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ESTIMATING BUILDING MATERIAL CONTRIBUTIONS TO INDOOR AIR POLLUTION

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ABSTRACT

Many professionals and scientists are attempting to identify low-emitting building materials during building design. Others need to model indoor air quality (IAQ) for problem building investigations or for research. Manufacturers improve their products' performance using such modeling. These efforts focus on volatile organic compound (VOC) emissions from building materials. A step-wise procedure for the use of IAQ modeling may ultimately improve building performance. A procedure is described and its important steps are illustrated in this paper. Reasonably accurate estimates can be made based on careful use of available data. Barriers to reliable use of modeling include insufficient data characterizing emissions from many important indoor pollutant sources.

INTRODUCTION

Efforts to select low-emitting building materials during design or to model indoor air quality (IAQ) often focus on volatile organic compound (VOC) emissions from building materials and products (1-3). Methodologies involving modeling can be used to estimate air concentrations for design, investigations, or other applications (4). This paper outlines procedures to develop such estimates that perform reasonably well when compared to measured air concentrations. A systematic approach to evaluating the contributions of VOCs to total lifetime occupant exposure must consider the total mass and area of each material present, the emission characteristics of the embodied VOCs, its maintenance requirements, and its life cycle characteristics. Based on these considerations, some materials are far more important than others, with orders of magnitude more mass, surface area, or emission factors. Other materials will give rise to larger emissions from chemicals applied to clean, maintain, or renew their surfaces during their lifetimes (4).

METHODS

A step-wise procedure is used including the followed steps

1. Identify materials used in the building
2. Estimate quantities for area and mass of materials used
3. Determine prevalence and select modeling target materials
4. Determine materials' constituents and composition
5. Determine emission characteristics of materials
6. Determine time period to be modeled
7. Determine ventilation rates and scheduling for building, model
8. Select emission factors and decay rates
9. Select model equations and run model
10. Evaluate model performance

1. Identify materials to be modeled

Information is obtained from various sources including architects, engineers, contractors, and product manufacturers. Plans and specifications for the buildings are used to determine the type and quantities of materials used. There often are hundreds of products used including multiple types of many product classes. For example, it is not unusual to have from three to eight (or more) different types of paints used in a building and more than five adhesives.

2. Quantitative estimates of area and mass of materials

Quantity "take-offs" are made in the normal manner for construction materials list preparation or construction cost estimation. This involves measurements from plans and calculation of surface areas or lengths of materials. In some cases, where available, construction cost estimator's quantitative take-offs are used. Quantities of different materials used in buildings vary greatly. Floor, wall, and ceiling surfaces are the most dominant exposed surfaces inside the building. Furnishings such as open office systems furniture (work stations), drapery, seating, and bedding can also be important. Concealed surfaces exposed to circulating air must also be considered. These include spaces above suspended ceilings or inside structural assemblies like walls and floors. All surfaces exposed to circulating air should be included in area calculations.

3. Prevalence determinations and selection of model targets

Analysis of dominance can be useful in reducing the number of products modeled based on prevalence determinations. These determinations are made based on both area (m^2) and mass (g) of the materials, and they are compared as loading ratios to the volumes of the spaces in which they occur. Manufacturers' product data sheets are used to determine product density (mass per unit volume), application rates, installation procedures, drying or cure times, and other relevant characteristics necessary for estimating emissions. Areas or lengths and product densities are used to calculate mass per unit area (g/m^2) or length (g/m). These values are necessary for calculations of emission rates (mg/h) used in modeling concentrations resulting from a particular source. Experience indicates that there is a very wide range ($> 10^5$) of prevalence of materials in any building and that there are also large variations among buildings (5). After consideration of emission characteristics with respect to quantity and known human response (odor, irritation, toxicity), the number of materials to be modeled should be reduced to a few considered most important.

For both adhesives and wet surface coatings, there is a large potential variation in the quantities applied depending on the application tools chosen, the substrate surface characteristics, water activity or moisture at and near the surface of the substrate, and the installer's technique. Estimates solicited from knowledgeable individuals indicate large uncertainties accompany these numbers. These sources are important due to the large organic chemical solvent content of wet products (often 25 to 55%) and the large quantities of these materials used. Where organic solvents are used, there are also important indoor air quality implications. There is a trend currently toward reduced quantities of solvents in these products due to regulatory requirements and increasing manufacturer awareness.

4. Identify material constituents

Identification of material or product constituents is made from various sources. In the US, Material Safety Data Sheets (MSDSs) are prepared for each product under requirements of the Occupational Safety and Health Administration (OSHA). These sheets often list most of the major components although only regulated or listed hazardous materials are required to be shown. Constituents present at less than 1% of the total mass are not required to be listed and are often omitted. These may include biocides and other toxic chemicals. Additional information is requested from manufacturers' technical staff regarding detailed chemical contents of the products and estimated drying or cure times for "wet-applied" products. Cooperation by such individuals is highly variable but is improving as such information requests become more frequent.

5. Emission characteristics of materials

Products can be classified according to the rate at which their emissions decay (slow, fast) and the type of mass transfer process governing emissions (diffusion- or evaporation-limited). The most difficult and one of the most critical steps in the process is quantification of the emission profiles of the materials. Tests have been conducted for only a small fraction of all products. Tests results are not necessarily comparable due to variations in test methods, conditions, and laboratory performance. Product formulations and manufacturing processes vary, both intentionally and otherwise, often without re-labeling products. Secondary emissions (sink effects) should be considered since they contribute significantly to indoor concentrations (6, 7).

