Designation: D7143 – 17

Standard Practice for
Emission Cells for the Determination of Volatile Organic Emissions from Indoor Materials/Products[1]

This standard is issued under the fixed designation D7143; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

This practice complements Guide D5116 and Practice D6670.

1. Scope

1.1 This practice is intended for determining volatile organic compound (VOC) emissions from materials and products using emission cells. It can be applied in principle to most construction materials and many products used indoors. Objectives include:

1.1.1 To provide manufacturers, builders, and end users with emission data useful for evaluating the impact of building products, new or old, on indoor air concentrations in a model room.

1.1.2 To promote the development of products with lower VOC emissions.

1.2 This practice is for identifying emitted VOCs and for determining the area specific emission rate of VOCs from newly produced building products under defined climate conditions. The method can also be applied to aged products.

1.3 In accordance with the definition of an emission cell, it is also possible to perform nondestructive emission measurements on building products on-site in buildings. However, the procedure for such measurements is not described in this practice.

1.4 This practice describes the design, construction, performance evaluation and use of emission cells for VOC emission testing. Sampling, transport and storage of materials to be tested, and preparation of test specimens are also described.

1.5 Air sampling and analytical methods for the determination of VOCs are described in Practice D6196. Alternative sampling and analytical approaches for formaldehyde and other carbonyls are described in Test Method D5197.

NOTE 1—All volatile (vapor-phase) carbonyls except formaldehyde can be analyzed by either Practice D6196 or by Test Method D5197.

NOTE 2—Direct-reading instruments can also be applied for specific objectives.

NOTE 3—Some volatile inorganic compounds can, in principle, also be analyzed (for example, ammonia).

1.6 An example of an emission cell is described in Appendix X2 of this practice.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D1356 Terminology Relating to Sampling and Analysis of Atmospheres

D1914 Practice for Conversion Units and Factors Relating to Sampling and Analysis of Atmospheres

D5116 Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products

D5197 Test Method for Determination of Formaldehyde and Other Carbonyl Compounds in Air (Active Sampler Methodology)

D5337 Practice for Flow Rate Adjustment of Personal Sampling Pumps

D6196 Practice for Choosing Sorbents, Sampling Parameters and Thermal Desorption Analytical Conditions for Monitoring Volatile Organic Chemicals in Air

---

[1] This practice is under the jurisdiction of ASTM Committee D22 on Air Quality and is the direct responsibility of Subcommittee D22.05 on Indoor Air.

Current edition approved March 1, 2017. Published April 2017. Originally approved in 2005. Last previous edition approved in 2016 as D7143 – 11 (2016). DOI:10.1520/D7143-17.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

D6330 Practice for Determination of Volatile Organic Compounds (Excluding Formaldehyde) Emissions from Wood-Based Panels Using Small Environmental Chambers Under Defined Test Conditions

D6670 Practice for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials/Products

D7339 Test Method for Determination of Volatile Organic Compounds Emitted from Carpet using a Specific Sorbent Tube and Thermal Desorption / Gas Chromatography

2.2 *Others Standards and Documents:*

EN 196-1 Methods of Testing Cement—Part 1: Determination of Strength[3]

EN 428 Resilient Floor Coverings—Determination of Overall Thickness[3]

EN 430 Resilient Floor Coverings—Determination of Mass per Unit Area[3]

EN 927-1 Paints and Varnishes—Coating Materials and Coating Systems for Exterior Wood[3]

EN 1937 Test Method for Hydraulic Setting Floor Smoothing and/or Leveling Compounds—Standard Mixing Procedures[3]

EN 13892-1 Methods of Test for Screed Materials—Part 2: Sampling, Making, and Curing Specimens for Test[3]

ISO 554 Standard Atmospheres for Conditioning and/or Testing[4]

ISO 1765 Machine-Made Textile Floor Coverings—Determination of Thickness[4]

ISO 2811 Paints and Varnishes—Determination of Density[4]

ISO 3233 Paints and Varnishes—Determination of Percentage Volume of Non-Volatile Matter by Measuring the Density of a Dried Coating[4]

ISO 3251 Paints and Varnishes—Determination of Non-Volatile Matter of Paints, Varnishes, and Binders for Paints and Varnishes[4]

ISO 8543 Textile Floor Coverings—Methods for Determination of Mass[4]

ISO 16000-6 Indoor Air—Part 6: Determination of Volatile Organic Compounds in Indoor and Test Chamber Air by Active Sampling on Tenax TA Sorbent, Thermal Desorption and Gas Chromatography Using MS/FID[4]

ISO 16000-9 Indoor Air—Part 9: Determination of the Emission of Volatile Organic Compounds from Building Products and Furnishing—Emission Test Chamber Method[4]

ISO 16000-10 Indoor Air—Part 10: Determination of the Emission of Volatile Organic Compounds from Building Products and Furnishing—Emission Test Cell Method[4]

ISO 16017-1 Indoor, Ambient and Workplace Air—Sampling and Analysis of Volatile Organic Compounds by Sorbent Tube/Thermal Desorption/Capillary Gas Chromatography—Part 1: Pumped Sampling[4]

EPA-600/4-89/017 U.S. EPA Compendium of Methods for Determination of Toxic Organic Compounds in Ambient Air.[5] This report contains U.S, EPA Method TO-17—Determination of Volatile Organic Compounds in Ambient Air using Active Sampling onto Sorbent Tubes.

Nordtest NT Build 438 (1995) Building Materials: Emission of Volatile Chemicals—Field and Laboratory Emission Cell[6]

3. Terminology

3.1 *Definitions*—For definitions and terms commonly used in ASTM standards, including this practice, refer to Terminology D1356. For definitions and terms commonly used when testing materials and products for VOC emissions, refer to Guide D5116. For an explanation of general units, symbols and conversion factors, refer to Practice D1914.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 For the purposes of this practice, the following terms and definitions apply.

3.2.2 *emission cell*—a portable device for the determination of volatile organic compounds emitted from indoor materials/products.

3.2.2.1 *Discussion*—The emission cell is placed against the surface of the test specimen, such that the surface of the test specimen itself becomes part of the emission cell. This is the fundamental difference between emission cells and emission chambers. The air inlet of the emission cell is designed such that the flow of air is directed over the surface of the test specimen.

3.2.2.2 *Discussion*—An example emission cell is described in Appendix X2.

4. Summary of Practice

4.1 Emission cells are suitable for relatively-homogeneous indoor materials/products, which present a planar surface to the emission cell.

NOTE 4—Small emissions chambers are similarly limited with respect to sample inhomogeneity. To overcome this issue, with either emission cells or small emission chambers, multiple measurements should be made from different parts of the same sample in order to obtain an average emission measurement.

4.2 Indoor materials/products which have a planar surface (wood-based panel products, dried paints or coatings, flooring products, textiles, foams, polymer sheeting, dried adhesive layers, and so forth) or which can be made to present a planar surface to the emission cell (polymer beads, carpet, mold cultures in Petri dishes, and so forth) are placed under the emission cell such that the test specimen itself forms one face of the emission cell. Pure, humidified air is passed into the cell through a baffle around the perimeter such that it passes over the whole surface of the test specimen. The temperature and humidity are closely controlled. As air passes over the test specimen, vapor-phase organics emitted from the surface are

---

[3] Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, http://www.cen.eu.

[4] Available from International Organization for Standardization (ISO), ISO Central Secretariat, BIBC II, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, http://www.iso.org.

[5] Available from National Technical Information Service (NTIS), Order No. PB90-116989, 5301 Shawnee Rd., Alexandria, VA 22312, http://www.ntis.gov.

[6] Available from Nordtest, Slettetoften 9, DK-2630 Taastrup, Denmark, http://www.nordtest.info.

swept away from the test specimen in the flow of air. The air/vapor exit (exhaust) point is usually located centrally, immediately above the test specimen surface, to avoid unswept volumes and sink effects (see 7.6 and Appendix X2). The exhaust air is fully mixed such that air sampled at the exit point is representative of the air in the cell. Approximately 80 % of the flow of air into the cell is pumped onto two sample tubes. The excess air is allowed to exhaust through an overflow vent to ensure that a slight positive pressure is maintained inside the cell to prevent ingress of background air.

4.3 The air flow rate is set such that the air velocity over the surface of the test specimen has no effect on the area specific emission rate (see 6.4). The emission tests are carried out at fixed times after preparation of the test specimen (for example, after 2 hours, 24 hours, 72 hours, 10 days, 28 days, 56 days, or 182 days (26 weeks)). Throughout the entire test period, test pieces shall either be kept under the emission cell under the flow of pure, humidified air, or stored in a clean, well-ventilated environment, under controlled conditions of temperature and humidity, with no risk of contamination from other samples or other emission sources.

NOTE 5—The air flow rate at the surface of the test specimen is particularly critical for wet indoor materials / products where the primary emission process is evaporation (external diffusion). In these cases, while it will remain possible to compare emission data from wet samples collected using similar emission cells under identical conditions, the non-uniformity and relative slowness of the air velocity at the surface of the test specimen, will make it difficult to compare emission cell data with that obtained using an emission chamber (see Appendix X4).

NOTE 6—Similar limitations make it difficult to compare emission data from two different small chambers or from the same chamber under different operating conditions, if that data is obtained during the drying/curing stages of a wet product.

4.4 The sample tubes used for collecting VOCs are analyzed by thermal desorption: gas chromatography (GC); usually with mass spectrometry (MS) and flame ionization detection (FID) to identify and quantify the target volatile organic compounds as described in Practice D6196, ISO 16000-6 or ISO 16017-1. The measured masses of volatile organic compounds retained by the sorbent tubes are then used to determine the area specific emission rates of the material or product. Alternative sampling and analytical techniques are used for formaldehyde (and for other carbonyls) as described in Test Method D5197.

5. Significance and Use

5.1 Indoor materials/products are products or materials used for construction works or in the indoor environment. The area specific emission rates of volatile organic compounds from an indoor material/product may be used to estimate the expected contribution of emissions from that material/product to the atmosphere of a given indoor environment.

5.2 Emission data may also be used to compare and categorize different indoor materials/products of similar function.

5.3 Emission cell testing of area specific emissions may alternatively be used for studying secondary interactions (for example, sink effects (absorption and re-emission of volatile organics by the indoor material/product) or emissions generated by chemical degradation of the indoor material/product caused by specific atmospheric agents such as water, ozone or NO_x).

6. Principles

6.1 *General Principles:*

6.1.1 Area specific emission rates at a given lapsed time (t) are calculated from the masses of target volatile organic compounds collected on the sample tubes, the flow of air pumped through each sample tube, the total flow of air entering the emission cell, the duration of the test and the exposed surface area of the test specimen. Area specific emission rates at a given lapsed time (t) can also be expressed as a function of the emission cell air concentrations for each VOC and the area specific air flow rate, q.

6.1.2 Air velocity at the surface of the test specimen (Appendix X3 and Appendix X4) is a critical parameter for the analysis of wet-applied indoor materials/products during the drying/curing stage when the dominant emission mechanism is evaporation (external diffusion) (see 6.4).

