Indoor Air, 4, 593-605 (1991)

A Multichamber Model For Assessing Consumer Inhalation Exposure

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Abstract

The Multichamber Consumer Exposure Model (MCCEM) is a user-friendly computer program that can be used to estimate indoor air concentrations and occupant inhalation exposures for chemicals released from products, materials, furnishings or appliances in structures such as residences. Among the major features of MCCEM are flexibility in running the model for durations from one hour to one year, a library of infiltration and interzonal airflow measurements for several hundred U.S. residences, a spreadsheet for input of time-varying emission rates, the ability to estimate inhalation exposure, and options for Monte Carlo simulation and sensitivity analysis. An illustrative application is given whereby assumptions concerning the emission profile and the number of chambers to be modeled are examined for impact on exposure estimates. Discussion is provided on the importance of model validation and an approach to validation is given for the illustrative application.

KEY WORDS:
Indoor air quality, Exposure assessment, Modeling, Multichamber, Monte Carlo simulation, Sensitivity analysis.

Manuscript received: 22 October 1990
Accepted for publication: 31 October 1991

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Overview of IAQ and Exposure Models

Indoor air quality (IAQ) can be modeled by considering factors such as source emissions, dilution by air exchange, and decay or removal in the context of conservation of pollutant mass (Nagda et al., 1987). By combining modeled concentrations with information such as individuals' location/activity patterns and associated breathing rates, it is also possible to model human inhalation exposure to air pollutants. Assessment of inhalation exposure and its potential consequences is of interest to a number of regulatory agencies. For example, the USEPA Office of Toxic Substances (Callahan et al., 1989) performs exposure assessments pertaining to airborne releases of chemical substances in various settings, including non-occupational indoor settings such as residences. In residential settings, chemical substances can be released from building materials, appliances, furnishings, or consumer products used by occupants. In this paper, the term "consumer exposure" refers to inhalation exposure incurred by occupants in non-occupational indoor settings, particularly in and around residences.

IAQ or exposure models generally can be distinguished by their basis, by the range of pollutants they can address, and by the extent of temporal or spatial detail they can accommodate in inputs, calculations, and outputs. Theoretical models, for example, are based on physical principles such as conservation of mass, whereas empirical models are based on approaches such as least-squares regression analysis using measurements under different conditions either within a structure or across a variety of structures. Theoretical models are suitable for a wide range of applications, whereas empirical models are applicable only within the range of measurements from which they were developed.

The focus of this overview is on theoretical models. Unlike many other applications, IAQ/exposure models typically are not software products that can be purchased as "off-the-shelf" items. Rather, most existing software models are research tools that have been developed for specific purposes and are in a continuing stage of development and refinement. The theoretical roots of most IAQ models can be traced to earlier work by Lidwell and Lovelock (1946), cited by a National Research Council report (1981) as among the first to use the mass-balance approach, and Turk (1963), who applied a mass-balance equation to several different cases and presented a detailed analysis of transient and steady-state behavior in a single-chamber model. These early efforts did not result in software products per se; at best, some computer code was shared among a limited group of researchers.

IAQ/exposure models that have been introduced in recent years represent considerable expansion of and enhancement to the earlier work. The technical capabilities of these models are quite varied and are principally related to the manner in which they treat indoor air spaces, source-release mechanisms, sink effects, and airflows. Practical aspects such as user friendliness and speed of execution are also quite variable.

Model treatment of indoor air spaces and airflows is interrelated. Some models treat the entire indoor air space as a single, well-mixed zone, whereas others divide this space into a series of interconnected zones or compartments. Axley (1990) further distinguishes microscopic models that are useful for studying the details of pollutant dispersal in small portions of building airflow systems from macroscopic models that focus on rooms or larger sections of buildings.

Source-release mechanisms are often product- and chemical-specific, and can be treated as instantaneous, constant over a defined time period, or time-dependent with underlying chemistry and physics related to processes such as evaporative or pressurized releases. Sources can be highly localized (e.g., shoe spray), widely dispersed (e.g., freshly painted rooms), or confined (e.g., recently dry-cleaned clothing in a closed closet). Release rates can be nearly constant over time, rapidly decaying, slowly decaying, or rising and falling in response to other parameters such as temperature.

