United States Environmental Protection Agency
Research and Development

Air and Energy Engineering Laboratory
Research Triangle Park NC 27711

EPA/600/S8-88/097 Jan. 1989

EPA

Project Summary

Indoor Air Quality Model Version 1.0

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The manual describes a microcomputer program written to estimate the impact of various sources on indoor air quality in a multiroom building. The model treats each room as a well-mixed chamber that contains pollutant sources and sinks. The model allows analysis of the impact of interroom air flows, HVAC (heating, ventilating, and air conditioning) systems, and air cleaners on indoor air quality. The model is written for the IBM-PC and compatible family of computers.

The model is designed for ease of use and is menu driven. Data entry is handled with a fill-in-the-form interface. Default values for interroom air movement and other input data are provided.

The predictions from the model have been compared with predictions from other models and with experimental data. The model predictions are in excellent agreement with both.

The model is completely documented, including a brief discussion of the theory on which the model is based. Most of the report is devoted to user instructions and demonstrations of how the model can be used.

The model is quite useful and allows rapid analysis of the impact of air pollution sources and mitigation measures on indoor air quality.

This Project Summary was developed by EPA's Air and Energy Engineering Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Indoor air quality is determined by the interactions of sources, sinks, and air movement between rooms and between the building and the outdoors. Sources may be located in rooms, in the HVAC system, or outside the building. Sinks may be located in the same locations. Sinks may also act as sources when the pollutant concentrations drop below a given value.

Air movement in a building consists of:

1. Natural air movement between rooms.
2. Air movement driven by a forces air (HVAC) system.
3. Air movement between the building and the outdoors.

The pollutant concentration in a room is calculated by a mass balance of the various pollutants flows. For the single room shown in Figure 1:

Amount in - Amount out + Amount produced - Amount removed = Amount accumulated

The analysis can be extended to multiple rooms by writing a system of equations for each room. The amount of air entering a room from all sources (the HVAC system, outdoors, and other rooms) must equal the amount of air leaving the room.

The type of mixing between the pollutant and the room air must be specified before the mass balance equations can be used in a model. Because mixing is complex, the exact

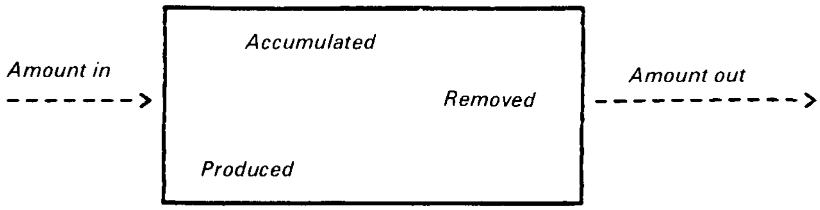

Figure 1. *Single room mass flows*

mixing cannot be specified; simplifying assumptions must be made. Plug-flow and well-mixed mixing are two common mixing possibilities.

In the plug-flow mixing model, the pollutant concentration varies from point to point along the air flow path. In the well-mixed model, the pollutant concentration is the same for every point in the room.

The current model uses the well-mixed model. This model was selected because data from the EPA test house showed that pollutant concentrations within a room do not vary significantly with position in the room.

Once the mixing is defined, the various mass balances discussed above can be used to write a set of linear differential equations. These equations can be solved using many techniques. The model used a midpoint method that is stable and accurate for reasonable time step sizes. When the room volumes are of about the same size, large time steps can be used with little difficulty (unless the source and sink terms exhibit short term time behavior). However, when the room volumes differ by orders of magnitude, as is possible when an HVAC system is included in the model, small time steps (10 sec or less) are needed to avoid numerical instabilities.

The User Interface

The IAQ model uses a menu-driven, fill-in-the-form, data-input user interface. This interface is easy to use and is self prompting. The user interface allows the user to change the input parameters quickly and easily and allows rapid analysis of several conditions.

The master menu shown in Figure 2 controls the operation of the program.

The model can be configured for various personal computers. It can run on a computer with a monochrome adapter, a color graphics adapter (CGA), or an enhanced graphics adapter (EGA). When the model is run with a monochrome adapter, all graphics are disabled.

Data entry is handled with a fill-in-the-form interface. Figure 3 is an example form used in the model.

Indoor Air Model Control Menu

<R>un indoor air model
<D>efine source strengths
<C>onfigure system
<Q>uit

Figure 2. *Master menu for AEERL IAQ model*

The form shown in the example is used to enter the number of rooms in the building and the total ventilation rate

The most complicated form used in the model is the room definition form, which is used to obtain data on individual rooms in the building. Figure 4 is an example of this form.