6.2 *Using Emission Data to Estimate Contribution to Atmospheric VOC Concentration Indoors:*

6.2.1 Provided the area specific air flow rate over the surface of the test specimen is similar to that found in the built environment, and provided the surface of the indoor material/product is sufficiently homogeneous to ensure that the area of the test specimen exposed in the emission cell is representative of the whole; area specific emission rates determined by these tests can be used to estimate the likely contribution to atmospheric VOC concentrations from that indoor material/product in real use, at time (t) after installation/application (assuming similar nominal conditions of temperature and humidity).

6.3 *Intercomparison of Emission Data:*

6.3.1 Provided the test conditions are duplicated, area specific emission rate data generated from these tests may be used for comparison with area specific emission rate data produced for the same or similar products by other laboratories using similar emission cells.

NOTE 7—The principles described in 6.2 and 6.3 are true for all applicable product types, whatever the dominant process of emission.

6.4 *Effect of the Emission Mechanism on Test Data and Comparison of Test Data:*

6.4.1 Provided the dominant emission mechanism is (internal) diffusion, not evaporation (external diffusion), area specific emission rate data will be broadly independent of air velocity over the surface of the indoor material/product. This will remain true provided the surface air velocity exceeds the minimum velocity required to prevent build up of vapor-phase contaminants at the surface of the indoor material/product (see Appendix X4).

6.4.2 Provided the dominant emission mechanism from a material/product is internal diffusion, it is possible to compare area specific emission rates generated from emission cells under different air flow conditions or to compare area specific emission rate data generated by emission cells with that obtained using test chambers (Guide D5116 or ISO 16000-9) (see Appendix X4).

NOTE 8—Evaporative emissions predominate during the drying/curing stages of wet-applied products and are significantly affected by the following factors: sample conditioning procedures; timing of the test; loading factor (and related vapor concentration within the cell); and air velocity over the test specimen surface. Comparative tests on wet-applied products during the drying/curing stage should therefore be carried out using identical equipment, conditions and procedures and using an air velocity which approximates to that seen in real-world use (**1-3**).[7] These restrictions apply in principle to both cells and small chambers.

NOTE 9—Emissions testing of wet-applied materials/products is typically carried out after the drying/curing stage, when internal diffusion-controlled emission processes predominate. This is more representative of real-world use. People or animals are unlikely to occupy a room or building until wet-applied coatings have dried or cured.

6.5 *Precautions for Inhomogeneous Materials:*

6.5.1 If the indoor material/product under test is not homogeneous (for example, natural wood), the test will have to be repeated for multiple test specimens of the same material in order to establish a mean area specific emission rate. This is also true in principle for emissions testing using small chambers.

6.6 *Controlling Key Test Parameters:*

6.6.1 In order to produce meaningful area specific emission rate data from emission cells or chambers (large or small), the following key parameters must meet minimum performance criteria:

6.6.1.1 Background interferences (see 8.2).

6.6.1.2 Control of humidity and temperature (see 8.1).

6.6.1.3 Control of the air velocity at the surface of the test specimen (see 7.3 and Appendix X3) and throughout the emission cell such that there are no unswept volumes (volumes of still air) and ideally such that it closely matches that expected under real use conditions. The latter is particularly relevant during evaporative (external) diffusion.

NOTE 10—The relationship between air flow rate into the emission cell and air velocity at the surface of the test specimen, for the type of emission cell described in Appendix X2, is discussed in Appendix X2 and Appendix X3.

6.6.2 Examples are presented in Table X2.1. Typical inlet air flow rates are in the order of 200 to 1400 mL/min, for the type of emission cell described in Appendix X2 (see 8.3).

6.6.2.1 Thorough mixing of the air such that the concentration at the sampling (exit/exhaust) point is representative of the air within the emission cell (see 7.3).

6.6.2.2 Air leaks (see 7.4).

6.6.2.3 Recovery and sink effects (see 7.6 and Appendix X5).

7. Apparatus

NOTE 11—General specifications and requirements, which apply to all types of emission cells, are given in 7.1 to 7.7 below. An example emission cell is described in Appendix X2.

NOTE 12—Quality assurance/quality control activities shall be carried out as described in Annex A1.

7.1 *Introduction:*

7.1.1 A complete emission cell system, designed and operated to determine area specific emission rates of VOCs from building products, shall comprise the following key components: emission cell, clean air generation and humidification system and monitoring and control systems (to ensure that the test is carried out in accordance with specified conditions). Appropriate sample tubes are also required.

NOTE 13—Analysis of VOC or carbonyl samples collected from emissions cells can be carried out remotely.

7.1.2 For rigid (non-compressible) materials/products with a smooth planar surface, the emission test cell is placed directly onto the surface of the test specimen. Other compressible or textured products shall be placed in specially constructed test specimen holders (see 7.7).

7.2 *Emission Cell Construction Materials:*

7.2.1 The emission cell itself and all parts of the sampling system that come into contact with emitted VOCs (all tubing and couplings) are normally made of surface treated (polished) stainless steel or glass. However, in all cases the requirements specified in 7.3 and 7.5 shall be fulfilled.

7.2.2 The sealing material (gasket or o-ring) which links together the emission cell and the test specimen (or test specimen holder) shall be low emitting and low absorbing and shall not contribute to the emission cell background concentration. It shall be easy to remove and replace the o-ring or gasket to facilitate cleaning of the emission cell.

7.3 *Air Supply and Mixing Facilities:*

7.3.1 The emission cell shall be supplied with pure and humidified air and have a device for controlling the air flow rate with an accuracy of ±3 %. The air velocity in the emission cell shall be distributed over the entire test specimen surface (see Appendix X3). There should be no volumes of still air within the cell. Inlet air flow rates between 200 and 1400 mL/min are typical for the type of emission cell described in Appendix X2 (see 8.3).

7.4 *Air Leaks:*

7.4.1 The emission cell shall be operated above atmospheric pressure to avoid any influence from the laboratory atmosphere. This is achieved by ensuring that the sum of the pump sampling flows is <90 % (typically 75–80 %) of the inlet flow rate. The excess air shall exit through an exhaust vent.

7.4.2 The emission cell is considered sufficiently leak-free if the inlet air flow differs from the sum of the outlet air flows (pump flow rates plus exhaust flow) by less than 10 %. This should be checked at the start of every recovery test (see 7.6), background test (see 12.1) and emissions test (see 12.6).

7.4.3 Indoor materials/products that are permeable to air shall be placed in air tight test specimen holders or sealed on to air tight, inert base plates to avoid permeation through the back of the test specimen.

7.5 *Air Sampling:*

7.5.1 The air at the emission cell outlet shall be used for sampling. Sampling of the outlet air (for example, with a sampling pump) is achieved by connecting sample tubes to the outlet couplings of the emission cell. The sum of sampling air flows shall be less than 90 % (typically 75–80 %) of the inlet air flow to the emission cell. The excess air shall exit through an exhaust vent.

---

[7] The boldface numbers in parentheses refer to the list of references at the end of this standard.

7.5.2 A multiport sampling manifold can provide the flexibility for duplicate air sampling. The sampling manifold shall enter directly into the outlet air stream of the emission cell. If a duct is used, it shall be as short as possible and maintained at the same temperature as the emission cell.

NOTE 14—The exhaust from the emission cell should be ducted into a fume hood, ensuring that any chemicals emitted from the test specimen are isolated from the laboratory environment.

7.6 *Recovery and Sink Effects:*

7.6.1 The recovery of a target VOC can be determined using a VOC source of known specific emission rate in the emission cell. This test can be carried out, for example, using permeation, or diffusion-controlled, vials of pure liquid VOC_x, sunk into a polished steel or glass plate and placed centrally under the emission cell (see Appendix X5). The concentrations generated shall be of similar magnitude to those expected during the emission tests of indoor materials/products.

NOTE 15—If a compound more volatile than toluene is being tested for recovery, it may be necessary to cap the vial, for example with a ground glass plug with a capillary hole through it, to reduce the rate of emission.

7.6.2 Recovery tests shall be performed in the emission cell using at least toluene and n-dodecane (see Note 17). An example polar compound such as ethylhexanol should also be used if any of the target VOCs are polar. Emission cell air concentrations shall be determined several times during the recovery test, typically 24–72 h after start of the test (see Note 19). Emission cell air concentrations shall be determined using the procedure outlined in 12.6 and an average air concentration established. At the end of the recovery test, the actual weight loss of the permeation, or diffusion-controlled, emission source, shall be measured and used to generate an expected average vapor concentration in the emission cell during the recovery test. The experimentally determined mean emission cell concentration of vapor must be at least 90 % of that expected from the actual weight loss of the emission source.

7.6.3 The results of this recovery test shall be reported in the test report as concentration expected versus concentration measured.

NOTE 16—Dehumidified air should be present in the case of determination of the recovery of hygroscopic VOCs such that weight measurements are not affected by the sorption of water. (This may not be necessary for permeation tubes, depending on the material of construction of the permeation tube).

NOTE 17—Failure to meet the minimum recovery requirements can be the result of leaks, poor calibration of the analytical system, and, possibly, sink/wall effects, especially for polar high boiling VOCs. It is a test of the performance of the whole procedure. Sink and adsorption characteristics are very much dependent on the type of compound emitted. Additional recovery tests using target VOCs with different molecular weight and polarity can be used to increase understanding of these effects.

NOTE 18—Emission cells as described in Appendix X2 have an exit centrally located, immediately above the surface of the test specimen and have polished, inner walls formed into a shallow trumpet shape which narrows towards the vapor exit. This reduces turbulence and helps eliminate volumes of still air thus minimizing risk of condensation and sink effects

NOTE 19—Recovery tests can be carried out over shorter periods of time (for example, 1–24 h) for more volatile analytes.

7.7 *Test Specimen Holders:*

7.7.1 Test specimen holders shall be designed such that the weight of the emission cell is carried by the rim of the test specimen holder, not the material itself. Test specimen holders shall have a flat rim with dimensions such that the emission cell o-ring or gasket seals effectively onto the rim of the holder. The internal dimensions of the holder shall match that of the exposed area of the test specimen within the cell. The depth of the test specimen holder shall be adjustable such that the test specimen surface can be raised or lowered to an appropriate height so that the internal volume of the emission cell is unaffected (relative to its volume when placed directly onto the surface of rigid products).

7.7.2 Preparation of test specimens for insertion into test specimen holders, in such a way as to minimize edge effects, is described in 10.4.

NOTE 20—Typical test specimen holders for the type of emission cell described in Appendix X2 comprise cylinders with an internal diameter of 15 cm and with adjustable depth. They also have a flat rim, >1-cm wide, with an appropriate diameter to match that of the sealing o-ring of the emission cell.