Removal processes, or sinks, in the indoor environment can include chemical reactions, physical processes such as gravitational settling, air-cleaning devices such as filters or adsorption media, and local exhaust (e.g., in proximity to known sources). Mathematical treatments have ranged in complexity from simple first-order rate constants to dynamic submodels that respond to changing conditions. Nazaroff and Cass (1986, 1989), for example, have developed fairly rigorous mathematical treatments for chemically reactive pollutants and indoor aerosols, and Dunn (1987) and Tichenor et al. (1990) have dealt with the issue of reversible sinks (i.e., pollutant mass that is initially removed from but later returned to the indoor air).

With this background in mind, some of the salient features of theoretical IAQ/exposure models known to the authors are highlighted in Table 1. All but one of the six models in the table can be applied in personal-computing environments. The list is not necessarily exhaustive, nor does it necessarily reflect the most recently released version of each model. In comparison to some of the models, the Multichamber Consumer Exposure Model (MCCEM) that is the focus of this paper has some limitation on the number of chambers and the complexity

Table 1 Selected features or limitations of theoretical IAQ/exposure models

Model (reference)	Feature/limitation
CCEM (Versar, 1987)	Single chamber, no sink term Outdoor concentrations not considered Modules for time-dependent releases, direct discharge of aerosol products, and evaporation from chemical films Exposure calculations Menu-driven user interface
CONTAM (Axley, 1988)	Microscopic model Multiple contaminants in a single run Discrete time histories for contaminant emission rates Chamber-specific sink effects Command-driven processor
INDOOR Version 1.0 (Sparks, 1988)	Room-specific airflows Incorporates HVAC system Source-specific emission factors and preformatted emission function Sink term (deposition velocity, surface area) and re-emission from sink Graphics display of results Menu-driven interface
MIAQ (Nazaroff and Cass, 1986, 1989)	Multiple zones and contaminants Time-varying airflows, including HVAC system Area or point-source emissions Pollutant-specific decomposition/loss rates, photolytic reactions Command-driven processor Limited to 24-hour time period Restricted to VAX/VMS operating system
IAQPC (Ensor et al., 1989)	Up to 20 rooms and 6 pollutants concurrently Interconnections among rooms, outdoors, and HVAC system Emission rates for common sources Sink and re-emission rates Air cleaners with user-specified collection efficiencies Graphics display of results Menu-driven interface
MCCEM (GEOMET, 1989a)	Up to four chambers (rooms or room combinations) Library of measured airflow rates for residences Spreadsheet environment for time-varying emission rates Sink term (first-order rate constant) Uncertainty analysis (Monte Carlo, sensitivity) Exposure calculations Menu-driven interface

with which sink terms can be specified, but has greater flexibility in inputting time-varying emission rates in addition to features such as access to residential airflow measurement results, exposure calculations, and uncertainty analysis. These relative advantages and limitations are directly related to MCCEM's developmental objectives of providing a more sophisticated tool for exposure assessment while retaining user friendliness and relative ease of model inputs.

In contrast to the models in Table 1 that can be used to model specific situations on a one-at-a-time basis, a macromodel (Traynor et al., 1989) has been developed that estimates indoor air distributions across a variety of residences through a combination of deterministic and Monte Carlo simulation techniques in development of distributions for input parameters. With this focus on distributions rather than specific cases, the macromodel is currently restricted to combustion pollutants, a single zone, and steady-state assumptions in predicting average indoor concentrations over a one-week time interval. By comparison, the models in the table can provide time-varying indoor concentrations at a temporal resolution on the order of minutes.

Certain "physical-stochastic" models also exist that utilize Monte Carlo techniques to simulate human behavior, represent time-varying pollutant concentrations in various microenvironments, and address uncertainty in the knowledge of model parameters. Earlier models developed along these lines include the NAAQS Exposure Model (NEM) (Johnson and Paul, 1983) and the Simulation of Human Activity and Pollutant Exposure (SHAPE) model (Ott, 1984). Recent alternatives to NEM, such as the Regional Air Human Exposure (REHEX) model (Lurmann et al., 1988) and the personal air quality model (Hayes, 1989), are largely attempts to expand aspects such as the number of microenvironments or time-activity patterns or to provide more refined use of certain data bases for model inputs. With their focus on total exposure across microenvironments, these models tend to provide a more simplified treatment of indoor environments in that indoor sources are not explicitly treated; instead, measured indoor or outdoor concentration distributions are commonly used.

