# INDOOR AIR QUALITY SIMULATION: IAQPC

M. K. Owen, P. A. Lawless, D. S. Ensor
Research Triangle Institute
and
L. E. Sparks
U.S. EPA

## ABSTRACT

The Indoor Air Quality Simulator for personal **computers (IAQPC) has been developed in response to the growing need for** quick, accurate predictions of indoor air contamination levels. Many building energy use programs are currently in use, but heating, ventilating, and air conditioning (HVAC) system designers need a way to determine if a planned system will ensure the health of building occupants. Scientists will find this program useful as an experimental design aid, and building personnel will be able to use it to determine approaches that will alleviate contamination problems.

This program models up to six pollutants concurrently for buildings of up to 20 rooms. Most single-story buildings can be adapted to one of the six available floor plans. Buildings with more than one story may be modeled if the stack effects can be ignored.

IAQPC allows inclusion of sources, sinks, and air cleaners in the rooms and in the HVAC system. Up to eight sources, four sinks, and two air cleaners can be described, then selected for the individual rooms. In addition to the room air cleaners, up to two types may be selected for the HVAC system. Outdoor air concentrations are specified and the method for determining initial indoor concentrations is chosen. Air flows are calculated by the program based on the cross-sectional interconnections between the rooms, the HVAC system, and the outdoor air. The total flow through the system is specified, then an iterative approach determines the flows.

The improved algorithms used to determine the concentrations have been tested against experimental data and found to yield accurate predictions in a fraction of the time necessary for other current models. This paper will describe the model's inputs, calculations, and outputs.

## INTRODUCTION

Building simulation has traditionally focused on heating and cooling loads. However, as the awareness of the potential health and air quality control problems resulting from indoor air contamination has increased, it has become increasingly important to include contaminant concentrations in HVAC simulation. Building design and alteration plans need to be based not only on the cost of conditioning the air, but the effects on the people and equipment in the building. An indoor air quality simulator needs to be used in conjunction with a heating/cooling load program. IAQPC is a quick, versatile, easy-to-use indoor air quality simulator that runs on personal computers. It will fill the need for building air-quality simulation.

This program is based on recent research in determining the concentrations of pollutants in indoor air. Many potential sources have been characterized. Work has begun in testing air cleaning devices both in laboratories and in buildings. Some studies have been done to determine actual contaminant levels in occupied spaces. Through this program, this information can be used by building designers, HVAC system operators, and occupants.

IAQPC's menus are used to enter data, to describe the specific building, to run the program, and to output the results. This edition of the model, version 2, has been developed under a cooperative agreement with the U. S. Environmental Protection Agency. This program extends Version 1 (Sparks et al., 1988) with more extensive input menus and output options. Faster algorithms for contaminant transport and flow have been employed.

## DESCRIPTION OF THE PROGRAM

This program is designed to model a single-story building with an HVAC system. From 2 to 20 rooms with an additional (optional) hall are allowed. Up to six pollutants can be modeled. The calculations assume that each room is well-mixed. Although much input is required, this program is easy to use. Menus provide easy access to data input, run the program, and output options. Default values are provided for all variables. Thus, even if users do not have a specific value, the program will still run.

The Main Menu (figure 1) gives the user access to the data entry, calculation, and output options. The Basic Design Menu (figure 2) allows the user to specify the building floor plan, room volumes, and interconnections. Six standard configurations for the building are possible (see figure 3). Each layout has a minimum number of rooms, as shown, with a maximum of up to 20 rooms. Note that the floor plan that is most appropriate for modeling a building actually may not look like the building. The important consideration is to match function. In some cases, it may be advantageous to use one room to model a block of actual rooms. This might be the case if only limited information is available on a large area believed to be well-mixed or to have negligible sources. It would probably be simpler and yield essentially the same information to model this area as one large room instead of as two rooms.