7.8 *Equipment:*

7.8.1 The apparatus necessary for carrying out tests with an emission cell are listed below:

7.8.1.1 Clean air supply (for example, pressurized purified air or synthetic air in gas cylinders),

7.8.1.2 Emission cell system,

7.8.1.3 Humidification system,

7.8.1.4 Humidity and temperature monitoring systems,

7.8.1.5 Capped, conditioned sample tubes containing one or more sorbents. (Tenax TA sorbent is most commonly used and is suitable for most compounds ranging in volatility from n-hexane to n-hexadecane. Further advice on sorbent selection (for example, for more or less volatile compounds) and on the preparation and use of sorbent tubes for thermal desorption is given in Practice D6196, ISO 16017-1, ISO 16000-6, and US EPA Method TO-17.) Each measurement typically requires four or five identical sample tubes: one or two for collecting a sample from the blank emission cell as a background check (see 12.1), two for air sample collection during the emissions test (see 12.5), and one to be used as a blank.

NOTE 21—A suitable internal standard (for example deuterated toluene) can be added to blank tubes prior to air sample collection if desired. Recovery of the internal standard, determined during subsequent TD-GC-MS analysis, can then be used as a check on the entire process of sample tube storage, air sample collection and analysis (see A1.4).

7.8.1.6 Two sampling pumps capable of pumping flows of 80-500 mL/min through sorbent tubes and calibrated in accordance with Practice D5337. Constant flow type pumps, offering electronic mass flow control, are recommended.

7.8.1.7 One or more calibrated air flow meters.

7.8.1.8 Suitable test specimen holders (if required, see 7.1).

7.8.1.9 Facilities for recovery testing (see Appendix X5).

7.8.1.10 Either a cleaning agent for the emission cell or a vacuum oven for heating and cleaning the emission cell.

NOTE 22—The apparatus listed here is for sampling general VOCs and is described in more detail in Practice D6196. Alternative sampling apparatus for formaldehyde and other carbonyls is described in Test Method D5197.

8. Test Conditions

8.1 *Temperature and Relative Humidity:*

8.1.1 Temperature and relative humidity inside the emission cell shall be 23 ± 2°C and 50 ± 5 % RH during the emission test (see ISO 554) unless there is some specific alternative testing requirement (for example, if the indoor material/product is used at elevated temperatures in real world applications, or if it is only used in dry (for example, desert) environments).

8.2 *Quality of Supplied Air and Background Concentrations of VOCs:*

8.2.1 Supplied air shall not contain any VOCs at levels greater than the emission cell background requirements.

8.2.2 The sum of VOC (TVOC) (see Practice D6330) background concentration shall be lower than 20 µg.m–3. The background concentration of any single target VOC shall be lower than 2 µg.m–3.

8.2.3 Emissions tests for specific target VOCs can be carried out at lower concentrations, but background levels of target compounds shall be shown to be below 10 % of measured emission cell concentrations in all cases.

8.2.4 Water used for humidification shall not contain interfering VOCs.

8.3 *Air Velocity:*

8.3.1 The air velocity over the surface of the test specimen shall be in the range of 0.003 m.s–1 to 0.1 m.s–1 (see Appendix X2 and Appendix X3) which, for the type of emission cell described in Appendix X2, will require an inlet air flow rate in the range 100 to 2800 mL/min (see Table X2.1). Typical inlet air flow rates are in the range 200 to 1400 mL/min with associated tube sampling rates of 80 to 500 mL/min, respectively.

NOTE 23—Air velocity is generally significant for evaporative controlled (external diffusion) emissions, for example, from liquid products before they have dried/cured (see Section 6). This depends on the substrate.

NOTE 24—For certain types of material/product, secondary source emissions can occur at high air velocities.

NOTE 25—Examples of air velocity calculations are given in Appendix X2 and Appendix X3.

8.4 *Relationship Between Air Flow Rate, Air Change Rate, and Vapor Concentrations:*

8.4.1 Vapor concentrations inside the emission cell depend on air flow rate, the exposed surface area of the test specimen and the area specific emission rate.

8.4.2 The air change rate is simply a function of the volume of the cell and the air flow rate and has no independent impact on VOC emissions or vapor concentrations inside the emission cell.

NOTE 26—Example air change rates for one type of emission cell are shown in Table X2.1 of Appendix X2.

9. Verification of Test Conditions

9.1 *General:*

9.1.1 All control measures shall be traceable to a certified standard in accordance with the quality assurance and quality control schemes (see Annex A1).

9.2 *Temperature and Relative Humidity Control Systems:*

9.2.1 Control of temperature can be made by placing the emission cell within a location controlled to the required temperature.

9.2.2 Control of relative humidity can be made by various systems (for example, using integrated humidification of the air supply).

9.2.3 Temperature and relative humidity shall be measured independently of the systems for controlling the temperature and relative humidity.

9.3 *Test Conditions in the Emission Cell:*

9.3.1 Temperature, relative humidity, and air flow rate shall be measured with the following accuracy:

9.3.1.1 Temperature ±0.1°C,

9.3.1.2 Relative humidity ±3 % RH, and

9.3.1.3 Air flow rate ±3 %.

9.3.2 The relative humidity shall be measured at the outlet from the emission cell. The temperature sensors shall be placed either in the emission cell or in the air outlet.

9.4 *Air Flow Rate and Air Velocity in the Emission Cell:*

9.4.1 The inlet and outlet air flow rates shall be checked and readjusted prior to air sampling using a non-restricting calibrated gas flow meter. The air flow rates shall not vary by more than ±3 % of the set value. For the type of emission cell described in Appendix X2, typical (inlet) air flow rates are in the range of 200–1400 cm3.min–1 and typical pumped sample collection flow rates are in the order of 80–500 cm3.min–1. The air velocity in the emission cell can be calculated from the air flow rate (see Appendix X2 and Appendix X3).

NOTE 27—If the test is carried out with a gas volume meter/flow meter, which is not permanently installed, be aware that the back pressure, introduced by the meter, can lower the flow rate through the emission cell.

9.5 *Air Leaks Into or Out of the Emission Cell:*

9.5.1 Air leaks into or out of the emission cell shall be checked at the beginning of every recovery, background and emissions test (see 7.4).

10. Test Specimens

10.1 Studies of the emission of volatile organic compounds from unused indoor materials/products in emission cells require proper handling of the test specimen prior to testing, and during the testing period.

10.2 This practice is generic and can be applied to many different indoor materials/products. Types of indoor materials/products are defined as solid, liquid and combined. For each type of product the sampling procedure, transport conditions, storage, and substrate used (which can all affect emissions) shall be specified in the test report. For individual materials/products within each product class, the preparation of the test specimen is prescribed in Annex A2 and Annex A3.

NOTE 28—Depending on the inhomogeneity of the material/product, it can be necessary to make measurements on multiple test specimens from the same sample to determine the mean specific emission rate (see 6.5).

10.3 *Product Sampling and Sample Transport/Storage:*

10.3.1 *Sampling of Indoor Materials/Products to be Tested:*

10.3.1.1 Samples of materials/products collected at the point of manufacture shall be taken from the normal manufacturing process. Product samples can also be collected from retail stores.

10.3.2 *Sample Packaging and Transport:*

10.3.2.1 Samples shall be thoroughly protected from chemical contamination or any physical exposure (for example, heat, light, humidity, and contaminated atmospheres). For solid products, this can usually be achieved by shipping the product inside the manufacturers packaging or, if this is too large for practical purposes, by selecting a sample (Annex A2), wrapping it separately in aluminum foil and then placing it in a polyethylene bag. Alternatively, each sample can be wrapped in aluminized packaging lined with polyethylene or clear polyvinyl fluoride film. Samples should be wrapped within one hour of selecting them at the production line. Liquid products shall be shipped in unopened cans, tubes, and so forth (see Annex A3).

NOTE 29—Transportation of collected samples can affect the emission characteristics of the product. The possible effects of temperature, humidity and high VOC levels are of particular concern.

10.3.3 *Sample Description:*

10.3.3.1 The sample shall be labeled with the details of the source (store or manufacturer), source location, type of product, date of manufacture (if known), any identification numbers, (for example, batch numbers), and details of the complete chain of custody between source and receipt at the laboratory.

10.3.4 *Sample Storage Prior to Testing:*

10.3.4.1 In many cases it is necessary to store the sample in the laboratory before starting the test. The sample shall be kept in its packaging (see 10.3.2), and stored under normal indoor conditions (23 ± 5°C, 50 ± 5 % RH) before testing begins.

NOTE 30—Storage may affect the emission properties due to ageing of the sample even if it is well wrapped. It is recommended to minimize the storage time of the sample before it is prepared for emissions testing.

10.4 *Test Specimen Preparation:*

10.4.1 The procedures to be used for preparing different types of sample/test specimen for emissions testing are prescribed in Annex A2 and Annex A3 and described in Appendix X6. The period of time between unpacking the sample and preparation of the test specimen shall be as short as possible and shall be recorded. After preparation of the test specimen, it shall immediately be put in conditioned storage in accordance with Section 8 and 12.5 or under the emission cell itself. This time shall be regarded as the starting time of the emission test (that is, $t = t_0$).

10.4.2 If the indoor material/product is compressible or textured and requires a test specimen holder, the size of the test specimen taken should be such that it is a tight fit inside the test specimen holder to eliminate edge effects. Once a test specimen has been placed inside a holder at time t_0 it should be stored in that specimen holder (either under the emission cell or in the conditioned storage area) throughout the duration of the emissions test.

10.4.3 If the material/product is permeable, secure the underside of the test specimen to a sheet of clean glass or stainless steel using non-contaminating aluminum tape (see A2.3.1).

11. Emission Cell Preparation

11.1 The emission cell shall be cleaned in accordance with either 11.2 or 11.3.

NOTE 31—It will be necessary to remove the sealing material (gasket or o-ring) before cleaning the emission cell by either method.

11.2 *Cleaning Using a Detergent:*

11.2.1 The emission cell can be cleaned by washing the inner surface with a diluted alkaline detergent, followed by two separate rinsings with freshly distilled water. The inner surface is then washed with non-denatured ethanol or another appropriate solvent.

11.3 *Cleaning by Thermal Desorption:*

11.3.1 The emission cell can also be cleaned by heating in a vacuum oven at elevated temperature (70°C to 100°C) for approximately two hours.

12. Test Method

12.1 *Measuring Background Concentrations:*

12.1.1 An air sample of the emission cell background is taken before the start of an emission test to quantify any background contribution of volatile organic compounds from the air supply or from the emission cell apparatus itself.

12.1.2 Place the emission cell, complete with its sealing material (o-ring or gasket) on a clean and planar surface (for example, a glass or stainless steel plate). Set the air flow to a similar rate to that to be used for emissions testing and flush the emission cell with clean, humidified air, to vent, for approximately 15 minutes. Check for leakage in accordance with 7.4. Connect one or two conditioned sample tube and pump assemblies to the outlet ports of the emission cell, setting similar sample flows to those to be used for materials emissions testing (see 12.6). Check the inlet and sampling air flows quickly at the beginning of the background test (see 7.4).