Description of MCCEM

MCCEM calculates time-varying indoor air concentrations in up to four separate chambers, or zones, based on a system of simultaneous mass-balance equations that can be stated as follows:

$$V_i \cdot \frac{d_{Ci}}{dt} = G_i + \sum_{j=1}^{n} Q_{ji} \cdot C_j - \sum_{j=1}^{n} Q_{ij} \cdot C_i - kC_i \cdot V_i \quad (1)$$

where

V_i = volume of ith chamber (m^3)
C_i = concentration in ith chamber (g/m^3)
G_i = source release rate in the ith chamber (g/h)
Q_{ji} = flow from jth to ith chamber (m^3/h)
Q_{ij} = flow from ith to jth chamber (m^3/h)
k = rate constant for contaminant decay (1/h).

For the above set of equations, and for Equation 2 below, Q_{ji} and Q_{ij} are set to zero when $i = j$. Equation 1 is constrained by the following airflow balance for each chamber:

$$\sum_{j=1}^{n} Q_{ji} = \sum_{j=1}^{n} Q_{ij} \quad (2)$$

Among the major features of MCCEM are (1) flexibility in running the model for durations ranging from one hour to one year, (2) a built-in library of infiltration and interzonal airflow rates measured in several hundred U.S. residences, (3) a spreadsheet environment for input of time-varying emission rates, individual locations and outdoor concentrations, (4) the ability to estimate inhalation exposure, and (5) options for Monte Carlo simulation and sensitivity analysis.

The basic steps in running the model are as follows:

1. Select or define a residence (chamber descriptions/volumes, airflow matrix)
2. Choose length of model run
3. Provide inputs for mass-balance or location parameters
   - Emission rates
   - Individual locations
   - Outdoor concentrations
   - Decay rates
4. Choose options for uncertainty or exposure analysis
   - Monte Carlo simulation
   - Sensitivity analysis
   - Percent of concentrations above a user-defined level of concern
   - Lifetime average daily exposure (LADE)

5. Execute the model and review summary statistics
6. Decide whether to save input/output files.

Model features are described in greater detail below in relation to these operational steps.

Selecting or Defining a Residence

The opening menu for selecting or defining a residence is shown in Figure 1. MCCEM contains a library of infiltration/exfiltration airflows, interzonal airflows, and zone volumes/descriptions for approximately 350 residences in 13 different states. This information was collected from various projects in which the researchers used perfluorocarbon tracers (Dietz and Cote, 1982) to determine prevailing airflow rates over a period of several days in each residence. If a one-, two- or three-story house is selected, subsequent screens will direct the user to choose a state and then choose a specific residence from the list for that state. Information such as total volume, chamber descriptions, and seasonal infiltration rate provides some guidance in choosing a residence. Selected residences are better characterized through multiple measurements during each of several seasons, including two-story residences in California, Maryland, and New York. The user can also choose a "generic house" that was defined by the model developers based on commonalities in airflow patterns across several hundred homes. Each of the generic houses is defined as two zones, one with a bedroom area distinguished from the remainder of the house and the other with the kitchen segregated.

More detailed information about the cho-

```
                        TYPE OF RESIDENCE
You can choose from 4 types of residences with information
stored in MCCEM data files or select a hypothetical house
with user-specified volumes and airflow rates.

 1.  One-story structure (e.g., apartment, slab-on-grade home)
 2.  Two-story structure (e.g., rancher with basement)
 3.  Three-story structure (e.g., townhouse)
 4.  Generic house
 5.  Hypothetical house

    Enter choice: [2]

     F1 - further explanation                  F10 - exit program
  Escape - previous screen                  Return - next screen
```

Fig. 1 MCCEM menu for selection of a residence.

```
              SELECTED HOUSE <1121A, 2-STORY, MD>
                        SEASON <SUMMER>

ZONE   DESCRIPT.      VOLUME   TOTAL-FLOW-IN   TOTAL-FLOW-OUT
                      (m^3)       (m^3/hr)         (m^3/hr)
 1    [1ST STORY]   [215   ]       65.60             65.60
 2    [BASEMENT ]   [115   ]       72.80             72.80
 3    [         ]   [      ]
 4    [         ]   [      ]

AIRFLOW RATES      TO:
   (m^3/hr)        ZONE 0    ZONE 1    ZONE 2    ZONE 3    ZONE 4
 FROM: ZONE 0     [......] [13.2  ] [40.7  ]
       ZONE 1     [33.5  ] [......] [32.1  ]
       ZONE 2     [20.4  ] [52.4  ] [......]
       ZONE 3
       ZONE 4

     F1 - further explanation                  F10 - exit program
 Escape - previous screen                  Return - next screen
```

