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PREDICTING INDOOR AIR QUALITY WITH IAQPC

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The ability to predict the level of air contamination for any building for known sources and air cleaners has long been desired. Indoor air quality (IAQ) consultants, building occupants, and especially, building designers and builders must be able to predict what type of indoor environment will result from their decisions. This paper presents the results of a model study using the Indoor Air Quality Simulator for Personal Computers (IAQPC). The building modeled is a test house characterized in several studies. Experimental values for air cleaners efficiencies, source strengths, and ventilation rates have been combined to predict the contamination level in the house. In particular this paper addresses the effect of vacuum cleaning and cigarette smoking on a home's air supply and investigates the results of employing furnace filters relative to an ASHRAE rated filter and an electronic air cleaner.

INTRODUCTION

Over the past decade researchers have identified the indoor environment as potentially one of the major sources of human exposure to air pollutants becuase indoor contamination may exceed established ambient limits. Since most people spend 80% or more of their time indoors, indoor air pollution can yield a greater potential for harmful exposure to air pollution than exists outdoors (1, 2, 3). Thus attention has been focused on indoor air quality, making it important to be able to determine the effects of heating, ventilating, and air-conditioning (HVAC) system operating parameters on indoor air pollutant concentrations, including particles. Studies have been performed to determine the effects of various sources, ventilation rates, and air cleaners. The results of these studies can be used as the basis for IAQ predictions.

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. The improved algorithms used to determine the concentrations have been tested against experimental data and found to yield accurate predictions.

This paper discusses the results of simulator predictions of contaminant concentrations for a home. The particular building has been used for several studies, one of which was used earlier as part of the validation of the IAQPC. This comparison with some details of the study and an introduction to the simulator is presented in Owen et al. (4). The development of the IAQPC and experimental air cleaner efficiencies are discussed briefly to show the basis of the modelling efforts. Then predictive runs for both vacuuming and smoking with various air cleaners and HVAC parameters are presented.

INDOOR AIR QUALITY SIMULATOR DESCRIPTION

The IAQPC models up to 6 pollutants concurrently for a single story building with an HVAC system and up to 20 rooms. There are 6 floor plans available which can be expanded from a minimum number of rooms up to the full 20. Buildings with more than one story may be modeled if the stack effects can be ignored. The rooms are assumed to be well mixed. Although much input is required, this program is easy to use. Menus provide easy access to data input, run simulation, and output options. Default values are provided for all variables.

IAQPC allows inclusion of sources, sinks, and air cleaners in the rooms and in the HVAC system. Up to 8 sources, 4 sinks and 2 air cleaners can be described, then selected for the individual rooms. In addition to the room air cleaners, up to two types of air cleaners 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 percentage. The areas are specified to account for vents, doors, windows, etc. The total flow through the system is specified, then an iterative approach determines the flowrates.

The improved algorithms used to determine the concentrations have been tested against experimental data and found to yield quick, accurate predictions. For a more complete discussion of the algorithm, see Yamamoto et al. (5). The program is described with additional experimental validation in Owen et al. (6). The program and its manuals are available through NTIS (7).

TEST HOUSE DESCRIPTION AND MODELLING

The house modeled in this paper is the EPA test house in Cary, NC. For more details about the test house, see Sparks et al. (8). In order to model this house, a floor plan had to be chosen. The floor plan shown in Figure 1 was used. Figure 1 is essentially the screen seen when running the program. The hexagons indicate the sizes of the HVAC openings; the rectangles indicate the sizes and locations of the doors as described in the notation below the floor plan. The volumes indicated are in ft³. English units are used here since these are the units of the IAQPC, chosen to reflect those used most often by the expected users.

The room volumes were determined directly from the floor plan, then entered into the program.