Figure 4 shows the overall room definition screen. The options available from this screen are:

Select room number,
Define room size and initial concentration (definition),
Define sources,
Define sinks, and
Define interconnections with outside, HVAC system, and other rooms.

The various options are selected by moving the highlight bar across the top of the screen, using the left and right arrow keys.

The results of the model calculations are displayed as plots of concentration versus time for the various rooms. The plots require that a graphics adapter and a monitor be installed on the computer.

Source Terms

A wide range of source terms are available in the model including random on/off sources (cigarettes), sources that are on for a specified period of time (heaters), steady-state sources (moth crystals), and sources with high initial emission rates followed by low steady-state (floor wax). The IAQ model accommodates all these possibilities in an idealized fashion. Each source in the model is discussed below.

Cigarette Smoking

Cigarette smoking is modeled as a random event with from 1 to n cigarettes smoked per hour. The cigarette is turned on at some random time during the hour. A second cigarette is not allowed on until the first cigarette is smoked. Multiple smokers are accommodated in the model; however, all smokers smoke at the same time.

Unvented Kerosene and Gas Heaters

Unvented kerosene and gas heaters are common sources of indoor air pollution. These heaters are modeled as steady-state on/off heaters. The on and off times are part of the data input to the program. Up to three on/off cycles per day are allowed.

Building Definition

Item	*Value*
Number of rooms Max = 10	7
Total ventilation rate air changes/hr	0

Figure 3. *Example form used in model*

```
:: room number   definition   sources   sinks   interconnections   done
1
2
3
4

[Status of room 1]                          [Air flows]
Building vol   150 m² Co   0.0 mg/m³        Air flows           Case 1   Case 2
Vol 150 m³ Wall 77 m² sink 0                Air from hvac         0.0      0 0
Sources selected                            Air to hvac           0 0      0.0
k-heater                                    Air from outside    150 0      0 0
                                            Air to outside      150 0      0 0

[Interconnections]
Room#   Air out to   Air in from            [Air Balances]
                                                              Case 1   Case 2
                                            Air entering      150 0      0 0
                                            Air leaving       150 0      0 0
                                            Balance             0 0      0 0

Pollutant being modeled Particulate
```

Figure 4. Room definition screen

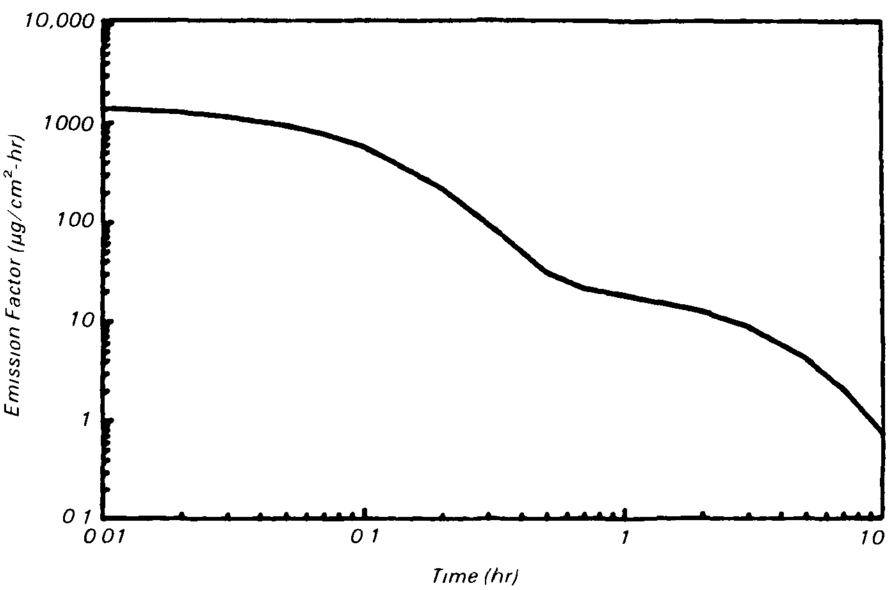

Figure 5. Floor wax emission factor

Moth Crystal Cakes

Moth crystal cakes can be an important source of volatile organic compound (VOC) emissions indoors. Moth crystal cakes are long-term steady-state sources. The emissions from moth crystals are a function of the temperature and the surface area of the cakes.