Fig. 2 Zone and flow information for a selected residence.

sen house that is displayed by MCCEM is shown in Figure 2. If the user is not satisfied with the choice at this point, it is possible to escape to prior menus to make a different choice. The user can also provide his/her own inputs for zone descriptions, volumes, and airflow rates by choosing a "hypothetical house" (see Figure 1). In this case, the screen shown in Figure 2 would require entries by the user. MCCEM assists the user in obtaining a total flow balance by updating the total flow to and from each zone as the user enters individual flow elements.

Choosing a Length of Model Run

The model can be run for durations ranging from one hour to one year. With the short-term model option, model calculations are performed on a minute-by-minute basis for up to one week; user inputs or model outputs can be provided for an averaging period as long as one hour. With the long-term model option, model calculations are performed on an hour-by-hour basis, with inputs/outputs provided for an averaging period of up to one day.

Providing Inputs

Emission Rates and Individual's Location

A spreadsheet environment (see Figure 3) is provided to accommodate time-varying descriptions of emission rates (in g/h) in each zone using standard arithmetic operators and mathematical functions. Formulas or values entered in individual cells can be copied to other cells. Fixed-format ASCII files, created externally, can also be imported into the spreadsheet. A separate column is provided

```
     File:MDS2S002     * Total of     480 Time Steps *      Day: 1
                 Zones 1) 1ST STORY    2) BASEMENT    3)          4)

  Step  Hour Min                 Emission Rate [g/hr]       Exposure
  (A)   (B)  (C)    Zone1(D)  Zone2(E)  Zone3(F)  Zone4(G)  Zone(H)
    1     1    1  [0       ] [0       ] [        ] [        ]  [0]
    2     1    2  [0       ] [0       ] [        ] [        ]  [0]
    3     1    3  [0       ] [0       ] [        ] [        ]  [0]
    4     1    4  [0       ] [0       ] [        ] [        ]  [0]
    5     1    5  [0       ] [0       ] [        ] [        ]  [0]
    6     1    6  [0       ] [0       ] [        ] [        ]  [0]
    7     1    7  [0       ] [0       ] [        ] [        ]  [0]
    8     1    8  [0       ] [0       ] [        ] [        ]  [0]
    9     1    9  [0       ] [0       ] [        ] [        ]  [0]
   10     1   10  [0       ] [0       ] [        ] [        ]  [0]
   11     1   11  [0       ] [0       ] [        ] [        ]  [0]
   12     1   12  [0       ] [0       ] [        ] [        ]  [0]
   13     1   13  [0       ] [0       ] [        ] [        ]  [0]
   14     1   14  [0       ] [0       ] [        ] [        ]  [0]
   15     1   15  [0       ] [0       ] [        ] [        ]  [0]
   16     1   16  [0       ] [0       ] [        ] [        ]  [0]

F1-Help F2-Edit/Formula F3-Import F5-Goto F6-Copy F7-Done F10-Exit
     [(Ctrl+) Arrows, Home/End, PgUp/PgDn]-Move Cursor    Esc-Cancel
```

Fig. 3 Input spreadsheet for emission rates and exposure zone.

for indicating the location (exposure zone) of an individual within the building during each time step, with an entry of zero indicating that the individual is not within the building.

Outdoor Concentrations and Decay Rate
A spreadsheet environment similar to that for emission rates enables the user to enter time-varying outdoor concentrations or to import these values from an external ASCII file. The model accepts a user-specified sink term, stated in terms of a first-order rate constant, to describe pollutant removal processes. During model execution, indoor concentrations are homogeneously initialized (under steady-state assumptions) using the outdoor concentration value assigned to the very first time step together with the overall infiltration rate and decay rate.

Choosing Options

Monte Carlo and Sensitivity Options
MCCEM allows the user to perform Monte Carlo simulation with 10 to 1000 trials. Uniform, normal, and triangular distributions can be used to characterize the uncertainty in infiltration rates, emission rates, decay rates, or outdoor concentrations. Random numbers generated by MCCEM can be saved for later access in subsequent runs with the same number of trials. Sensitivity analysis can be applied to the indoor volume, infiltration rate, emission rate, decay rate, or outdoor concentration by specifying a multiplicative factor between 0.001 and 1000.