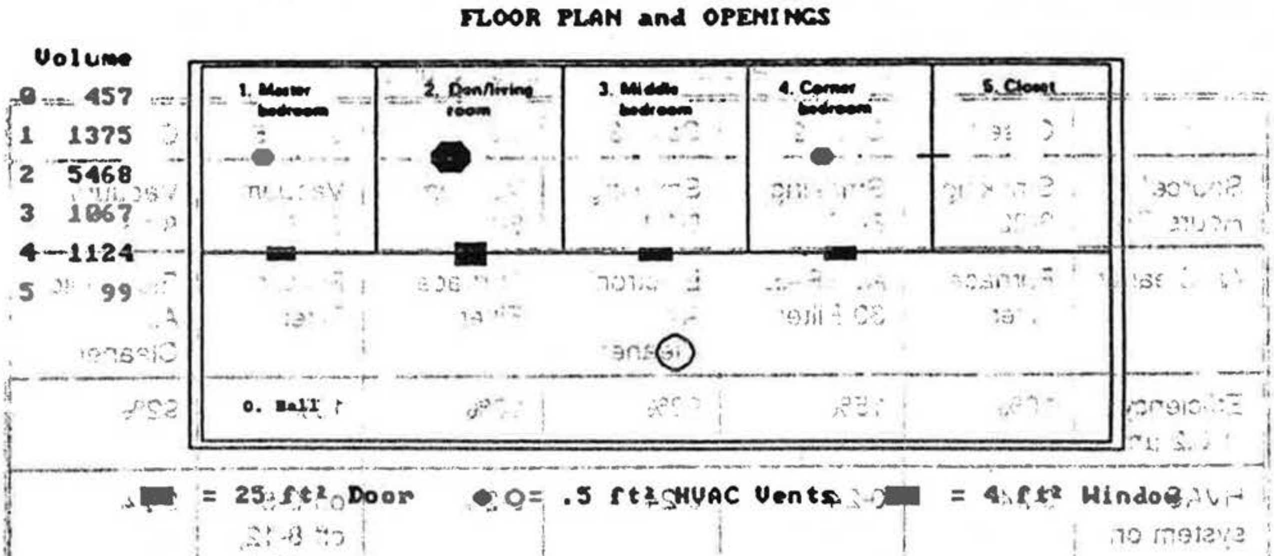

Figure 1 Layout for Simulation of EPA Test House

Reasonable guesses were made for all of the interconnecting areas. For example, it was assumed that open doors would connect all the rooms to the hall, except the closet. This resulted in the use of 21 ft^2 (3 ft x 7 ft) for the interconnection between the four main rooms and the hall. The outlet and return vents were assigned much smaller values. The door to the closet was assumed shut, so a small value was given to the area between the room and the closet. In order to force air through the closet, a value was given for an HVAC vent. Also, all four rooms with outside walls were given values to represent cracks or slightly open windows so that air could escape from the building.

The total volume of the five rooms and the air exchange rate were used to determine the amount of outdoor air entering the building. The flows were summed and entered into the program as the total flow and fraction of outdoor air values. Then the airflows were balanced through the HVAC system design menu. The airflows were then examined and adjustments were made to the interconnecting areas so that the flowrates corresponded to the actual values. The final flowrates are shown in Table 1.

Table 1 Airflows (cfm)

Room	Name	Measured HVAC Airflow	Simulator Airflows
0	Hall	no inlet	0
1	Master Bedroom	165	162
2	Den/Living Room	400	404
3	Middle Bedroom	165	21
4	Corner Bedroom	164	161
5	Closet		4

Once the building layout was set, sources and air cleaners were chosen. Six cases were run as described in Table 2. The first three simulations used cigarette smoke as the source. Since approximately 30% of American adults smoke and cigarette emissions have been characterized, this is a reasonable source to examine. The smoking was started at 8 am and continued until 10 pm (hour 22), at a rate of 1 cigarette per hour. A typical rate of 30 mg/cigarette of 0.2 µm particles led to a rate of 30 mg/hr. Smoking was modelled as occurring only in the den/living room. The three cases show the effect of the source on the indoor air concentration for three

Table 2 Description of the Case Studies

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
Source/ Hours On	Smoking 8-22	Smoking 8-22	Smoking 8-22	Vacuum 8-13	Vacuum 8-13	Vacuum 8-13
Air Cleaner	Furnace Filter	ASHRAE 30 Filter	Electronic Air Cleaner	Furnace Filter	Furnace Filter	Electronic Air Cleaner
Efficiency at 0.2 µm	10%	15%	92%	10%	10%	92%
HVAC system on	0-24	0-24	0-24	0-24	on 0-8, off 8-12, on 12-24	0-24

efficiencies of air cleaners. The HVAC system was set to on continuously, so actual overall concentrations where the HVAC operated intermittently would be higher.

The particle emission rate for vacuum cleaners was determined from the appropriate figure in Smith et al. (9). The mode of the particle size distribution during vacuuming occurred at 0.2 μm diameter with a value of 10^9 particles/min. Assuming a density of 1 g/cm^3, this yields a mass emission rate of 314 mg/min. Since this testing was performed with carpet loaded with standard ASTM dust mixture (a much higher dirt level than most homes would have), a portion of the emission rate (one-twentieth) was chosen for the simulation. Due to the on/off nature of vacuuming in normal operation (on for a few minutes, then off to move the chair or pick up toys, then on...), the source timing scheme was set as vacuuming beginning at 8 am with 6 min vacuuming, then 6 minutes off for one hour per room beginning with the hall (room 0) moving to room 1, etc. For case 5, the HVAC system was on from midnight to 8 am, turned off from 8-noon, then turned on again. This was done to emphasize the effect of the ventilation system.

The filtration efficiencies used for the ASHRAE 30 filter and the electronic air cleaner (EAC) were determined in studies reported in Ensor et al. (10).

RESULTS

Figure 2, the concentration curves for one day for Case 1, shows how the concentration increases as the source emits. It also shows how the hall, which is directly connected to the den (source location), increases more rapidly and rises to a higher maximum than the bedrooms. Only one bedroom is shown as the predicted concentrations are the same. Thus a source in one part of the house does affect the remainder of the rooms. Note that the concentration at time 0 (midnight) is set equal to the outdoor concentration; the indoor concentrations is lowered as the air cleaner treats the air.