INDOOR AIR QUALITY
SIMULATOR
Main Menu

Basic Building Design
HVAC System Description
Pollutant Characteristics
Air Cleaners/Sinks
In-Room Locations
Start Simulator
Continue Simulation
Graphical Output
Output Results
Runtime Configuration

Quit to Prior Menu <Esc>

Use the arrow keys to position the cursor.
Use <Enter> to select the option.

**Figure 1. IAQPC's main menu.**

The interconnections between the rooms, doors, and HVAC system are specified as total connecting areas. These areas provide a relative measure of flow resistance and are not necessarily equal to the physical area. For example, if a room has an open 3 x 7 ft hall door the approximate hall interconnection value will be 21. If the door is shut, a small value for the crack under the door, possibly 0.25 (for 1 in. x 3 ft), would be specified. A summary of the room volumes and connecting areas can be viewed in a convenient on-screen table. In addition, a graphical representation is available that shows the room configuration, relative sizes of HVAC vents, connections between rooms, and outdoor openings.

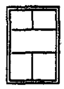
Data required for the HVAC system include the total flow, flow when the system is off, and fraction of makeup air. A submenu allows selection of times for on/off changes in the HVAC system. This system is assumed to be off until the first time specified. The airflows may be displayed, after balancings, allowing the user to check the values before running the simulator. This is especially useful for experimentally characterized buildings. The user may determine if the calculated values reflect the real values, then change the input data to achieve precise results.

Up to six pollutants may be modeled. These are selected in the Pollutant Characteristics Menu, which also allows the user to enter source rates, air cleaner efficiencies, acceptable limits, and outdoor concentrations. At this point there are no pollutant-specific calculations, so any of the pollutant listings can be used to simulate any pollutant as long as the corresponding source and sink terms are correct. (A sink is anything that removes a pollutant from the air.)

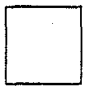
Source rates for many common pollutant sources can be specified here. Since

Expanded Floor Plan 3

Central Hall
4 rooms & hall



Hall
Outside



Connecting Area (ft$^2$)

1 2
0
4 3

| | |
|---|---|
| HVAC room inlet | .4 |
| Outside wall(s) | .2 |
| Next room | 0 |
| Prior room | 0 |
| Hall | 0 |
| HVAC room return | 1 |

Quit <Esc>

BASIC BUILDING DESIGN

| | |
|---|---|
| Floor Plan Selection | 3 |
| Number of Rooms | 4 |
| Room Number | 0 |
| Volume (ft$^3$) | 200 |
| Interconnections | |
| Upward Room# Copy | <F3> |
| Downward Room# Copy | <F4> |
| Building Statistics | |
| Load Building Design | |

Save Building Design

Quit to Main Menu <Esc>

Use cursor keys to select option.
Use <Enter> to activate option.
Use ←/→ to change room number.

**Figure 2. IAQPC's basic building design menu.**

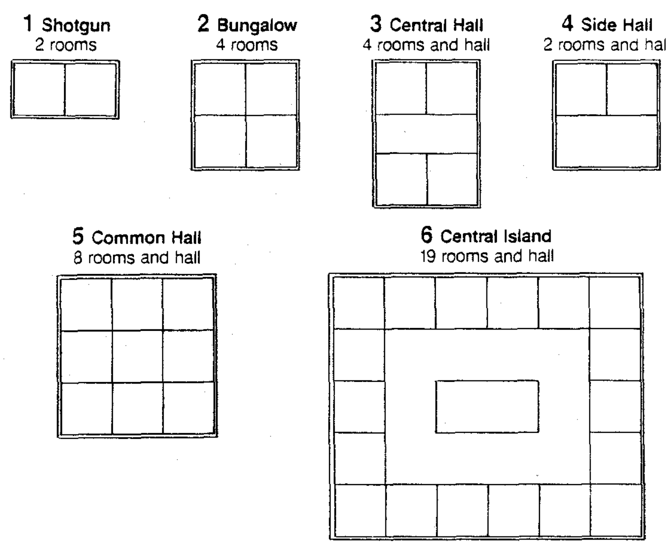



**Figure 3. The six available building layouts.**

typical values are provided as default values, it is often not necessary to enter values unless the actual rates are known. For example, if a certain brand of cigarette is a source, the specific production rate for that cigarette can be looked up and entered. In the same manner, collection and reemission rates for the sinks can be specified.