12.1.3 Background concentrations shall meet the requirements in 8.2.

12.2 *Test Specimen Location in the Emission Cell:*

12.2.1 If the indoor material/product to be tested is not to be stored under the emission cell, it must be placed (or replaced) under the emission cell at least 15 minutes prior to air sample collection (in the case of most dry materials/products) or at least two hours prior to air sample collection whenever the test specimen is a dried/cured coating or target compounds include highly polar species. The supply of clean humidified air must be turned on as soon as the emission cell is placed over the test specimen. The positioning of the emission cell shall ensure that the air flow is distributed over the entire emitting surface of the test specimen.

NOTE 32—The action of placing the emission cell on the surface of the product or material must not distort the test specimen surface. If the indoor material/product is compressible or textured, it must be placed in a suitable test specimen holder such that the weight of the cell seals onto the rim of the test specimen holder not onto the product itself (see 7.1).

12.3 *Preparation for Air Sample Collection:*

12.3.1 The inlet air flow rate should be selected based on the target air velocity or area specific air flow rate. For the type of emission cell described in Appendix X2, example inlet air flow rates and respective air velocities and area specific air flow rates are given in Table X2.1. Two conditioned and calibrated sample tube and pump assemblies should be connected to the outlet ports of the emission cell. When the pumps are switched on, this marks the beginning of air sample collection. Quickly check for leaks (see 7.4).

NOTE 33—In order to ensure that the air inside the test cell is maintained at slight positive pressure, the sum of the sampled air flows must not exceed 90 % of the inlet air flow. This means that if the inlet air flow rate is required to be set at 200 mL/min, the two air samples are typically collected at 80 mL/min. Similarly if the inlet air flow rate is required to be set at 500 mL/min, the two air samples are usually collected at 200 mL/min.

12.4 *Time for Measurements of Emission Cell Air Concentration:*

12.4.1 The concentration measurements shall be carried out at predefined sampling times, depending on the objective of the test. Emission test duration is determined by the objective of the test. (More information on test duration is given in 12.6.)

NOTE 34—Typical sample collection times are 2 hours, 24 hours, 72 hours, 10 days, 28 days, 56 days, and 182 days (26 weeks) after preparation of the test specimen at time t_0.

NOTE 35—The mid-point of the period of air sample collection is considered the sampling time.

12.5 *Storage of Test Specimen between Emission Tests:*

12.5.1 Throughout the entire test period, test specimens shall either be kept under the test cell under the flow of pure humidified air, or stored in clean, well-ventilated environments, under controlled conditions of temperature and humidity, with minimal risk of contamination from other samples or other emission sources (see Section 8).

12.6 *Air Sample Collection:*

12.6.1 Two air samples shall be collected at each sampling time whenever practicable. The duration of each air sample collection period depends on the analytical methods to be used and shall be documented. Typical air sample collection periods for general VOCs range from 15 minutes to 2 hours and typical pumped sample flow rates used for air sample collection range from 80 to 500 cm3.min–1. Follow guidance given in Practice D6196 or Test Method D5197. Different pump flow rates within this range may be used to sample onto each of the two sample tubes attached to the emission cell, provided that the actual period of sample collection is the same.

12.7 *Sealing the Sample Tubes after Air Sample Collection:*

12.7.1 Sampling pumps shall be switched off at the end of air sample collection and the duration of air sampling recorded. Sample tubes shall be disconnected from the sample pumps and emission cell immediately after air sample collection and quickly resealed using appropriate caps and fittings (see Practice D6196 and Test Method D5197). Store the sample tubes carefully before analysis following guidance given in Practice D6196 or Test Method D5197, appropriately.

12.8 *Cleaning the Emission Cell after Use:*

12.8.1 At the end of air sample collection, the emission cell shall be cleaned in accordance with Section 11.

13. Calculation of Area Specific Emission Rates (SER_a) and Expression of Results

13.1 *Calculation of SER_a*—The process of determining area specific emission rates from experiments using emission test cells is based on the same fundamental principles as used for other emission test apparatus. See Guide D5116, Test Method D7339, ISO 16000-6, ISO 16000-9, and ISO 16000-10.

13.2 *Calculation of SER_a from Experimental Parameters and Data—Assuming Negligible Background*—Parameters known or determined during the emission test are as follows:

13.2.1 A = Surface area of test specimen exposed to the clean humidified air ($cm^2 = (m^2 \times 10^4)$).

13.2.2 M_1 and M_2 = Mass of each target VOC_x retained by the first and second sample tubes respectively ($\mu g = ng \times 10^{-3}$)—Determined using a calibrated thermal desorption-GC-MS/FID analytical system and following Practice D6196, ISO 16000-6, ISO 16017-1, or equivalent. Alternatively, use Test Method D5197 for formaldehyde.

13.2.3 F = Flow rate of pure, humidified air into the cell (cm3.min–1 = (m3.h–1 × 10^5/6)).

13.2.4 F_1 and F_2 = Pump air flow rates through the first and second sample tubes respectively (cm3.min–1 = m3.h–1 × 10^5/6).

13.2.5 T = Duration of test (min = h × 60).

13.2.6 V = Volume of air ($cm^3 = (m^3 \times 10^6)$) passed into the cell during the emission test = F × T.

13.2.7 V_1 and V_2 = Volumes of air ($cm^3 = (m^3 \times 10^6)$) pumped through the first and second sample tube respectively = $F_1 \times T$ and $F_2 \times T$, respectively.

13.2.8 C_x = Concentration of x vapor within the emission cell (ng.cm–3 = µg.m–3 × 10^{-3}) = mean of that determined from sample Tube 1 (M_1/V_1) and that determined from sample Tube 2 (M_2/V_2).

NOTE 36—This practice requires the use of two parallel sample tubes monitoring the exhaust gases from the emission cell, whenever practicable. C_x derived from sample Tube 1 shall agree within 10 % to that derived from sample Tube 2 or the test must be repeated.

13.2.9 Assuming negligible background of each target VOC, the area specific emission rate SER_a for VOC_x can be simply derived from these parameters as follows:

13.2.10 Mass of x (µg) emitted by the exposed area of sample during the emissions test (M_x) is derived as follows:

$$M_x = C_x\,(\text{that is, mean of } M_1/V_1 \text{ and } M_2/V_2) \times V \qquad (1)$$

13.2.11 To derive the mass of x (µg) emitted by the exposed area of sample per hour, multiply M_x by 60 and divide by the actual duration of the test in minutes:

$$= M_x \times (60/T) \qquad (2)$$

13.2.12 To derive the area specific emission rate, at time (t), in µg.m–2.h–1, multiply the result from Eq 2 by 10 000 (cm^2) and divide by the actual test specimen area exposed (cm^2):

$$SER_a = M_x \times (60/T) \times 10\,000/A \qquad (3)$$

NOTE 37—The actual test specimen surface area exposed in the type of emission cell described in Appendix X2 is 177 cm^2.

13.3 *Background Correction of SER_a Data:*

13.3.1 To correct for background concentrations of VOC_x, derive the effective area specific emission rate (µg.m2.h–1) for the blank emission test (see 12.1) following the steps described in 13.2 and subtract this from the experimentally derived area specific emission rate for the test specimen.

NOTE 38—High background concentrations of target VOCs will invalidate the emissions test (see 8.2).

13.4 *Deriving Units for Comparison with Small Chamber Emission Tests:*

L = surface area (m^2) of test specimen exposed in cell/cell volume (m^3)

n = air change rate (changes per hour) = air flow rate entering cell (cm3.h–1)/volume of cell (cm^3)

q = area specific air flow rate = n/L

13.5 *Deriving SER_a from Vapor Concentration Using Analogous Methods to Those Used for Small Chamber Emissions Tests:*

13.5.1 At a given test condition, C_x depends on the area specific emission rate of the test specimen and the air flow rate through the emission test cell. For individual VOCs, the compounds found both in the material and in the background shall be subtracted compound by compound. For TVOC the measured background shall be subtracted. The relation between C_x, the area specific emission rate (SER_a) and the area specific air flow rate (q) of the emission test cell can be expressed as:

$$C_x = SER_a \,.\, (L/n) = SER_a/q \qquad (4)$$

13.5.2 Eq 4 shows that the area specific air flow rate equals the n/L ratio. For a given product tested under given emission test cell conditions, the concentration of VOC_x depends on the area specific air flow rate. C_x is the mean concentration of VOC_x calculated from a duplicate air sample as described in 13.2:

$$SER_a \times = C_x \,.\, q \text{ at time } (t) \qquad (5)$$

13.6 *Relating SER_a to the Time of the Emission Measurement:*

13.6.1 The result shall be related to the time of the emission measurement after t_0 and may be reported quantitatively as the area specific emission rate, of individual VOCs, or TVOC, or both, at time (t).

NOTE 39—The sum of emitted compounds, TVOC (see Practice D6330), should be regarded only as a factor specific to the product studied and to the monitoring method used. It is therefore only to be used for comparison of products with similar target VOC profiles if exactly the same test method has been used for each comparative measurement.

14. Test Report

14.1 The test report shall include the following information:

14.1.1 *Test Laboratory:*

14.1.1.1 Name and address of the laboratory,

14.1.1.2 Name of the responsible person,

14.1.1.3 Reference to this practice, and

14.1.1.4 Reference to the appropriate in-house protocol or detailed description of the equipment and methods used (that is, test cell, clean air system, environmental control, sample collection, analytical instrumentation, standard generation, and calibration);

14.1.2 *Sample/Test Specimen Description:*

14.1.2.1 Type of product (and brand name if appropriate),

14.1.2.2 Sample selection process (for example, random),

14.1.2.3 Product history (that is, date of production, date of arrival to the test laboratory), and

14.1.2.4 Description of packaging.

14.1.3 *Test Specimen Preparation:*

14.1.3.1 Date and time of unpacking and test specimens preparation [hour, day, month and year], and

14.1.3.2 Method of preparation, including thickness and substrate.

14.1.4 *Experimental Conditions and Procedures:*

14.1.4.1 Test cell conditions (that is, temperature, relative humidity, air change rate, air velocity),

14.1.4.2 Test specimen area and loading ratio (for liquid products, for example, paint, describe sample substrate and coating procedure, paint thickness and coating density [net mg/cm^2]),

14.1.4.3 Sampling of emitted compounds (that is, adsorbent used, volume sampled, sampling duration and times after introduction into the cell), and

14.1.4.4 Analytical conditions used (that is, thermal desorption parameters, GC column selected, GC-MS conditions, and so forth).

14.1.5 *Data Analysis:*

14.1.5.1 Describe the method used to derive specific emission rates from measured cell concentrations (specify mathematical models or equations used).

14.1.6 *Results:*

14.1.6.1 Specific emission rates shall be reported for each test specimen, for individual VOCs, or TVOC, or both, at the times of air sampling.

14.1.7 *Quality Assurance/Quality Control:*

14.1.7.1 Background test cell concentrations of target compounds,

14.1.7.2 Recovery data of toluene and n-dodecane (to evaluate the overall performance),

14.1.7.3 Recovery data for the three most significant target VOCs,

14.1.7.4 Results of duplicate sampling/analysis, and

14.1.7.5 Quality of the environmental variables (that is, temperature, relative humidity, air change rate, air velocity).

