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Standard Practice for Estimation of Short-term Inhalation Exposure to Volatile Organic Chemicals Emitted from Bedding Sets[1]

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1. Scope

1.1 This practice covers the procedures for estimation of short-term human inhalation exposure to volatile organic chemicals (VOCs) emitted from bedding sets when a new bedding set is first brought into a house.

1.2 The estimated exposure is based on an estimated emission profile of VOCs from bedding sets.

1.3 The VOC emission from bedding sets, as in the case of other household furnishings, usually are highest when the products are new. Procedures described in this practice also are applicable to used bedding sets.

1.4 Exposure to airborne VOC emissions in a residence is estimated for a household member, based on location and activity patterns.

1.5 The estimated exposure may be used for characterization of health risks that could result from short-term exposures to VOC emissions.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to its use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1356 Terminology Relating to Sampling and Analysis of Atmospheres[2]

D 5116 Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products[2]

D 5157 Guide for Statistical Evaluation of Indoor Air Quality Models[2]

D 6177 Practice for Determining Emission Profiles of Volatile Organic Chemicals Emitted from Bedding Sets[2]

3. Terminology

3.1 *Definitions*—For definitions and terms used in this practice, refer to Terminology D 1356.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *air change rate, n*—the volume of outdoor air that enters the indoor environment in one hour, divided by the volume of the indoor space.

3.2.2 *bedding set, n*—an ensemble that includes a mattress for sleeping and a supporting box spring.

3.2.3 *emission profile, n*—a time-series of emission rates of one or more compounds.

3.2.4 *exposure scenario, n*—a description of how and where an estimated exposure occurs, including (*1*) the location and emission profile of the product or material that causes exposure, (*2*) the indoor environment where the individual is exposed to airborne emissions from the product or material, and (*3*) the location and activity patterns of the exposed individual.

3.2.5 *potential inhaled dose, n*—the product of air concentration to which an individual is exposed times breathing rate times duration of exposure.

3.2.5.1 *Discussion*—The potential inhaled dose is different from the dose actually absorbed by a target organ.

3.2.6 *short-term exposure, n*—an exposure of one week or less in duration.

3.2.7 *volatile organic chemical, n*—an organic compound with saturation vapor pressure greater than 10^{-2} kPa at 25°C.

4. Summary of Practice

4.1 This practice describes procedures for estimation of inhalation exposure to VOCs emitted from new bedding sets (**1**)[3]. The estimation of exposure is based on the emission profiles for a bedding set, the environmental conditions in a residence where the bedding set is being used, and the location and activity patterns of an exposed individual. Emission profiles are derived from environmental chamber emission tests **2**(see Guide D 5116 and Practice D 6177).

4.2 Estimation of exposure involves development of exposure scenarios, modeling of indoor-air concentrations, and selection and calculation of exposure measures.

5. Significance and Use

5.1 The objective of this practice is to provide procedures

[1] This practice is under the jurisdiction of ASTM Committee D-22 on Sampling and Analysis of Atmospheres and is the direct responsibility of Subcommittee D22.05 on Indoor Air.

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[2] *Annual Book of ASTM Standards*, Vol 11.03.

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

for estimation of human inhalation exposure to VOCs emitted from bedding sets. The estimated inhalation exposure can be used as an input to characterization of health risks from short-term VOC exposures.

5.2 The results of exposure estimation for specific raw materials and components, or processes used in manufacturing different bedding sets, can be used to compare their relative impacts on exposures.

6. Procedures for Exposure Estimation

6.1 The procedures for exposure estimation include development of exposure scenarios, modeling of indoor-air concentrations, selection and calculation of exposure measures, and model evaluation.

6.2 *Development of Exposure Scenarios*:

6.2.1 An exposure scenario describes how and where exposure occurs. In specifying the exposure scenario(s), include a description of (*1*) the emitting product or material, in terms of its age, emission profile, and location, (*2*) the indoor environment where exposure occurs, and (*3*) the location and activity patterns of an exposed individual.

6.2.2 *Emitting Product or Material*—For this practice, the emitting product is a bedding set. Specify the assumed age, emission profile, indoor location, and size of the bedding set of interest.

6.2.2.1 For a conservative estimate of exposure, assume that the bedding set has just been purchased and the wrapper is not removed until it is placed in the residence.