The user may also choose which types of air cleaners are available and may specify the collection efficiencies of these devices. Efficiencies of the air cleaners for each pollutant may be specified. Outdoor air concentrations are also specified. These values may be used as the initial concentrations inside the building.

The locations for the sources and sinks are specified in the in-room sources and in-room sink options. These menus allow the choice of sources, sinks and air cleaners present in each room, the hall, and the HVAC system. The method the program uses to set the initial in-room concentrations is also chosen.

The program can be instructed to stop calculations at regular intervals. This allows the user to examine the values, then continue; or to escape, change parameters, and resume calculations. For example, if the user wishes to determine the effect of opening and closing a window every 2 h, the interrupt will be set to 2. Then the user will press escape, change the outside connection area in the appropriate room, and continue the program.

The program running options are to start (from time zero) and to continue (from point of last interrupt) calculations. In both cases, the screen clears, then plots the values as they are calculated (the "plot" runtime option is selected). Figure 4 is an example of the graphical output that shows the concentrations of two pollutants. Output options include tables of the current concentrations, the flow rates and the input data.

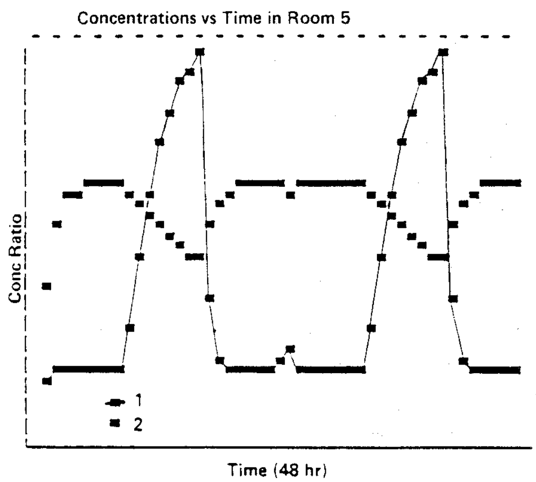



**Figure 4. A sample of IAQPC's graphical output.**

## TECHNICAL APPROACH

A fast, direct-solution method to describe a multizone indoor contaminant distribution was developed. It is assumed that mass is conserved and that each room is well-mixed. If the assumption is made that the neighboring concentrations and source terms do not change during the time step selected, then

$$C_i = C_i(t_o)\exp(-L_i t)+P_i(1-\exp(-L_i t))/L_i \quad (1)$$

where

$C_i(t_o)$ = the concentration for room i at time $t = t_o$,

$L_i$ = loss rate of pollutants leaving room i per unit time, and

$P_i$ = production rate of pollutants entering room i per unit time.

The discrete solution method approaches the exact solution as the time step decreases. At any given starting time, the concentration for each room is known or set by the initial conditions. After the concentrations of all zones during the time step have been computed, the pollutant concentration for supply air is computed. The just calculated concentration in each room is used as the initial concentration for the next time step. This procedure is repeated until the final time is reached. For a more complete description of the algorithm, see Yamamoto et al. (1988).

To compare the execution time for this program with that for CONTAM (a state-of-the-art program with extensive algorithms), identical cases were run with both programs. The comparison case represented a building for which we have experimental data. The algorithm used in IAQPC, another algorithm (also developed at RTI), and CONTAM were compared. All three gave results that were consistent with the experimental results; however, the IAQPC algorithm ran approximately 10 times as fast as CONTAM (Yamamoto et al. 1988). It also ran much faster than Version I of this program.

The flow-balancing algorithm uses pressure-driven flows, with a strict pressure balance maintained for the system with "areas" used to represent the flow resistance. The mass flow error in each room is used to provide a relaxation correction to the pressure in the room. Convergence to mass balance in all rooms is the criterion for overall convergence.

