Designation: ~~D6178 – 14~~ D6178 – 19

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

This standard is issued under the fixed designation D6178; 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.

## 1. Scope

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

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

1.7 *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~~ safety, health, and ~~health~~environmental practices and determine the applicability of regulatory limitations prior to ~~its~~ use.*

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
D5116 Guide for Small-Scale Environmental Chamber Determinations of Organic Emissions from Indoor Materials/Products
D5157 Guide for Statistical Evaluation of Indoor Air Quality Models
D6177 Practice for Determining Emission Profiles of Volatile Organic Chemicals Emitted from Bedding Sets
D6670 Practice for Full-Scale Chamber Determination of Volatile Organic Emissions from Indoor Materials/Products

## 3. Terminology

3.1 *Definitions*—For definitions and terms used in this practice, refer to Terminology D1356.

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.~~

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

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

[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.

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[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~~standard's Document Summary page on the ASTM website.

3.2.3 *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.

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

3.2.4.1 *Discussion—*

The potential inhaled dose is different from the dose actually absorbed by a target organ.

3.2.5 *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~~ and used bedding sets in homes. A recent literature review of human exposure to indoor air pollutants in sleep microenvironments describes the range of issues surrounding exposure during sleep (**1**).[3] ~~The~~This estimation of bedding 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 (see Practice D6670, Guide D5116, and Practice D6177).

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 for estimation of human inhalation exposure to VOCs emitted from bedding ~~sets.~~ sets in homes. The estimated inhalation exposure can be used as an input ~~to~~for 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 an exposure ~~scenarios, modeling of indoor-air concentrations, selection and calculation of exposure measures, and model evaluation.~~scenario and modeling of breathing zone concentrations accounting for emission rates, room size, air change rate, concentration distribution, occupant age, and activity patterns.

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 A key decision in determining the exposure scenario is determining the appropriate occupant for the bedding set (adult or infant). Infants inhale roughly six times more air per unit of body mass than adults and sleep longer (**2**). Hence, emissions from crib bedding should be analyzed differently than adult bedding.

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

6.3 *Modeling Approach:*

6.3.1 There are a several methods to model indoor air concentrations. Multizone models, such as CONTAM (**3**) or the Multi-Chamber Concentration and Exposure Model (MCCEM) (**4**), can be used to determine indoor air concentrations or interzonal airflow rates, or both. However, interzonal airflows has not been well characterized in the literature, and airflow patterns between the immediate vicinity of the bed and the rest of the room are also not well-known or easily characterized. Computational fluid dynamic models can also be used to model indoor environments. But these models require significant effort to define the environment (air inlets and outlets, windows, furniture, wall thermal properties). Other issues, such as the impacts of increased localized surface temperature and moisture near the human body, along with sleeping position, are usually not accounted for in these models (**1**). Because models will result in unknown errors dependent upon numerous assumptions the user may not be familiar with, this practice uses a simplified box model to estimate inhalation concentrations for the bedding occupant.

6.4 *Bedroom Volume:*

6.4.1 The indoor location for the bedding set is assumed to be a bedroom. The interquartile (or middle 50 %) volume of 500 bedrooms in Denmark measured by Beko et al. (**5**) was 20 $m^3$ to 30 $m^3$. Select a room volume or range of room volumes that is appropriate for the exposure scenario. The National Association of Home Builders determined that the average American master bedroom occupies 10.7 % of the floor area of new homes (total average area 270 $m^2$) built in 2018 (**6**).

6.5 ~~*Development of Exposure Scenarios:*~~*Emitting Product or Material:*

6.5.1 ~~An exposure scenario describes how and where exposure occurs. In specifying the exposure scenario(s), include a description of (~~For this practice, the ~~1) the emitting product or material, in terms of its~~ emitting product is a bedding set. Specify the assumed age, emission profile, and ~~location, (~~size of~~2) the indoor environment where exposure occurs, and (~~ the bedding set ~~3) the location and activity patterns of an exposed individual.~~of interest.

6.5.2 ~~*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.~~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.

~~6.2.2.1 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 D6177).~~

~~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.~~

6.5.3 ~~*Indoor Environment:*~~ Select a size of bedding set that is appropriate for the size of the bedroom (king, queen, full, twin, crib) and the occupant (adult or infant).

~~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 (492 $m^3$) listed in the *Exposure Factors Handbook* (**2**). For a conservative value of the residential volume, use the 10th percentile value (154 $m^3$) listed in the *Exposure Factors Handbook*. See Section 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.~~

6.5.4 ~~*Location and Activity Patterns*—Specify the locations of an exposed individual throughout~~Estimate the bedding emission profile using Practice D6177~~ a 24-h (or longer) period in relation to the two or three indoor zones previously described 6.2.3.1~~. ~~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 Section~~The time varying emission rate determined for new bedding in Practice D6177 ~~X1.2 for examples of location and activity patterns.~~ includes a first order emission rate decay constant.

6.6 ~~*Modeling of Indoor-air Concentrations:*~~ *Air Change Rate:*

6.6.1 ~~The two major steps in modeling~~ In general, building air change rates vary with time; ranging by at least a factor of five or more for a given building due to weather and occupant actions (opening windows) (**7**)~~.are selection of a model and provision of model input parameters.~~ Room air change rates are harder to define and measure due the complexities of interzonal airflows.

6.6.2 ~~*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~~ Air change rates in 500 bedrooms in apartments, single family homes, and rowhouses in Denmark were measured by Beko et al. (**3**~~**), EXPOSURE (4), and MCCEM (5**~~). ~~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.~~The lognormally distributed air change rates varied from 0.05 1/h to 4.5 1/h with a geometric mean value of 0.46 1/h.

6.6.3 *Model Inputs*—In addition to emission profiles, indoor zones, and location and activity patterns as previously described, specify (Select a value or range of values for the 1) an air change rate for the residence, (bedroom to2) airflow rates among the indoor zones, and ( be modeled. Smaller rooms and those with more3) parameters related to indoor sinks. Some models may also require or windows and door openings tend to have higher air change rates **allow (5the ).**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 (**6**) 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:

$$Q = V\,(0.078+0.31N) \quad (1)$$

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 (**6**).

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.



6.7 *Room Air Concentration Calculation:*

6.7.1 The room air concentration for the chemical of interest emitting from the bedding sheets can be determined assuming either steady state or time dependent conditions.

6.7.2 If it is assumed that the emission rate is constant, the air change rate is constant, the room air is sufficiently uniform that it can be represented by a single concentration, and no chemical loss mechanisms are present, then the room air concentration can be estimated by the following:

$$C_R = \left[C_o + \frac{AE}{NV}\right] \quad (1)$$

where:

$C_R$ = steady-state room air concentration (μg/$m^3$),
$C_O$ = inlet room air concentration (μg/$m^3$),
$N$ = air change rate (1/h),
$V$ = volume of room ($m^3$),
$A$ = surface area of bedding ($m^2$), and
$E$ = area specific emission rate (μg/$m^2$ $h^{-1}$).

6.7.3 If it is assumed that the emission rate decays with time as in Practice D6177, the air change rate is constant and no chemical loss mechanisms are present, then the room air concentration can determined by the analytical solution of the following mass balance:

$$\frac{dC_R}{dt} = NC_O - NC_R + \frac{AE_O e^{-kt}}{V} \quad (2)$$

$$C_R(t) = C_O(1 - e^{-Nt}) + \frac{AE_O}{V(N - K)}\left[e^{-kt} - e^{-Nt}\right] \quad (3)$$