Floor Wax

Flow wax is an example of a "wet" source of VOC emissions. Wet sources have an initial very high emission factor followed by a low-level, steady-state emission factor. The emission factor for floor wax is based on work conducted by EPA and is shown in Figure 5.

Other

The "other" source is provided as a user defined steady-state source. The source cannot be turned off.

Sinks

It is generally recognized that walls and furnishings can serve as collectors (sinks) of indoor air pollutants. Unfortunately, the data on sinks are limited. The model allows investigation of the behavior of sinks by providing a single sink that is a function of the surface area of the walls in the room. This sink can be a pure sink (i.e., pollutants trapped by the sink are not reemitted) or a reemitting sink.

Small chamber and test house studies are planned to provide fundamental data on sink behavior. The results of these studies will be incorporated into the model as soon as they are available.

The Air-Handling System

The airflows generated by an air-handling system are generally larger than natural airflows. Thus, when an HVAC system is on, the building's airflows are dominated by the HVAC system. Airflow patterns in a building with the air-handling system on may be significantly different from those in the same building with the air-handling system off. For example, many houses have a single return vent for the air-handling system. When the air-handling system is on, airflow is dominated by the flow to the return vent. When the air-handling system is off, airflow is less directed.

The on/off behavior of the air-handling system is modeled by allowing two different airflow patterns to exist in the building: one pattern is active when the air-handling system is on; and the other, when the air-handling system is off. The model switches between these two patterns depending on the state of the air-handling system. The state of the air-handling system (on or off) is determined by a random number generator that ensures that the air-handling system is on for a specified fraction of each hour. The air-handling system may switch from on to off and back several times in an hour. This random switching appears to provide a qualitative description of actual air-handling system behavior. Experiments are planned to determine how well the model fits actual air handler behavior.

EPA Test House Data Comparison with Model Predictions

The model was used to estimate the p-dichlorobenzene concentrations from moth crystals in the EPA test house. The emission factors for p-dichlorobenzene were determined in small chamber studies. The comparison between the model predictions and the measured concentrations are shown in Figure 6.

Hardware Requirements

The model requires an IBM-PC or compatible computer with at least 512 k-bytes of RAM, one floppy drive, and a monochrome or color monitor. The model provides graphics on a computer with a color graphics adapter (CGA) or an enhanced graphics adapter (EGA). Graphics are not provided on a monochrome display adapter.

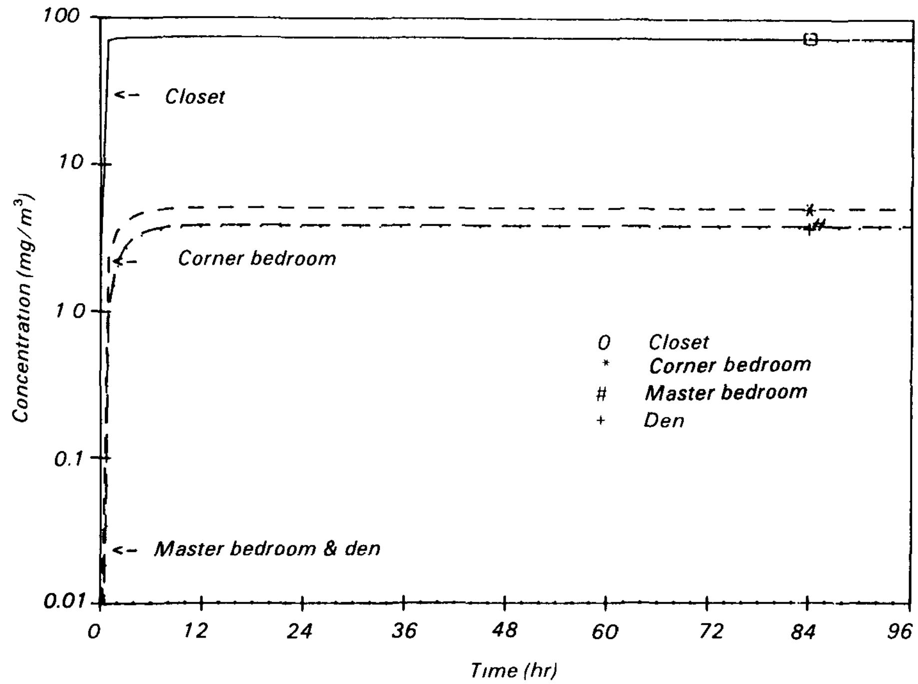

Figure 6. Final mode results with measured flows

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The complete report consists of two parts, entitled, "Indoor Air Quality Model Version 1.0,"

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