6.2.2.2 Estimate the emission profile using adjusted chamber air concentrations (Practice D 6177).

6.2.2.3 The indoor location for the bedding set is assumed to be a bedroom.

6.2.2.4 Select a size of bedding set that is appropriate for the size of the bedroom.

6.2.3 *Indoor Environment*:

6.2.3.1 Conceptualize the indoor environment as consisting of the following three zones: (*1*) the immediate vicinity of the bedding set; (*2*) the remainder of the bedroom in which the bedding set is located; and (*3*) the remainder of the house. Specify a volume for the entire residence and for each of the zones. For a typical volume of the total residence, use the average value (369 m^3) listed in the *Exposure Factors Handbook* (**3**). For a conservative value of the residential volume, use one of the 10th percentile values (147 m^3 or 167 m^3) listed in the *Exposure Factors Handbook*. See X1.1 for example calculations to determine the volumes for the bedroom and the vicinity of the bedding set.

6.2.3.2 To simplify calculations, the indoor environment can be considered as consisting of just two zones, the bedroom and the remainder of the house. Such calculations would result in less realistic yet useful estimates for screening purposes.

6.2.4 *Location and Activity Patterns*—Specify the locations of an exposed individual throughout a 24-h (or longer) period in relation to the two or three indoor zones previously described . Also specify the time spent outside the house, during which the individual is assumed not to be exposed to chemical emissions from the bedding set. See X1.2 for examples of location and activity patterns.

6.3 *Modeling of Indoor-air Concentrations*:

6.3.1 The two major steps in modeling are selection of a model and provision of model input parameters.

6.3.2 *Model Selection*—Select a model that is capable of estimating indoor-air concentrations in multiple zones and allows the user to specify various types of emission profiles in addition to the indoor zones, their volumes, their interzonal airflow rates, and zonal airflow rates to and from the outdoors. Three models that are known to meet these criteria are CONTAM (**4**), EXPOSURE (**5**), and MCCEM (**6**). All three models have been developed by or for U.S. government agencies, and are therefore in the public domain. Each model has advantages and disadvantages in terms of completeness, simulation capabilities, the user interface, and how it addresses exposure. For example, CONTAM has the capability of calculating airflows among zones whereas for EXPOSURE and MCCEM, the airflows need to be specified by the user; MCCEM includes a library of airflow rates for selected residences.

6.3.3 *Model Inputs*—In addition to emission profiles, indoor zones, and location and activity patterns as previously described, specify (*1*) an air change rate for the residence, (*2*) airflow rates among the indoor zones, and (*3*) parameters related to indoor sinks. Some models may also require or allow the user to choose a time step.

6.3.3.1 Select a value for the air change rate for the residence to be modeled. The air change rate for the residence with the outdoors has units of inverse hours (h^{-1}). A measured value for the residence representing the conditions to be modeled, if available, should be used as a first choice. An alternative is to select a value based on appropriate cases in the literature. For example, a conservative value in the range from 0.1 to 0.2 h^{-1} and a central value in the range from 0.4 to 0.6 h^{-1} were reported by Koontz and Rector (**7**) based on an analysis of measurements from several residential field studies. Representative values for the residential building stock are not available.

6.3.3.2 Multiply the air change rate by the zonal volume to obtain the airflow rate to and from the outdoors, in $m^3\ h^{-1}$. The simplifying assumption can be made that each zone has a balanced inflow and outflow with respect to outdoors. While this is generally not the case in a real building, one must have measured interzonal airflow rates or rates that were calculated with a multi-zone airflow model (such as CONTAM) to avoid using this assumption.

6.3.3.3 Use measured values, if available, for interzonal airflow rates between the bedroom and the remainder of the house. Alternatively, interzonal flows can be estimated using the CONTAM model (or some other multizone airflow model) or an equation such as the following:

$$Q = V\,(0.078 + 0.31N) \tag{1}$$

where:

Q = interzonal flow rate, m^3h^{-1}
V = volume of the house, m^3, and
N = air change rate of the house, h^{-1}.

The above empirical equation is based on an analysis of flow rates from several hundred nonrandomly selected residences (**7**).

6.3.3.4 If three zones are elected for calculations, the bedroom area in the vicinity of the bedding set is assumed to exchange air only with the rest of the bedroom. See X1.3 for example calculations to determine the airflow rate between the vicinity of the bedroom set and the remainder of the bedroom.

