Health Services (CDHS) have issued a guideline recommending a maximum formaldehyde air concentration of no more than 100 ppb (0.120 mg/m^3), and a target level of 50 ppb (0.060 mg/m^3) or less [25,26]. The target concentration has been recommended to protect asthmatic and allergic individuals, approximately one-third of the California population, according to a CDHS study [27,28].

The State of California also considers formaldehyde to be a probable human carcinogen, and, for that reason, recommends achieving the lowest levels practicable [25,26]. In order to meet this objective, design professionals have attempted to specify products containing no formaldehyde resins wherever possible. In any case, no product should emit formaldehyde at a rate that would contribute substantially to an airborne concentration approaching 50 ppb. Products with low formaldehyde emissions are considered preferable with respect to indoor air quality.

3. Cancer and Teratogenicity References

(a) The National Toxicology Program (NTP) Research and Testing Program issues an Annual Report on Carcinogens and a quarterly Management Status Report. The Management Status Report provides the status of chemicals studied, under study, or proposed for study by NTP. NTP technical reports are available from NTP Public Information Office, MD B2-04, P. O. Box 12233, Research Triangle Park, NC 27709, 919-541-3991.

(b) The International Agency for Research on Cancer (IARC) in Lyon, France, evaluates cancer risk to humans through critical reviews of existing data. Substances identified by IARC as carcinogens are included by OSHA under the Hazard Communication Standard.

(c) The California Proposition 65 list includes substances ". . . known to the State of California to cause cancer or birth defects in humans." Requirements in California mandate identification of such substances and notification of persons who may be exposed to them.

4. References for VOC Concentrations in Buildings

Several references give concentrations of individual VOCs in indoor air. These concentrations can be used as a basis for comparisons.

(a) Shah, J. J. and Singh, H. B., "Distribution of Volatile Organic Chemical in Outdoor and Indoor Air, *Environ. Sci. Technol.*, Vol. 22, 1988, pp. 1381–1388 [*29*].

(b) Sheldon, L., et al., "Indoor Air Quality in Public Buildings" [*30*].

(c) Wallace, Lance et al., EPA "Total Exposure Assessment Methodology (TEAM) Study [*31*].

(d) Wallace, L., The Total Exposure Assessment Methodology (TEAM) Study: Summary and Analysis: Volume I., EPA/600/6-87/602a [*32*].

(e) Brown, S., Sim, M., Abrahamson, M. J., Gray, C. N., Progress Towards National Indoor Air Quality Goals for Volatile Organic Compounds, Report to the Air Quality Panel of the National Health and Medical Research Council (Australia), 1992, Division of Building, Construction and Engineering, National Health and Medical Research Council, Australia [*33*]. See also, the summary article, of the same work, Brown, S. K., Sim, M. R., Abramson, M. J., Gray, C. N., "Concentrations of Volatile Organic Compounds in Indoor Air—A Review." *Indoor Air,* Vol. 4, 1994, pp. 123–134 [*34*].

5. TVOC References

TVOC limits have been recommended in the literature by several sources, but these are not consensus standards or guidelines based upon established health effects. Only emissions of specific compounds can be so evaluated. Nevertheless, it is assumed that, in general, products with lower TVOC emissions are more desirable, absent other considerations. Wallace et al. present a frequency distribution of TVOC values for residences obtained from a re-analysis of TEAM study data [*19*].

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