15. Keywords

15.1 emissions cells; indoor air quality; indoor materials; indoor products; materials emissions testing; organic emissions; volatile organic compounds

ANNEXES

(Mandatory Information)

A1. SYSTEM FOR QUALITY ASSURANCE/QUALITY CONTROL

A1.1 General

A1.1.1 Emission cell testing of organic emissions from indoor materials/products shall be conducted within the framework of a Quality Assurance Project Plan (QAPP). The QAPP shall contain a project description, data quality objectives/acceptance criteria, QA/QC approaches/activities, and QA/QC audits.

A1.2 Project Description

A1.2.1 A brief description shall include what materials are to be tested; how the testing is to be conducted; and who is responsible for various project activities. The project experimental design shall contain the necessary information for this portion of the QAPP.

A1.3 Data Quality Objectives/Acceptance Criteria

A1.3.1 This section of the QAPP defines the precision, accuracy, and completeness desired for each parameter being measured.

A1.4 QA/QC Approaches/Activities

A1.4.1 The types of QA/QC activities that can be specified in the QAPP include establishment of a system of records/notebooks to ensure proper operation of equipment and recording of data, such as:

A1.4.1.1 Sample log to record receipt, storage, and disposition of materials,

A1.4.1.2 GC standards preparation log to document preparation of all organic compound substances,

A1.4.1.3 Permeation/diffusion tube log to record weight loss data for all permeation/diffusion tubes used during recovery measurements,

A1.4.1.4 Calibration logs to contain environmental systems calibration data,

A1.4.1.5 Instrument maintenance logs to document maintenance and repairs of all equipment,

A1.4.1.6 Materials testing logs in which to record all pertinent information for each test, including sample details, sample ID number, and GC run ID number,

A1.4.1.7 Sorbent cartridge cleanup/desorption log detailing thermal cleanup and QC validation of sorbent cartridges,

A1.4.1.8 Floppy disk storage log to document location and content of electronically stored data, and

A1.4.1.9 Manuals governing operation of all equipment used by the project.

A1.4.2 QC activities are carried out by project staff in a routine, consistent manner to provide necessary feedback in operation of all measurement systems. Such activities are described in this and associated standards such as Practice D6196 or Test Method D5197 and can include:

A1.4.2.1 Routine maintenance and calibration of equipment and analytical systems used,

A1.4.2.2 Daily recording of GC calibration accuracy and precision (that is, control charting),

A1.4.2.3 Monitoring of percent recovery of internal standard, if added, to blank or sampled tubes,

A1.4.2.4 Correlation of data from duplicate samples,

A1.4.2.5 QC checking of the blank profile of organic collection sorbent tubes, and

A1.4.2.6 Periodic analysis of audit gases or certified standard reference tubes (pre-loaded with traceable masses of target VOCs) supplied by an independent source.

A1.5 QA/QC Audits

A1.5.1 Finally, the QA/QC program shall include periodic audits by QA personnel to evaluate compliance with QAPP protocols.

A2. SOLID PRODUCTS—PROCEDURE FOR SAMPLING AND TEST SPECIMEN PREPARATION

A2.1 General

A2.1.1 This method covers only unused products.

A2.2 Sampling

A2.2.1 *Selection of Samples from Rolls:*

A2.2.1.1 Discard one metre or at least the outer layer of the roll to take the sample (Fig. A2.1). Cut out a large sample (typically >1.2 m^2).

A2.2.1.2 Roll the sample up in the same direction as the original production roll and make sure that the roll is several layers thick. Secure with staples, wrap it in aluminum foil, and seal it in an unprinted, air tight (sealable) polyethylene bag. Each bag shall contain only one sample. Minimize the air space within the package. An alternative approach is to cut several 60 by 60 cm (or larger) squares and stack at them at least four high, before wrapping the set in aluminum foil. This approach helps minimize the volume of air inside the package. Not more than 1 h shall elapse from the time of selecting the test piece to placing it in the polyethylene bag. Pack the samples carefully and send them straight to the testing laboratory.

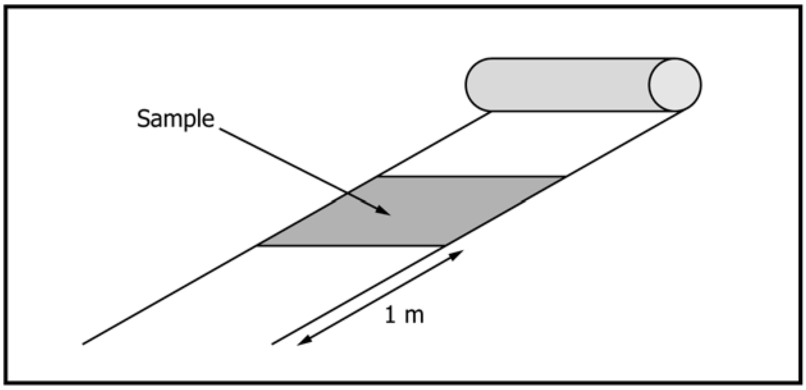

FIG. A2.1 Selection of Samples from Rolled Materials/Products

A2.2.2 *Selection of Samples of Rigid Products:*

A2.2.2.1 Send an unopened standard package of the material/product to the testing laboratory. Boards are transported in the normal manufacturer's delivery package unless the delivery package is large and impractical to handle. In this case a sample may be taken from the middle of a board and enclosed in air tight wrapping (see A2.2.1) for more convenient transportation. Tiles, laminated parquets and other products assembled from pieces are transported to the laboratory for emission testing in their original packaging.

A2.3 Preparation of Test Specimens

A2.3.1 *Preparing Test Specimens from Samples from Rolls:*

A2.3.1.1 Unpack the sample and select an appropriate area of the material/product at least 50 cm from any edge and cut out a test specimen (see Fig. A2.2). If a stack of multiple samples of the same product has been packaged together as described in A2.2.1, use one of the sheets from the center of the stack and cut the test specimen at least 10 cm from any edge. The area of the test specimen must be large enough for the emission cell. If the material/product is permeable, secure the underside of the test specimen to a sheet of clean glass or stainless steel without using adhesive. If the material/product is compressible or textured/contoured the test specimen must be cut out and placed into a suitable test specimen holder (see 7.7 and 10.4).

A2.3.2 *Preparing Test Specimens from Samples of Rigid Products:*

A2.3.2.1 Tiles, panels, and so forth are taken from the middle of the package and assembled side by side (see Fig. A2.3). If the surface to be tested is composed of several pieces as for example, laminated parquets or flooring tiles, the joints in the test piece shall be proportionally distributed over the surface of the test specimen (that is, the proportion of joint length to tile area shall be the same in the test specimen as in the finished floor). No adhesive shall be used in the joints. As an example, when parquet/laminate flooring is to be tested, at least two panels are to be taken from the middle of the package and the tongue and the groove pushed together without using an adhesive.

A2.3.3 *Preparing Test Specimens from Samples of Boards:*

A2.3.3.1 Test specimen from boards are selected excluding a (minimum) 50-cm wide strip at both ends of the board (see Fig. A2.4). If the material/product is permeable, secure the underside of the test specimen to a sheet of clean glass or stainless steel without using adhesive. Additional information is available in related standards such as Nordtest NT Build 438.

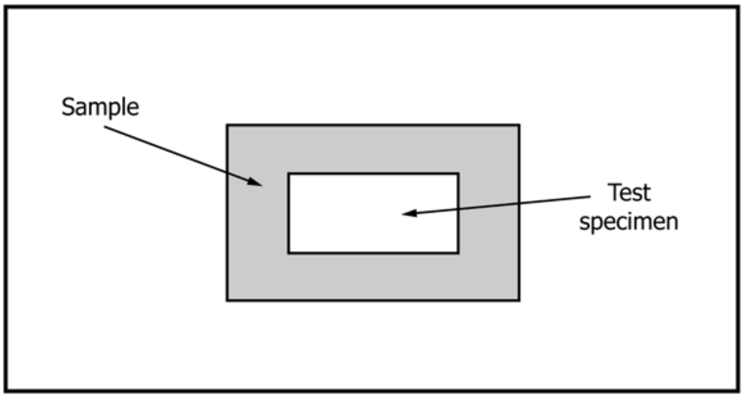

FIG. A2.2 Preparing Test Specimens from Samples from Rolls

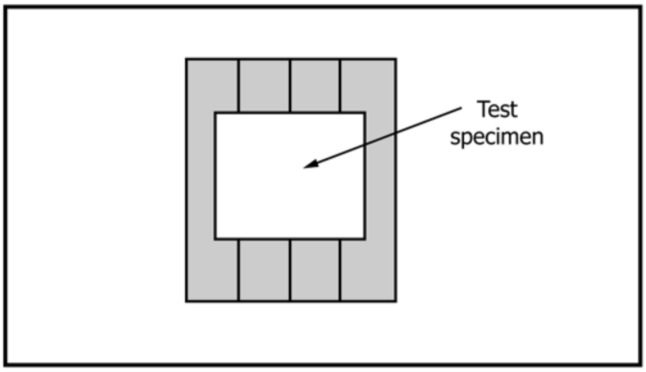

FIG. A2.3 Preparing Test Specimens from Samples of Rigid Products Composed of Several Pieces

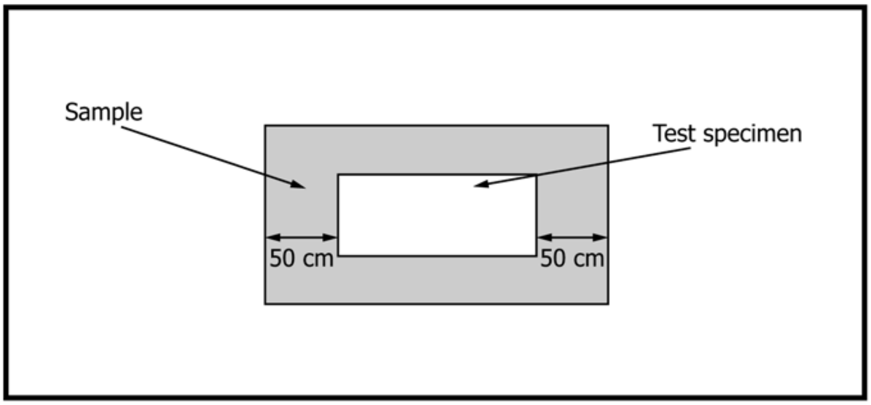

FIG. A2.4 Preparing Test Specimens from Samples of Boards

A3. LIQUID PRODUCTS—PROCEDURE FOR SAMPLING AND TEST SPECIMEN PREPARATION

A3.1 Introduction (Life Cycle of Liquid Products)

A3.1.1 After application, liquid products begin a life cycle which normally comprises three stages:

(1) The liquid product undergoes a physical transformation from the liquid state to the solid state. This takes place by evaporation of volatile components (water, or organic solvents, or both). In some cases, the transition is achieved by a chemical reaction.

(2) Transition to the final state via a physical or chemical process.

(3) When the product has reached its final state, the specific emission rates are expected to be considerably lower than during Stages 1 and 2.