6.3.3.5 For a conservative approach, assume no indoor sinks. If indoor sinks are present, they are likely to be reversible. Both CONTAM and EXPOSURE are capable of handling reversible sinks. The MCCEM allows only a one-way sink, expressed as a first-order rate constant in units of h^{-1}.

6.3.3.6 If the model requires or allows user input for the time step, then specify a time step of no longer than 15 min, and preferably as short as 5 min or 1 min. A shorter time step will result in longer execution time but will increase the resolution of the results.

6.4 *Selection and Calculation of Exposure Measures*:

6.4.1 Two commonly used measures of exposure are the potential inhaled dose and the maximum indoor concentration to which an individual is exposed.

6.4.2 *Potential Inhaled Dose*—The potential inhaled dose is the product of indoor-air concentration times breathing rate times duration of exposure. This dose needs to be calculated separately for each contiguous period of time when the exposed individual is in a different zone of the indoor environment; the resultant estimates are then summed to determine the total inhaled dose. The time period over which the total inhaled dose is determined could be 1 h, 8 h, or 24 h, or longer, depending on the health end point of potential concern.

6.4.3 *Maximum Indoor Concentration*—The maximum indoor concentration to which an individual is exposed typically is integrated over a relatively short time period such as 1 h or 8 h, depending on the reference value against which the time-integrated concentration will be compared. In determining this maximum concentration, it is necessary to track the exposed individual's location within the indoor environment, integrating across contiguous time periods in each zone as previously described for the potential inhaled dose.

6.5 *Model Evaluation*—Ideally, the models that predict indoor air concentrations for the purposes of exposure estimation should be evaluated with concentration measurements from actual residences. Use tools described in Guide D 5157 to judge the comparability of predicted and measured concentrations.

7. Report

7.1 The report on estimation of inhalation exposure should contain the sections listed as follows:

7.2 *Bedding Set Samples*—Give description of the bedding sets (for example, size, style), sample selection process (for example, random), and brand name (if appropriate).

7.3 *Emission Profiles*—List the time-varying emissions, or provide an equation describing the time-varying emissions, for each chemical emitted from a bedding set. Describe the chamber conditions and the technique used for estimating emissions from the chamber data.

7.4 *Exposure Scenarios*—Describe all assumptions used in estimating exposures, including the age and indoor location of the bedding set, the emission profile, the volume and partitioning of the indoor environment, the air change rate, interzonal airflows, and human location and activity patterns, and associated breathing rates.

7.5 *Modeling of Indoor-Concentrations*—Describe model selection. List all inputs including the number of zones, air change rates, interzonal airflow rates, zonal volumes, and the time step used in modeling. Include the comparison of predicted and measured concentrations, if available.

7.6 *Exposure Estimates*—Describe the exposure measures selected, the manner in which each exposure measure was calculated, and the resultant exposure estimates.

8. Keywords

8.1 activity pattern; air change rate; bedding set; emission profile; emissions; environmental chamber; exposure assessment; exposure scenario; indoor air quality; inhalation exposure; potential inhaled dose

APPENDIX

(Nonmandatory Information)

X1. SUPPLEMENTAL MATERIAL

X1.1 *Example Calculations for Bedroom and Bedding Set*:

X1.1.1 *Volume of Bedroom*—There is little published information on measured volumes of bedrooms in residences. The volume can vary considerably, with length typically varying from 8 to 12 ft, width from 10 to 20 ft, and ceiling height from 7 to 9 ft. Intuitively, a smaller bedroom has a length on the order of 8 to 9 ft, a width of 10 to 12 ft, and a ceiling height of 7 to 8 ft, resulting in a nominal volume of about 700 ft^3 or 20 m^3. This volume would be appropriate for a conservative estimate of exposure. A typical value would be associated with a bedroom having a length on the order of 10 ft, a width of 12 ft, and a ceiling height of 8 ft, resulting in a nominal volume of 960 ft^3 or 27 m^3.

X1.1.2 *Size of Bedding Set*—The size of bedding set should be consistent with the bedroom volume. For example, use a twin- or full-size bedding set for a bedroom volume of 30 m^3 or smaller.

X1.1.3 *Vicinity of Bedding Set*—Although uniform mixing of chemicals released from a bedding set eventually might prevail within the bedroom, higher exposure intuitively can be expected in close proximity to the bed. For inhalation exposure during sleeping hours, then, a source cloud (**8**) near the bed should be considered, to define a virtual volume containing freshly emitted chemicals before they are mixed into the larger room volume. One way to postulate the source-cloud volume is to consider a cylinder, 2 m in length by 1 m in diameter. The total volume of this cylinder would be about 1.6 m^3, and the total surface area would be about 3.1 m^2.