If the base infiltration rate is changed through either of these options, then all interior airflows are changed in the same proportion to maintain a mass-flow balance. Similarly, if the indoor volume is changed through the sensitivity option, then all flow rates are changed in the same proportion to preserve the base infiltration/exfiltration rate for the building as well as the flow balance.

Exposure Calculations

The model can calculate the percent of observations above a user-specified level of concern as well as LADE. The LADE is calculated in units of mg/kg-day based on user inputs for breathing rate, body weight, number of exposure events per year, number of years of exposure, and individual's average lifetime. Other inputs to this calculation are average consumer exposure during the model run, as estimated by the model, length of the exposure event (assumed equal to the length of the model run), and percent of time in the residence, determined from user inputs for the individual's location during the model run.

Reviewing Inputs and Outputs

After all user inputs have been provided, a summary review screen is provided from which the user can go directly to any of the input screens to revise inputs if desired. Model execution begins when the user exits the review screen. Following model execution, summary statistics are displayed on the screen for the concentrations in each zone of the residence and for consumer exposure. As shown in Figure 4, these statistics include the mean, standard deviation, maximum, the percent of cases at or above a user-specified level of concern, percent of time in the residence, and LADE. At the user's option, time-varying indoor concentrations and consumer exposure can be writ-

```
                SINGLE RUN SUMMARY STATISTICS

                     ZONE 1      ZONE 2    ZONE 3    ZONE 4   CONSUMER
                     ST STORY    BASEMENT
AVERAGE, mg/m^3      2 .10E+03  5.28E+02                       1.37E+03
STD. DEVIATION       1 .15E+03  5.28E+02                       1.37E+03
MAXIMUM, mg/m^3      4 .56E+03  5.28E+02                       1.37E+03
PERCENT OF CASES          96.7      46.7                           74.1
  >=500 mg/m^3
PERCENT OF TIME IN RESIDENCE                                       64.4
LIFETIME AVG. DAILY EXPOSURE, mg/kg-day                        4.44E+01

  Output files generated for this model run are:
  1. MDF2L001.RVE  -  Summary of model inputs and
                      summary statistics for model outputs
  2. MDF2L001.PRN  -  Time-varying concentrations by zone
                      and consumer exposure

 Do you wish to keep the output files? (Y/N) Y
 Do you wish to keep the input/run files (VAL,FML,RUN)? (Y/N) Y
```

Fig. 4 Summary statistics and file name descriptions provided by MCCEM.

ten to an ASCII file for later access. For a model run with the Monte Carlo option, the summary statistics for zone-specific concentrations and consumer exposure pertaining to each trial are written to output files. The user also has the option to save all inputs for access in subsequent modeling sessions.

Illustrative Application

A scenario consisting of painting a bedroom with latex paint was to be examined for possible consequences of consumer inhalation to a vapor released from the paint. The generic house segregating the bedroom from the remainder of the house and an annual average air infiltration rate of 0.5 air changes per hour (ACH) were chosen for the modeling application. The zone descriptions and volumes are shown together with the corresponding airflow matrix in Figure 5. One gallon of paint weighing 4.8 kg was applied over a two-hour period. It was assumed that the chemical of concern, representing one percent of the paint by weight (i.e., 48 g), could be released in two ways: (1) at a constant emission rate of 3 g/h over 16 hours, or (2) at an emission rate starting at 3 g/h but exponentially declining over a six-day period due to retardation of vapor release by the paint film.

The model was run over a seven-day period in one-hour time steps to compare the resultant exposures for the different emission assumptions. Operationally, the time-varying profile was obtained by inputting the following formula in the emissions spreadsheet:

$$E_t = E_o \cdot e^{-kt} \qquad (3)$$

```
                    GENERIC HOUSE <GN001>

ZONE   DESCRIPT.      VOLUME    TOTAL-FLOW-IN   TOTAL-FLOW-OUT
                      (m^3)       (m^3/hr)         (m^3/hr)
 1    [BEDROOM  ]  [40     ]        83.20            83.20
 2    [REMAINDER]  [252    ]       189.20           189.20
 3    [         ]  [       ]
 4    [         ]  [       ]

AIRFLOW RATES      TO:
   (m^3/hr)        ZONE 0    ZONE 1    ZONE 2    ZONE 3    ZONE 4
 FROM: ZONE 0     [......] [20     ] [126    ]
       ZONE 1     [20    ] [......] [63.2   ]
       ZONE 2     [126   ] [63.2   ] [......]
       ZONE 3
       ZONE 4

     F1 - further explanation                  F10 - exit program
 Escape - previous screen                   Return - next screen
```

Fig. 5 Zone and flow information for illustrative MCCEM application.