6. Determine time period to be modeled

Often ignored, the timing (in the life of the material) of the emissions modeling (and of any emissions testing) is critical due to the emissions decay process (8). Explicit assumptions must be made about environmental conditions, exposure, and length of time from manufacture to time period of interest.

7. Determine ventilation rates and scheduling for building, model

Ventilation rates in buildings are highly variable among buildings and over time within buildings (9, 10). Therefore, it is important to determine accurately the ventilation rate of the building both while mechanical ventilation systems operate and when they are off. Buildings generally exchange air with the outdoors through leaks in the envelope, and outdoor weather affects the rate of this exchange (9).

8. Select emission factors and decay rates

Emission factors are based on measurements reported in the literature for similar products of similar age with corrections for environmental conditions as necessary (1,4). There are, among similar products, large variations in emissions, often up to an order of magnitude, occasionally up to two orders of magnitude (4, 8, 11) Therefore, it is important to carefully identify the product being modeled and the product(s) for which emissions test data are available, and to achieve as close a match as possible (12). Differences in nomenclature used within and among countries contribute to considerable confusion and mistaken assumptions of the appropriateness of reported test results. Where large uncertainty accompanies the available emission factors for products, assumptions must be made to enable estimation. These assumptions should include exponential emission decay rates within a mass-balance approach.

Large uncertainty accompanies emission factors for wet-applied products (13). This is important because wet-applied products are often dominant emission sources, at least early in the products' useful lifetimes. Some materials also continue emitting for very long periods of time (14). Important factors include product chemical composition, application thickness, substrate properties, and environmental conditions. Variations among these factors in actual building installations suggest that emissions test data must be interpreted carefully before emissions factors are chosen for use in modeling. As paints or adhesives dry, a skin-like layer may form over the outer surface producing a barrier to migration of vapors from the deeper layers into the adjacent air. Thus, a multi-stage process may occur. When wet products are applied to absorbent substrates such as concrete, wood, and gypsum board, significant absorption may occur onto the substrate creating yet another stage of delayed vapor transfer from the materials to the air. Paint film thickness was identified as an important factor capable of significantly affecting emission rates (13). Sealants applied to composite wood products inhibit formaldehyde emissions thereby showing the efficacy of barriers to emissions.

In the case of emissions from adhesives that are covered by another product shortly after application, emissions from the adhesive must travel through the covering material. The resistance to diffusion through the covering (flooring, wallpaper, etc.) will be an extremely important determinant of emissions once the covering is installed. Emissions occurring before installation of the covering will be large but may vary quite widely due to the factors identified above. In the case of adhesives, applications consist of fairly thick layers compared with paints or other architectural coatings. Several sub-layers may actually form in the adhesive as in the paints.

For paints, assumptions are made regarding the amount emitted during the initial burst (normal drying period), ~ 4 h to 168 h. The time was determined by discussions with manufacturers and other knowledgeable parties. A rough estimate of the mass emitted as a fraction of the volatile content can be obtained by assuming the initial burst to account for ~25% - 50% of total lifetime emissions. After the initial burst, it may be reasonably assumed that 90% of the available remaining volatile mass would be emitted in the next two hundred hours, after that, 90% of the remainder in the next two thousand hours, and so forth. While such estimates are not presumed to be precise, they are accurate within an order of magnitude or better after the initial drying occurs. Thus, unless it is necessary to estimate exposure during the initial drying period, estimates made this way may achieve acceptable accuracy.

9. Select model equations and run model

Emission factors are used together with information on test chamber and building environmental conditions to estimate quasi-steady state concentrations using equations in Reference (15). Several PC-based models are available with a range of complexity and sophistication (16-18) Or, a simple model can be developed from the equations in reference (15) and run in a spreadsheet program.

10. Evaluate model performance

Model results can be compared to concentration measurements in actual buildings to evaluate model performance. A detailed approach to evaluate the correspondence between predicted and measured values is described in reference (19).

DISCUSSION

Modeling results depend on the adequacy of the model and the data used. There are large differences among buildings of different types and construction characteristics. Therefore, building specific analyses are required to properly prioritize materials that are to be addressed in the material selection process during design or in rigorous investigations of emission characteristics for modeling purposes. The results of exposure analysis from a life cycle perspective indicates that emissions from the materials themselves may not always dominate total occupant VOC exposure due to building material characteristics. Instead, maintenance and re-finishing requirements may be more important for some surface materials, particularly floor and wall-coverings (20). These requirements and the chemicals used should, therefore, be important considerations in material selection.

Among the most inscrutable emissions are those from "wet-applied" products, especially adhesives used for floor and wall coverings. Very little research has been conducted on this subject so that considerable uncertainty accompanies estimates of the behavior of emissions from this type of product in buildings. Further work is needed to improve the reliability of modeling involving these and other indoor air pollutant sources.

CONCLUSIONS

Modeling conducted in accordance with the procedure outline in this paper can achieve reasonably reliable and useful results for designers, manufacturers, building investigators, and scientists. Further emissions testing and research are necessary, and they can improve considerably the reliability and utility of modeling work, investigations, and materials selection.

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