## DISCUSSION

Simple-to-use, easy-to-understand menus enable any user to benefit from this contaminant calculation program. Ay new user with basic knowledge of concentration levels and building design will have little trouble using this program because on-screen instructions are provided. A user's manual, complete with tutorial and program flowchart, is available.

Building description is accomplished through a choice of floor plans. This procedure sets up the connections between rooms without the neccessity of laboriously specifying which room is connected to what. The chosen floor plan need not match the actual layout but should match the simulated building in function.

The connections between rooms are specified by cross-sectional areas; therefore, a building may be characterized using floor plans and a determination of which doors, etc., are open. It is not necessary to have airflow data to determine approximate airflows in the building. However, if actual flow rates are available, the interconnecting areas can be specified, then refined to produce more accurate values. This approach makes it simple to determine the results of changes in the building such as the opening of a window.

By specifying various values for total HVAC airflow and percent makeup air, it is possible to determine the effect of these two parameters on the indoor concentrations. Because energy efficiency is directly related to the flow rate and, even more, to the percentage of outdoor air (which may have to be cooled or heated), it is important to be able to determine minimum acceptable flows. With IAQPC these values can be changed quickly and their effects studied. Also, sources can be changed to determine whether lower flows would be acceptable if certain sources were eliminated, moved, or vented. In the same way, a scientist can use these options to aid in experimental design. The results of computer runs will indicate what parameters will be influential and will need actual study.

Because up to six pollutants can be modeled, much time can be saved over the separate runs required in previous air quality programs. The generic sources (cigarette, heater, etc.) have default values that are standard for the particular source; this allows the user to specify sources without having to look up source strengths. However, actual emissions data for specific sources will result in greater accuracy. This ability enables the user to compare the effect of source strength on final concentrations.

The sinks and air cleaners can be manipulated to determine, for example, the effect of more efficient filters. Knowledge of the effect of various air cleaning devices could benefit a designer by helping to determine the lowest pressure drop for a filter that will yield acceptable air conditions, therefore helping to size the building fans.

Because the locations of both the sources and sinks can be specified, IAQPC is very versatile. Sources can be moved to determine the best location for the copy machine or how smokers should be placed to have the least impact on an office building as a whole.

The runtime and program output options make it possible to obtain the required data in the most readily usable form. All of the options, combined with the speed of IAQPC, make this program the ideal tool for many HVAC professionals and building occupants, as well as for scientists investigating indoor air phenomena. A sample case is presented in Owen et al., 1989.

This program and appropriate documentation will be available through normal EPA channels as soon as release approval has been obtained.

## CONCLUSIONS

1. IAQPC fills the current need for a quick, user-friendly method of determining potential indoor air problems. This model will allow both building users and designers to determine potential problem areas and IAQ control approaches.

2. IAQPC, if combined with a building energy load program, will help determine the best design for a healthy, efficient building.

3. Experimental data verify that the program does predict actual values.

**PLANNED DEVELOPMENTS**

1. Data from experiments will be used to further verify or modify the assumptions in the model.

2. Additional sink types and pollutant interactions will be included as these phenomena become better understood. Eventually a model that incorporates costs and health effects will be developed.

**REFERENCES**

*CONTAM Users Manual*, National Bureau of Standards, January 1987.

Owen, M.K., P.A. Lawless, T. Yamamoto, D.S. Ensor, and L.E. Sparks. "IAQPC: An Indoor Air Quality Simulator," presented at ASHRAE's IAQ '89 conference, San Diego, CA, April 1989.

Sparks, L. E., M. D. Jackson, and B. A. Tichenor. "Comparison of EPA Test House Data with Predictions of an Indoor Air Quality Model," in: *Proceedings of IAQ '88*, ASHRAE, Atlanta, GA, 1988.

Yamamoto, T., D. S. Ensor, P. A. Lawless, A. S. Damle, M. K. Owen, and L. E. Sparks. "Fast Direct Solution Method for Multizone Indoor Model," in proceedings of conference on Building Systems: Room Air and Air Contaminant Distribution, University of Illinois, December 1988.