A3.2 Test Specimen Preparation

A3.2 Since the solid content of liquid products differs widely depending on the type of binder, nature of intended use, appearance and formulation, it is essential, in order to obtain comparative results, that tests are undertaken using a reproducible method of application that is appropriate for the product type.

A3.2.1 *Paints, Varnishes, and Impregnating Primers:*

A3.2.1.1 *Classification of a Paint Product:*

(1) The product shall be classified in accordance with the dry film thickness recommended by the manufacturer. The emission test shall be performed using the dry film thickness specified for that class of product (see Table A3.1).

TABLE A3.1 Classification of Product by Dry Film Thickness[A]

Class	Manufacturers' Recommended Mean Dry Film Thickness, –T_m	Dry Film Thickness Chosen for Testing, –T_c
minimal	<5 µm	5 µm
low	5–20 µm	15 µm
medium	20–60 µm	40 µm
high	>60 µm	60 µm

[A] The information in this table can be found in EN 927-1:1996.

(2) The recommended paint usage is given by the manufacturer in square metres per litre of wet product. The resulting dry film thickness is then calculated in accordance with

$$T_m = (S/X) \times 10 \tag{A3.1}$$

where:

T_m = dry film thickness following recommendations of the manufacturer, in µm,
S = solid content of the paint in % by volume, and
X = recommended amount of product in square metres per litre wet product.

(3) The film thickness class in which the product is tested shall be given in the test report.

NOTE A3.1—In most cases, painting is carried out as multi-layer systems of various paints of different function. The simplest form of system painting (excluding simple repainting) consists of a primer and a top coat. Other more complicated systems include floor paints for concrete which are built up by a primer, a clear varnish with decorative flakes, and then 1–2 layers of clear varnishes on top. Another example of composite applications is stains for interior walls consisting of a primer, a thin layer of stain, and then 1–2 layers of clear varnish on top.

NOTE A3.2—Depending on the objective of the emission study, a paint can be tested separately or in a composite paint system. Paint systems are tested as combined products (see Appendix X6).

NOTE A3.3—For certain purposes (for example, assessment of health effects), the paint or varnish can be applied to absorbent materials and treated as a combined product (see Appendix X6). In this case, more realistic substrates, such as wood based panels, gypsum board or flooring materials should be used. The use of such substrates will, in most cases, give a different specific emission rate to the same product when applied to glass, stainless steel or polyester.

NOTE A3.4—Penetrating wood stains, oils, and waxes may also be tested as combined products, (that is, on substrates other than glass, stainless steel or polyester) (see Appendix X6).

A3.2.1.2 *Preparation of the Test Specimen:*

(1) The product shall be applied on a substrate of glass, or stainless steel or a polyester sheet of sufficient rigidity (minimum 150 µm thick). The product shall be applied to the substrate using suitable equipment (brushes, spray pistols, rollers, spatulas or drawdown bars) to produce an even film of the required thickness. The quantity of wet product applied to a certain area to receive a specified dry film thickness is calculated in accordance with:

$$\Omega = (T_c \cdot \alpha \cdot \delta)/(S \cdot 100) \tag{A3.2}$$

where:

Ω = the amount of wet product to be applied, in grams,
T_c = dry film thickness chosen for testing, in µm (see Table A3.1),
α = painted area in square centimetres,
δ = density of wet product in g.cm–3 (given by the manufacturer), and
S = solid content of the product in % by volume (given by the manufacturer),

(2) To assess that the correct amount of paint is added to the test substrate, the substrate shall be weighed before and after application of the product.

(3) Density can also be measured in accordance with ISO 2811-1974. Solid content in % by volume can also be measured in accordance with ISO 3233-1984 or calculated from the solid content in % by weight as measured in accordance with EN ISO 3251.

A3.2.2 *Adhesives*—The product shall be applied to a glass or stainless steel plate. Mechanically stir the sample until it is homogeneous. Transfer an excess of sample onto a weighed base plate and spread it uniformly with a trowel notched in accordance with manufacturers' specifications. Weigh the base plate again and add or remove more adhesive until it is an even film, covering the whole plate, weighing 300 ± 15 g.m–2. Complete application of the product to the glass or steel plate within five minutes.

NOTE A3.5—If anything other than a thin film is applied and if there is any danger of the adhesive, or any other material, touching the inner surfaces of the emission cell, the sample should be applied to a disc substrate that can subsequently be inserted into a cylindrical specimen holder of adjustable depth (see 7.7).

A3.2.3 *Leveling Compounds, Synthetic Resin Flooring and Plasters*—Mix the material in accordance with EN 1937 or EN 13892-1. Place a 3-mm thick, uniform layer of the mixture onto a glass or stainless steel plate. Use a plate with a glass or stainless steel border or an inert, 3-mm deep mold for low-viscosity leveling compounds. High-viscosity products can be applied with a flat spatula.

A3.2.4 *Screed Materials Other Than H 2.3; and Concrete*—Mix the material and fill the molds in accordance with EN 13892-1. The molds shall be made of emission-free material having an appropriate size in accordance with the test cell and a depth of 50 ± 1 mm. Make sure that the molds are level, and filled to the rim. Some materials (for example, concrete), may settle during the first hours with some water forming on the surface. In such a case, the surface is finished with a steel tool after the water has evaporated.

A3.2.5 *Sealants and Fillers*—Test specimens shall be prepared in an inert mold of depth 3 mm and width 10 mm. The length of the test specimen depends on the test cell. Specific emission rates shall be reported in µg.m2.h–1.

A3.2.6 *Putty*—Place a 2-mm thick and uniform layer of putty on glass or stainless steel. Use a spatula or any other putty application device. Use a border made of glass or stainless steel for low-viscosity products. Alternatively, an inert mold of a size defined by the test cell can be used.

APPENDIXES

(Nonmandatory Information)

X1. EXAMPLES OF AREA SPECIFIC AIR FLOW RATES IN A MODEL ROOM

X1.1 See Table X1.1.

TABLE X1.1 Examples of Area Specific Air Flow Rates in a Model Room

Model Room[A]	Area Specific Air Flow Rate
17.4 m^3, n = 0.5 h^{-1}	
Floor Area = 7 m^2	1.3
Wall Area = 24 m^2	0.4
Sealant Area = 0.2 m^2	44

[A] Danish standard as referenced in the References section.

X2. DESCRIPTION OF AN EXAMPLE OF AN EMISSION CELL

X2.1 See Fig. X2.1 and Table X2.1.

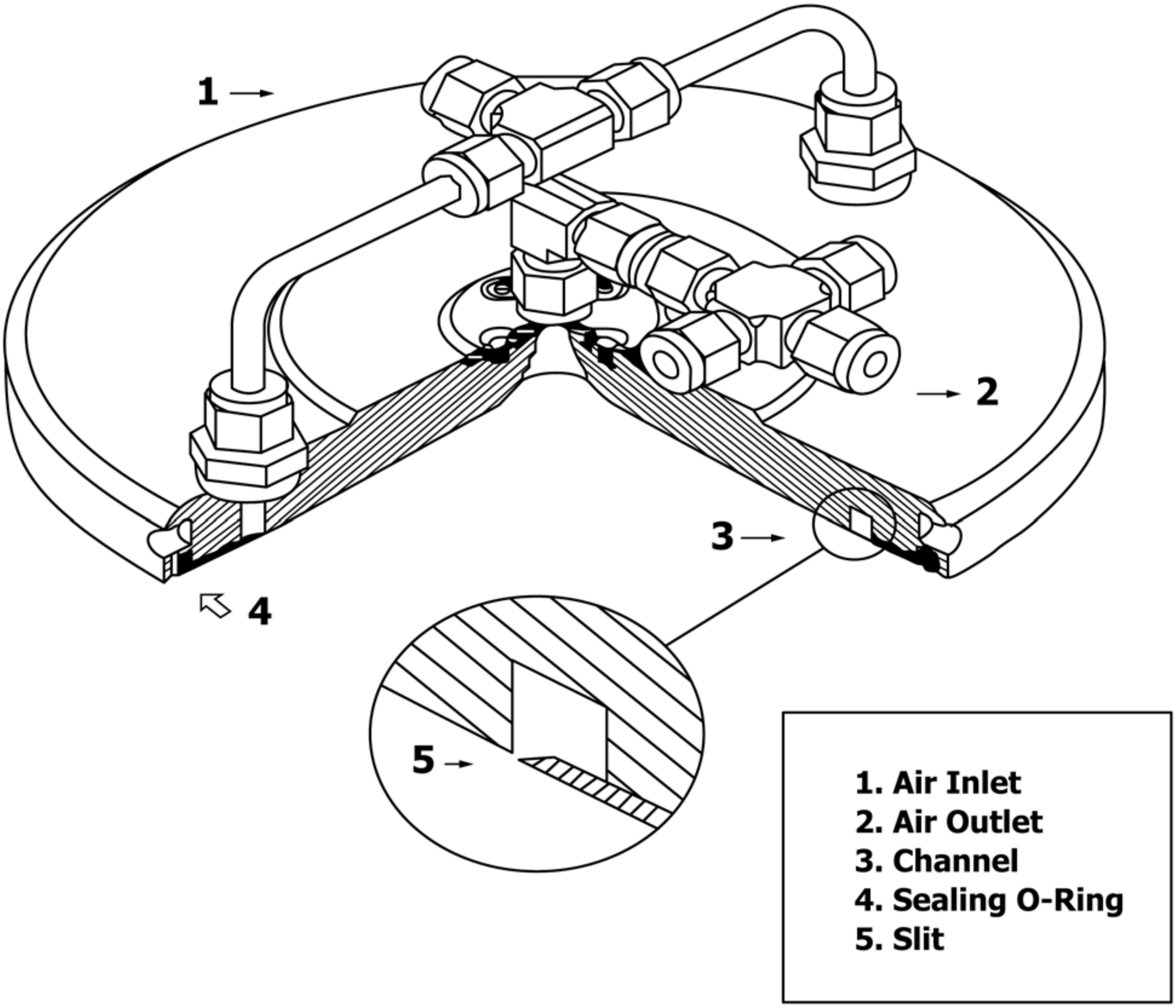

FIG. X2.1 Description of an Example of an Emission Cell

TABLE X2.1 Performance Data for the Type of Emission Cell Shown in Fig. X2.1

Volume (m^3)	3.5×10^{-5}			
Maximum exposed test surface area (m^2)	0.0177			
Inlet air slit (mm)	1.0			
Diameter (mm)	150			
Height at center (mm)	18			
Maximum material loading (m^2/m^3)	507			
Airflow rate (L/min)	0.100	0.300	1.400	2.800
Air change rate, n (h^{-1})	171	514	2400	4800
Air velocity[A] at slit (m/s)	0.0035	0.01	~0.05	~0.1
Area specific airflow rate[B] (m^3/(h·m^2))	0.1	1	5	9
Reynold's number (20°C), Re				10
Wall surface microstructure[C] (µm)	<0.1			
Wall sink		Time to reach emission cell equilibrium for polar VOCs <2h at an air supply of 400 mL/min (air velocity ~ 0.014 m/s)		
Recovery percentage of VOC (%)[D]				
Dodecane	106 ± 2			
2-ethylhexanol	99 ± 2			

[A] Calculated in accordance with the geometry and airflow.