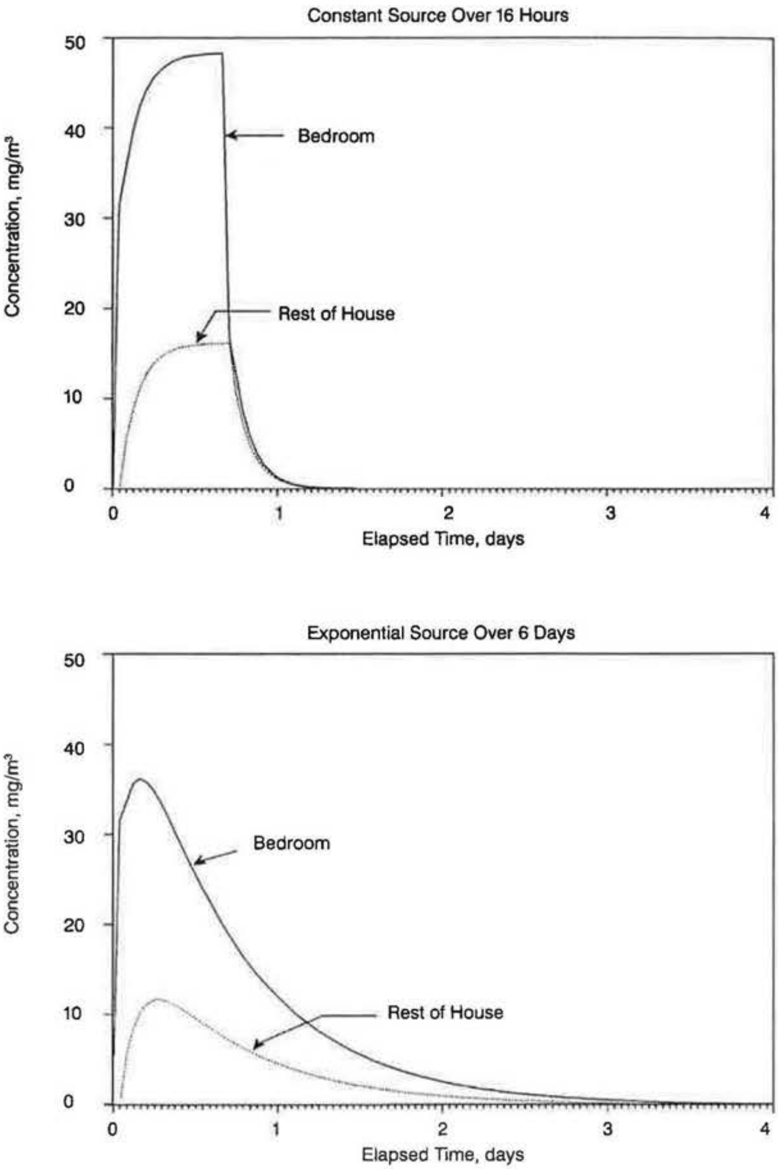

Fig. 6 Modeled indoor air concentrations for MCCEM runs with different assumed emission profiles.

where
E_t is the emission rate at time t (g/h)
E_o is the initial emission rate (3 g/h)
k is a constant to progressively retard the emission rate over time (0.065)
t is the elapsed time, in hours ($0 \leq t \leq 143$)

For this formula, E_o was taken to be the same as that for the constant-emission case and k was defined such that all the chemical mass would be released over a period of six days.

In addition to running the default two-zone model, MCCEM was also run for each emission profile while exercising a one-zone model (i.e., ignore interzonal airflow rates and calculate concentrations assumed to be uniform throughout the house at any point in time).