X1.2 *Example of Location and Activity Patterns*—For an estimate of typical exposure, assume 8 h in bed, followed by 0.25 h of personal (light) activity in the bedroom and 0.75 h of moderate to light activity in the remainder of the house. This pattern is followed by an 8-h period away from the house that does not contribute to exposure. Upon return to the house, there is a 6.75-h period of moderate to light activity in the remainder of the house, followed by a 0.25-h period of light activity in the bedroom. For a conservative estimate of exposure, assume a convalescent who is in bed for the entire 24 h. These 24-h patterns can be assumed to be repeated over any number of days. Use a breathing rate of 0.5 m^3 h^{-1} for sleeping (for both typical and conservative estimate), 0.6 m^3 h^{-1} for light activity in the bedroom, and 1.35 m^3 h^{-1} for moderate to light activities in the remainder of the house.

X1.3 *Example Calculations for Airflow Rate Between Vicinity of the Bedding Set and Remainder of the Bedroom*:

X1.3.1 In simulating the reclining human form, only half of the surface area (1.6 m^2) would be in contact with room air. The exchange coefficient between this hypothetical volume and the remainder of the room can be defined from room air velocities. Assuming homogeneous mixing (that is, draft-free conditions), room air would enter the source cloud through one half (0.8 m^2) of the surface area in contact with the room air and would exit through the other half. The flux through the entry/exit surface is the product of air velocity (m h^{-1}) and surface area (m^2), giving a net volume flow (m^3 h^{-1}).

X1.3.2 Matthews et al (**9**) measured room air velocities in six occupied houses and one research house. In the master bedroom for three of the occupied houses, the median air velocity was found to be 1.8 cm s^{-1}(65 m h^{-1}) with the central heating and air conditioning (HAC) system off, increasing to 6.1 cm s^{-1}(220 m h^{-1}) with the HAC system on. The value with the HAC system off is suggested as a conservative approach, because not all houses have central HAC systems and the HAC fan does not run constantly in those that have central systems. Multiplying the HAC-off median air velocity of 65 m h^{-1} by the entry/exit surface area of 0.8 m^2 yields a net airflow of 52 m^3 h^{-1}.

References

(**1**) "Assessment of Potential Health Risks Resulting from Chemical Emissions from New Bedding Sets," Project 2797, Prepared for Sleep Products Safety Council, Versar, Inc., Springfield, VA, July 1995.

(**2**) Research Triangle Institute, "Final Report-Performance of Testing in Support of Research by the SPSC Indoor Air Quality Task Force," RTI/5736/00–02RFR, Research Triangle Park, NC, September 1995.

(**3**) U.S. Environmental Protection Agency, *Exposure Factors Handbook*, (Update to Exposure Factors Handbook EPA/600/8-89/043 of May 1989), U.S. Environmental Protection Agency, National Center for Environmental Assessment, Washington, DC, 1996.

(**4**) Walton, G.N., *CONTAM93—User Manual*, NISTIR 5385, National Institute of Standards and Technology, Gaithersburg, MD, March 1994 or later edition.

(**5**) Sparks, L.E., Tichenor, B.A., and White, J.B. "Modeling Individual Exposure from Indoor Sources," *Modeling of Indoor Air Quality and Exposure, ASTM STP* 1205, N.L. Nagda, ed., American Society for Testing and Materials, Philadelphia, PA, 1993, pp 245-256.

(**6**) Koontz, M.D. and Nagda, N. L., "A Multichamber Model for Assessing Consumer Inhalation Exposure," *Indoor Air*, Vol 4, pp. 593-605, 1991.

(**7**) Koontz, M.D. and Rector, H. E., "*Estimation of Distributions for Residential Air Exchange Rates*," GEOMET Report IE-2603, prepared for the U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics, under contracts 68-D9-0166 and 68-D3-0013, Germantown, MD, March 1995.

(**8**) Roach, S.A., "On the Role of Turbulent Diffusion in Ventilation," *Annals of Occupational Hygiene*, Vol 24, No. 1, 1981, pp. 105-132.

(**9**) Matthews, T. G., et al," 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.