[B] Total exposed area of the test specimen.

[C] Inner surface is hand polished–uniform surface microstructure, Ra = Roughness value (ISO 1302).

[D] The air supply was 100 mL/min at 50 % relative humidity, but for 2-ethylhexanol 0 % relative humidity was used instead.

X3. ESTIMATION OF AIR VELOCITY AT THE SURFACE OF A TEST SPECIMEN IN AN EMISSION CELL

X3.1 Actual air velocities within an emission cell under different air flow conditions can be studied using 3-dimensional Computational Fluid Dynamics (3D-CFD) (**4**) (see Appendix X4). An estimation of mean air velocity at the test specimen surface can also be made based on emission cell dimensions. For the type of circular emission cell described in Appendix X2, this estimation can be carried out as follows:

X3.1.1 Air enters the type of emission cell described in Appendix X2 through a baffle around the perimeter (radius: 7.5 cm) and exits through a single point located centrally and immediately above the test specimen surface. The volume of this cell is 35 cm^3. This means that if air was flowing into the cell at 35 cm3.min–1, it would take approximately one minute to pass from the inlet to the outlet of the cell and the mean air velocity over the surface of the test specimen would therefore be approximately 7.5 cm.min–1. This equates to 1.25×10^{-3} m.s–1. At 140 cm3.min–1 inlet air flow rate (which is near to the lower limit), this means that the average air velocity over the surface of the test specimen would be approximately 0.005 m.s–1. Similarly at 350 cm3.min–1 (typical inlet air flow), the air velocity over the surface of the test specimen would be approximately 0.0125 cm.s–1. At an inlet air flow rate of 1400 cm3.min–1 the mean air velocity over the surface of the test specimen would be in the order of 0.05 cm.s–1 and at a high inlet air flow rate of 2800 cm3.min–1 the mean air velocity over the surface of the test specimen would be in the order of 0.1 cm.s–1.

NOTE X3.1—Mean air velocities in the domestic indoor air environment are in the order of 0.07 m.s–1 (**1**).

X4. CORRELATION OF VOC EMISSION DATA FROM SMALL-CHAMBERS AND TEST CELLS

X4.1 Evaluating the Performance of an Emission Cell Using 3D-CFD

X4.1.1 The flow field and emission field of volatile organic compounds from the surface of indoor building materials in the cavity of the type of emission cell described in Appendix X2 have been examined using 3-dimensional Computational Fluid Dynamics (3D-CFD) (**4**) and in other studies (**5**). Measurements were made under two different emission conditions: *(1)* emissions controlled by evaporation (external diffusion) (typical of wet materials such as paints and coatings before they have dried or cured) and *(2)* emissions controlled by internal diffusion (typical of dry products and dried/cured paints and coatings).

X4.1.2 With an inlet air flow rate of 200 cm3.min–1, the air velocity over the exposed test specimen surface was found to vary. However, it was shown that, in the case of diffusion-controlled emissions (dry products), the air flow variation did not affect the VOC emission rate which was shown to be uniform across the entire exposed surface of the test specimen. This means that, for indoor materials/products where emissions are primarily controlled by internal diffusion, quantitative emissions test data was obtained using the type of emission cell described in Appendix X2 and could be directly compared to similarly quantitative emissions data obtained from small or large emission chambers.

X4.1.3 This was not true of evaporative-controlled emissions from wet materials. In this case, the emission rate was shown to be dependent on the loading factor (m2.m–3) (and the related concentration of vapors within the cell) and the surface air velocity. Emissions data for wet materials obtained using the type of emission cell described in Appendix X2 cannot, therefore, be compared with data from small or large emission chambers (which would normally have a much smaller loading factor and hence lower inherent vapor concentration in the chamber air) while evaporative emissions predominate.

X4.2 Laboratory Intercomparison of the Performance of an Emission Cell Versus Emission Chambers

X4.2.1 Several interlaboratory comparisons have been carried out involving both wet products (for example, paints, lacquers, and waxes) and solid building products (for example, textiles, PVC flooring, and particle board) (see Table X4.1 and **(6-17)**). These tests have been carried out over periods ranging from one day to several weeks and generally comparable data has been generated. Any discrepancies which did occur were primarily ascribed to procedural errors such as:

(1) Poor calibration of the analytical system,
(2) Inaccurate integration of chromatographic data,
(3) Lack of analytical quality assurance/control,
(4) Poor recovery (see 7.6 and Appendix X5),
(5) Sample inhomogeneity (see 6.5), and
(6) Use of unsuitable/uncontrolled storage conditions for test specimens between emissions tests.

NOTE X4.1—Errors *(1)* to *(3)* in above are the result of failure to comply with the requirements of the analytical methodology (see Practice D6196 or Test Method D5197, as appropriate).

X4.2.2 In addition, if product emissions were dominated by evaporation during the early stages of a test (for example, while wet products dried or cured), it was found that type of emissions chamber/cell used had a very significant impact on emissions test data (see 6.4). This confirms the findings of X4.1.

X4.2.3 The precise time for carrying out the emissions test was also found to be critical for both evaporative emissions and for tests of aldehydes emitted from wood-based materials.

X4.3 Summary

X4.3.1 In summary, data from emission cells (as described in Appendix X2) generally compares well with that obtained from small/large emission test chambers for diffusion-controlled emission processes.

X4.3.2 Inter-comparative testing of wet products requires identical surface air velocities and product loading factors (during the curing/drying process). This means that emissions data obtained from emission cells is unlikely to compare well with that from chambers in these cases. Similarly, use of different sorts of emission test chambers or use of identical emission test chambers under different conditions (air flow, test specimen orientation, etc.) can produce variable emission data from identical products in these cases.

X4.3.3 Emission and inter-comparison data can always be compromised by failure to apply correct analytical procedures and rigorous analytical quality control. In the case of emissions testing, this is particularly true of failure to demonstrate satisfactory recovery of target analytes (see 7.6 and Appendix X5). If the VOC emission rate changes rapidly with time, it is also critical to precisely control the time of the emissions test if comparative test data is to be obtained.

TABLE X4.1 Parallel Emission Testing of Emission Chambers and the Type of Emission Cell Described in Appendix X2

Chamber Size/Type Duration/Time of Testing	Building Product	Compound	Comments
250 l stainless steel 3 weeks	PVC flooring	Cyclohexanone, Phenol, TXIB	Good correlation between different emission cells and one chamber—some apparent in-homogeneity
50 l stainless steel 2 weeks	Paint, Wax	Ethylene glycol, Texanol, TVOC	Good correlations, especially after about 50 hours. NOTE: Emission cell SERs generally somewhat higher
1 m^3 stainless steel or glass 1 week	Wood	Terpenes	Good correlation with glass chamber in one test. Apparent inhomogeneity in another test, or domination of evaporative emission (velocity dependent), or both. NOTE: Emission cell SERs generally somewhat higher.
34 m^3 wood walls, PVC floor 20 h	Floor polish	2-(2-ethoxyethoxy)ethanol	Fairly good comparison (<x2). Modeled and measured peak concentration appear after 30 min and 100 min, respectively.
1 m^3, 187 l stainless steel months + office air – months	Linoleum floor	Hexanal	Poor correlation. Chambers considerably higher SER, partly assigned to edge effects (application effects). Good correlation between measured hexanal SER in office and emission cell
1 m^3 stainless steel ca. 13 days	Wood based products	Formaldehyde	Excellent correlation (corr. Coeff. = 0.98)
European Round-Robin (18 labs) Up to 1 m^3 st.st./glass 48 hours	Carpet PVC Paint	VOCs	Main causes of discrepancies were: i) Analytical errors, ii) Sorption on walls, and iii) In-homogeneity of the building products. Also variable film thicknesses of paint were used. NOTE: 28 hours may not be sufficient to achieve quasi equilibrium (mixture of mechanisms).
20 m^3, 1 m^3 and 20 l stainless steel 28 days	UV-cured lacquers	TVOC	Emission cell time/concentration profile was highest during first 10 days, thereafter super-imposable with that for 20L l.20 m^3 and 1 m^3 chambers showed lowest time/concentration profiles.
German Round-Robin (9 labs) Up to 1 m^3 st.st. 28 days	UV-cured acrylic lacquer	Sum of VOCs + SVOCs and individual VOCs	Good comparability, differences ≤15 %
ADSEC (stainless steel)	Wood based	Formaldehyde	Excellent correlation (> 0.99)
1 m^3 st.st, (51 1L glass) 11-/24 hours	Paint on steel plate	Higher aldehydes Decanol	Good comparison. The variation ≤15 %
Round-Robin (8 labs) 12- up to 200 days	Lacquer on MDF	VOCs	Good recovery analyses, generally better than 90 %. Good analyses of spiked tubes. Apparent in-homogeneity

X5. RECOVERY MEASUREMENTS

X5.1 Purpose of Recovery Measurements

X5.1.1 To determine the recovery of individual emitted compounds as required by 7.6.

X5.2 General Description

X5.2.1 The apparatus shown (see Fig. X5.1) is compatible with emission cells such as that described in Appendix X2.

X5.2.2 The apparatus comprises:

X5.2.2.1 A glass plate with precision ground hole in the middle,

X5.2.2.2 A small (typically 2 mL) glass vial with a precision ground-glass neck (to exactly fit the hole in the ground glass plate), and

X5.2.2.3 An insulating pad with a central hole to locate the bottom of the glass vial.

X5.3 Procedure for Testing Recovery

X5.3.1 Recovery tests shall be carried out as described in 7.6. To use the apparatus shown, a volume of the compound of interest is placed in the ground glass vial and weighed. The vial is then fitted into the ground glass plate which is placed on the insulating cushion such that the bottom of the vial locates with the hole in the cushion. The emission cell is then placed centrally onto the glass plate with the inlet air flow applied and emissions measurements made as described in 7.6 and 12.6.

X5.3.2 The ground glass vial is re-weighed at the end of the recovery test and the weight loss used to calculate an expected average vapor concentration in the cell throughout the recovery test (see 7.6). This can then be compared with the measured vapor concentration to assess recovery.