It was assumed that the painting episode began at noon. The individual was assumed to be in the bedroom for the first two hours, in the remainder of the house for the next

Table 2 Consumer exposure calculations by MCCEM under alternative assumptions for number of zones and emission profile

Number of zones	Emission profile	Consumer exposure: Average concentration encountered, mg/m^3	Peak concentration encountered, mg/m^3	LADE, mg/kg-day
One	Constant	2.95	20.5	0.011
	Exponential decline	2.46	15.7	0.009
Two	Constant	4.59	48.3	0.016
	Exponential decline	3.72	33.5	0.013

eight hours, and then in the bedroom for eight hours overnight. For the remainder of the modeled time period, the individual was assumed to be in the bedroom for eight hours overnight, in the remainder of the house for one hour before leaving, out of the house for nine consecutive hours, and then back in the remainder of the house for six hours before retiring to the bedroom. For purposes of the LADE calculation, this seven-day exposure event was assumed to occur once a year for 70 years. Model defaults of 20 m^3/day breathing rate, 70 kg body weight, and lifetime of 70 years were retained.

Modeled concentration profiles for the two zones of the house – bedroom and remainder – are shown for each emission profile in Figure 6. In both cases, concentrations were highest on the day of painting. With the constant emission rate, concentrations returned to background within slightly more than one day, whereas concentrations were elevated for about three days with the declining emission rate. The range of exposure calculations, shown in Table 2 for both the single-zone and two-zone models with each emission profile, was within a factor of two for average exposure and LADE and within a factor of three for peak exposure. This magnitude of difference among the results for different modeling assumptions is considered relatively small given other potential sources of uncertainty in the exposure assessment. The results also indicate that the model outputs for this illustrative application were more sensitive to the number of zones assumed than to the assumed emission profile over time.

Discussion

Many directions can be taken in developing an IAQ/exposure model, depending on the underlying objective. MCCEM has a number of features that make it relatively straightforward to use and well suited to analysis of consumer inhalation exposure and attendant uncertainties. The illustrative modeling results indicated that the exposure estimates were more sensitive to the number of zones assumed than to the type of emission profile over time. Situations could be encountered, however, where the converse could be true; for example, the emission profile might be more critical in cases where the occupant spent only brief time periods in the area where the emissions occurred.

Considerable thought and care need to be exercised in choosing appropriate inputs for estimating consumer inhalation exposure through models. For example, not all of the chemical of concern may be emitted from the product or material in question. Concentrations in the immediate vicinity of the occupant may be distinctly different from the average concentration in a given indoor air space due to incomplete mixing. Without sufficient supporting information or knowledge, model users could assign unrealistic parameters to the exposure scenario or the number of assumed events per lifetime.

The above discussion points to the importance of and need for model validation. For the illustrative application discussed above, a simulated painting episode could be conducted under controlled and well-characterized conditions, including determination of the paint formulation and measurement of infiltration/exfiltration and interzonal airflow rates during and after the episode. Both air concentrations near the individual's breathing zone and average room-air concentrations in several locations would be measured. The model would then be run under several preassigned assumptions (i.e., those made with no knowledge of the monitoring results). Such an exercise would assist in determining the likely extent of error due to invalid model assumptions, which could then be assessed relative to other sources of error or uncertainty. Ultimately, this exercise would help determine where resources could best be spent in improving the accuracy of exposure assessments.

As part of a previous research project (GEOMET, 1989b), outputs from MCCEM were compared with those from several of the models in Table 1 (i.e., CCEM, CONTAM and INDOOR) for a variety of situations. Two of the data sets for this exercise were from experimental work in room-size chambers and three of the data sets were from experiments conducted in unoccupied research houses. All of the data sets included (1) measurement of time-varying chemical concentrations, (2) direct measurements or quantitative estimates of emissions, and (3) measurement of prevailing indoor-outdoor air exchange rates and, in the case of the research houses, airflow rates among different chambers within the residence. The multichamber models (MCCEM, CONTAM and INDOOR) provided virtually identical results when provided with the same inputs for these situations.

Acknowledgement

MCCEM was initially developed by GEOMET for the USEPA Office of Toxic Substances, Exposure Evaluation Division, under Contract No. 68-02-4254. Enhancements to the software were made under the same contract with support from the USEPA Office of Research and Development, Environmental Monitoring Systems Laboratory (Las Vegas), Exposure Assessment Research Division. The direction and suggestions provided by Patrick Kennedy and Karen Hammerstrom of the USEPA during the period of software development, are gratefully acknowledged. Continued support for model review and refinement has been provided by Dr. Joseph Behar of the USEPA. Programming support throughout the model's development has been provided by Mr. Sang Lee of GEOMET.

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