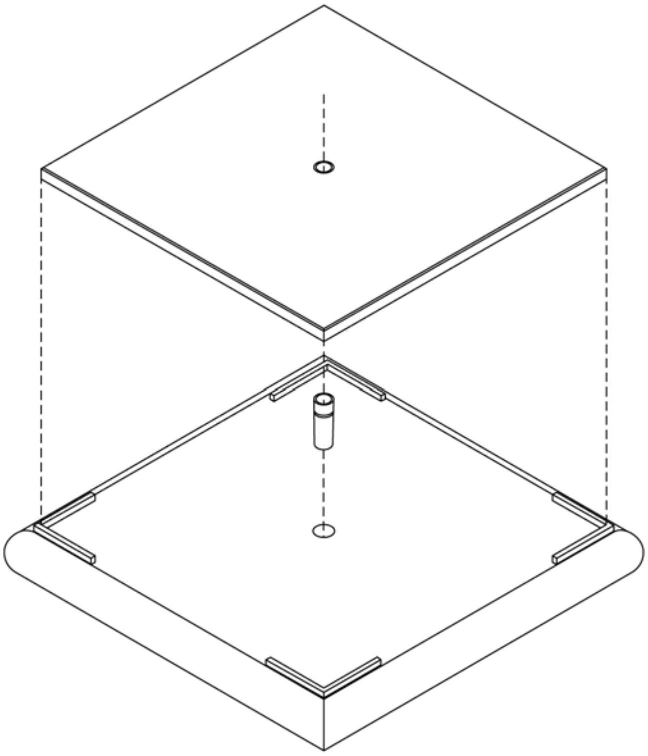

FIG. X5.1 Example Apparatus for Testing Analyte Recovery through Emission Cells

X6. SAMPLING COMBINED PRODUCTS FOR EMISSIONS TESTING

X6.1 General

X6.1.1 A combination of indoor materials/products can result in emissions which are different from the sum of those emitted by the individual products. The quantity of VOCs, the type of VOCs and how the emission profile changes over time are all influenced by interactions between the various materials/products in a composite sample. Since there are almost limitless numbers of possible material/product combinations, it is not possible to specify exactly how emissions testing should be carried out in every case. Therefore, this appendix only contains examples and general principles/guides as to how the testing of composite materials should be carried out.

NOTE X6.1—Examples of combined products include: flooring glued with an adhesive to a concrete substrate; interior wall covering comprising board (for example, gypsum or wood based board), glass fiber; insulation, sheets of plastic or paper, adhesives, and paints (primer and top coat); and penetrating oil or stain applied to wood.

X6.2 Principle

X6.2.1 Combinations of products should always be tested by comparing a control or reference specimen with a test specimen. The former consists of a known combination of well-defined components with a well characterized VOC emission profile. Only one material/product component in the test specimen, should be changed, relative to the reference specimen, at any one time (for example, changing the adhesive, or adding a new material/product such as a leveling compound). The reference specimen and the test specimen should be prepared simultaneously and treated identically throughout the duration of the emissions test.

X6.2.2 Once the reference and test specimens have been prepared, their emissions can be measured and compared. The test should continue for a sufficient time to detect long-term effects on emissions if this is the purpose of the test. Both TVOC and individual VOC emissions can be compared. Any speciated VOCs emitted by the composite material but which are not emitted by any of the individual products/materials in the combination, are of special interest. Such new emissions indicate that the combination of materials/products has initiated a new emitting process (for example, an alkali attack on adhesive or plasticizers). The result can be presented as a quotient between the emissions from the test specimen and the reference specimen.

X6.2.3 If long-term effects on emissions are to be studied, specimens should be subjected to the sort of conditions that would allow typical chemical reactions that produce emissions to occur – for example high moisture content. Products such as surface coatings or layers which are applied to recently cast concrete are examples of products/materials which should be tested in combination. In such cases, a standard concrete, as specified below, should be used for both reference and test specimens, unless it is the concrete itself that is under test.

X6.3 Example of a Reference Concrete Specimen

X6.3.1 The composition of the concrete should be the same as that used for testing cement in accordance with EN 196-1, that is, one part cement, three parts standard sand, and 0.5 parts water. Preferably, ordinary Portland cement should be used.

X6.3.2 The concrete is mixed and compacted in accordance with EN 13892-1. The mold should be constructed of emission free material with a depth of 100 ± 1 mm. Other mold dimensions are selected to fit the emission cell.

X6.3.3 The concrete should be allowed to stand uncovered for about three hours in a suitable storage area, so that it begins to set and any separated water evaporates. A steel scraper should then be applied moving from the middle of the test specimen towards the edge of the mold to produce a smooth, even surface. If any part of the test specimen surface is below the edge of the mold it should be filled in with fragments of the scraped-off concrete. Preparation of the test specimen is completed by cleaning the edge of the mold and weighing the specimen.

X6.3.4 The specimens should be stored for 14 days at 23 ± 2°C and 50 ± 5 % RH before being reweighed to assess the extent of drying. The surface coating or layer is then applied.

NOTE X6.2—These storage conditions typically create a moist and aggressive substrate.

X6.4 Example of a Test Procedure

X6.4.1 An example of a full test method for combined products is given in the Swedish Industry Standard "Measuring the emission characteristics of composite floor structures," published by the Swedish Flooring Federation.

NOTE X6.3—The purpose of the standard mentioned above is to study secondary emissions, thus it requires several measurements be made at various time intervals during the emissions test.

X6.5 Test Report

X6.5.1 When testing adhesive-bonded products as composite materials (for example floor coverings), the following details should be added to the test report:

X6.5.1.1 Thickness of each of the layers in the combined product (ISO 1765, ISO 8543 or EN 428),

X6.5.1.2 Weight per square metre of each of the layers (ISO 1765, ISO 8543 or EN 430),

X6.5.1.3 Number of test specimens,

X6.5.1.4 Other observations which can influence the test result as, for example, wood species, drying conditions, ageing, storing conditions, moisture content, surface treatment,

X6.5.1.5 Type of adhesive used,

X6.5.1.6 Quantity of adhesive used,

X6.5.1.7 Method of application of adhesive,

X6.5.1.8 Time between application of adhesive and application of surface material, and

X6.5.1.9 Type of base substrate.

REFERENCES AND ADDITIONAL SUPPORTING INFORMATION

(1) Matthews, T. G., Thompson, C. V., Wilson, D. L., and Hawthorne, A. R., "Air Velocities Inside Domestic Environments: An Important Parameter in the Study of Indoor Air Quality and Climate," *Environment International*, Vol 15, 1989, pp. 545–550.

(2) Girman, J. R., ,"Simple Modeling to Determine Appropriate Operating Conditions for Emission Testing in Small Chambers," *Modeling of Indoor Air Quality and Exposure*, edited by N.L. Nagda, Philadelphia: ASTM STP 1205, 1993, pp. 145–148.

(3) Kovanen, K., Seppänen, O., and Majanen, A., "Turbulent Air Flow Measurements in Ventilated Spaces," *Indoor Air*, Berlin, Vol 3, 1987, pp. 329–333

(4) Murakami, S., Kato, S., Zhu, Q., Ito, K., "3D-CFD Analysis of Diffusion and Emission of VOCs in a FLEC Cavity," Proceedings: 9th International Conference on Indoor Air Quality and Climate, H. Levin, Santa Cruz, *Indoor Air*, Vol 2, 2002, pp. 548–552.

(5) Uhde, E., Borgschulte, A., and Salthammer, T., "Characterisation of the Field and Laboratory Emission Cell— FLEC: Flow Field and Air Velocities," *Atmospheric Environment*, Vol 32, No. 4, 1998, pp. 773–781.

(6) Wolkoff, P., Clausen, P. A., Nielsen, P. A., Gustafsson, H., Jonsson, B. and Rasmusen, E.,,"Field and Laboratory Emission Cell: FLEC," *Healthy Buildings*, ASHRAE, 1991, pp. 160–165.

(7) Roache, N., Guo, Z., and Tichenor, B. A., "Comparing the Field and Laboratory Emission Cell (FLEC) with Traditional Emissions Testing Chambers," *Characterizing Sources of Indoor Air Pollution and Related Sink Effects Sinks*, edited by Tichenor, B. Philadelphia: ASTM STP 1287, 1996, pp. 98–111.

(8) Fuhrmann, F., and Salthammer, T., "Emission of Monoterpenes from Wooden Furniture," Yoshizawa, S., Kimura, K., Ikeda, K., Tanabe, S., and Iwata, T. (eds.), *Indoor Air*, Tokyo, Institute of Public Health, Vol 3, 1996, pp. 607–612.

(9) Vejrup, K. V., "The Importance of Chemical Components in Cleaning Agents for the Indoor Environment," Ph.D. Thesis, Danish Technical University, Lyngby, 1996, pp. 1–103.

(10) Zellweger, C., Hill, M., Gehrig, R., and Hofer, P., "Emissions of Volatile Organic Compounds (VOC) from Building Materials—Methods and Results," KWH-EMPA, Bundesamt für Energiewirtschaft, Dübendorf, 1997, pp. 1–104.

(11) Risholm-Sundman, M., "Determination of Formaldehyde Emission with Field and Laboratory Emission Cell (FLEC)—Recovery and Correlation to the Chamber Method," *Indoor Air*, Vol 9, 1999, pp. 268–272.

(12) De Bortoli, M., Kephalopoulos, S., Kirchner, S., Schauenburg, H. and Vissers, H.,"State-of-the-Art in the Measurement of Volatile Organic Compounds Emitted from Building Products: Results of an European Interlaboratory Comparison," *Indoor Air*, Vol 9, 1999, pp. 103–116.

(13) Jahn, O., Wilke, O., and Brödner, D., "Procedure for the Determination and Limitation of VOC-Emissions from Furniture and Coated Wood Based Products," Woods, J.E., Grimsrud, D., and Boschi, N. (eds.) *Healthy Buildings*, Blacksburg,VA, Healthy Buildings/IAQ '97, Vol 3, 1997, pp. 593–598.

(14) Jann,O., Wilke, O., Brödner, D., and Plehn, W., "ECO-Label for Low Emission Wood Products and Wood Base Products(RAL-UZ 38)—Part 2: Test Procedure and Results," Seppänen, O. and Säteri, J. (eds.), *Healthy Buildings*, Helsinki, SIY Indoor Air Formation, Vol 4, 2000, pp. 525–530.

(15) Akutsu, T., Kumagai, K., Uchiyama, S., and Tanabe, S. "Development of Measurement Device (ADSEC) for Aldehyde Emission Rates Using a Diffusive Sampler," Seppänen, O., and Säteri, J. (eds.), *Healthy Buildings*, Helsinki, SIY Indoor Air Formation, Vol 1, 2000, pp. 477–482.

(16) Afshari, A., "Determination of VOC Emissions from Surface Coatings by Environmental Chamber Measurements," Ph.D. Thesis, Chalmers University of Technology, 1999, pp. 1–152.

(17) Hansen, V., Larsen, A., and Wolkoff, P., "Nordic Round-Robin Emission Testing of a Lacquer: Consequences of Product In-Homogeneity," Seppänen, O. and Säteri, J. (eds.), *Healthy Buildings*, Helsinki, SIY Indoor Air Formation, Vol 4, 2000, pp. 99–104.

(18) Lor, M., Vause, K., Dinne, K., Goelen, E., Maes, F., Nicolas, J., Romain, A., and Degrave, C., "Horizontal Evaluation Method for the Implementation of the Construction Product Directive – HEMICPD" Belgian Science Policy, 2010.

(19) Wolkoff, P., Salthammer, T., and Woolfenden, E. A., "Emission Cells and Comparison to Small Chambers for Materials Emissions Testing," *Gefahrstoffe Reinhaltung der Luft*, Vol 65, No. 3, 2005, pp. 93–98.