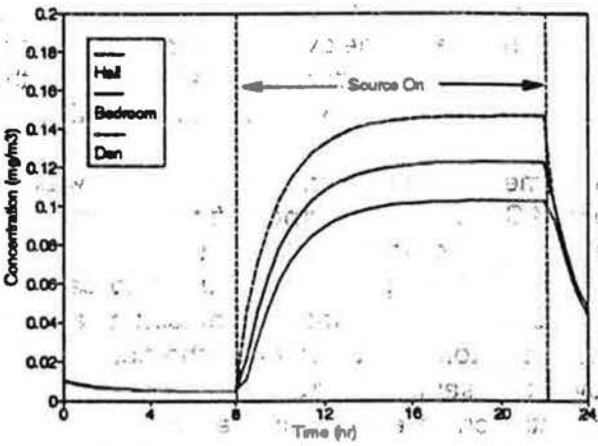

Figure 2 Case 1 Smoking Simulation with Furnace Filter

Figure 3 shows the effect of the somewhat more effective filter (5% more efficiency). In this simulation the concentrations in the den are reduced by 18% relative to Case 1; concentrations in the bedrooms are reduced by 26%. Thus an increase in the air cleaner's efficiency is clearly shown to improve the air quality and to reduce the spread of the contaminant in the building.

Case 3 gave much lower concentrations for all locations as shown in Figure 4. The den had 53% and the bedrooms 97% less particulate matter than for Case 2. The bedroom concentrations were even lower than outdoors. It is important to note that this simulation only looks at particles from a stationary source. This type of air cleaner does not remove the gaseous pollutants and movement to other rooms by the

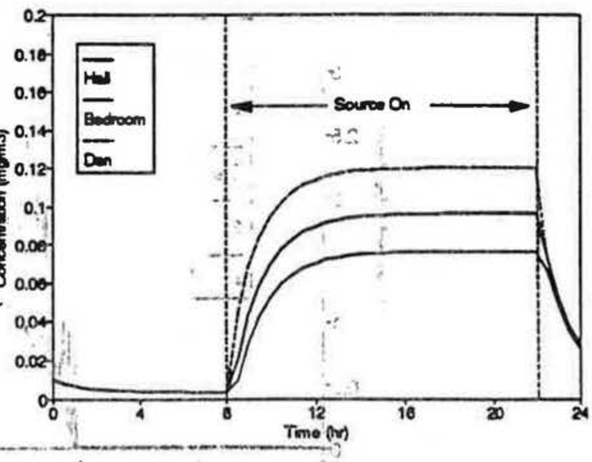

Figure 3 Case 2 EPA Test House Smoking Simulation with ASHRAE 30 Filter

smoker would raise the concentrations in those rooms.

These cases show that improving the efficiency of the air cleaner can very effectively improve the indoor air quality of the residence. However, source removal or reduction will also be effective. Also cost of the air cleaner and electricity must be considered in making air cleaner decisions.

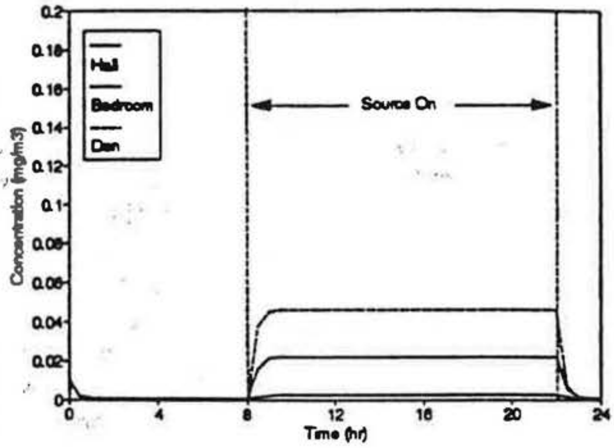

Figure 4 Case 3 Smoking Simulation with Electronic Air Cleaner

Cases 4-6 involve vacuuming, a non-stationary non-continuous source, which results in concentration spikes and large variation between the rooms. Figure 5 shows a plot of a full day's concentrations with the furnace filter in place and the HVAC turned on continuously. Since this plot shows essentially constant values until 8 am and a simple decline after 3 pm but a lot of variation in the interim, Figure 6 was produced to show the same data from 7 am to 3 pm. In this plot, the increases in the room as it is vacuumed are apparent, as is the overall rise in household concentrations as the vacuuming continues. The smaller peaks in the den relative to those in the other rooms show the influence of the added room volume and airflow through this particular room.

The same source pattern and air cleaner was modelled in the next case, with the exception that the HVAC system was turned off for the first four hours of the vacuuming. This was done to show the influence of the ventilation system in a manner that would enable the reader to see the differences in the graphs in an uncomplicated fashion (turning the system off and on every few minutes results in too many confusing peaks). The "off" time for the HVAC system is modelled as 200 cfm total airflow through the house to account for the natural convective flows. Figure 7 shows the same 7 - 15 hour time period for Case 5. (Note the y-scale change.) The concentrations are approximately 3 times those with the HVAC system on. The individual room values continue to rise throughout the vacuuming time for that room instead of reaching a psuedo-steady state condition. Concentrations also take a much longer time to decline after the source is removed from the room.

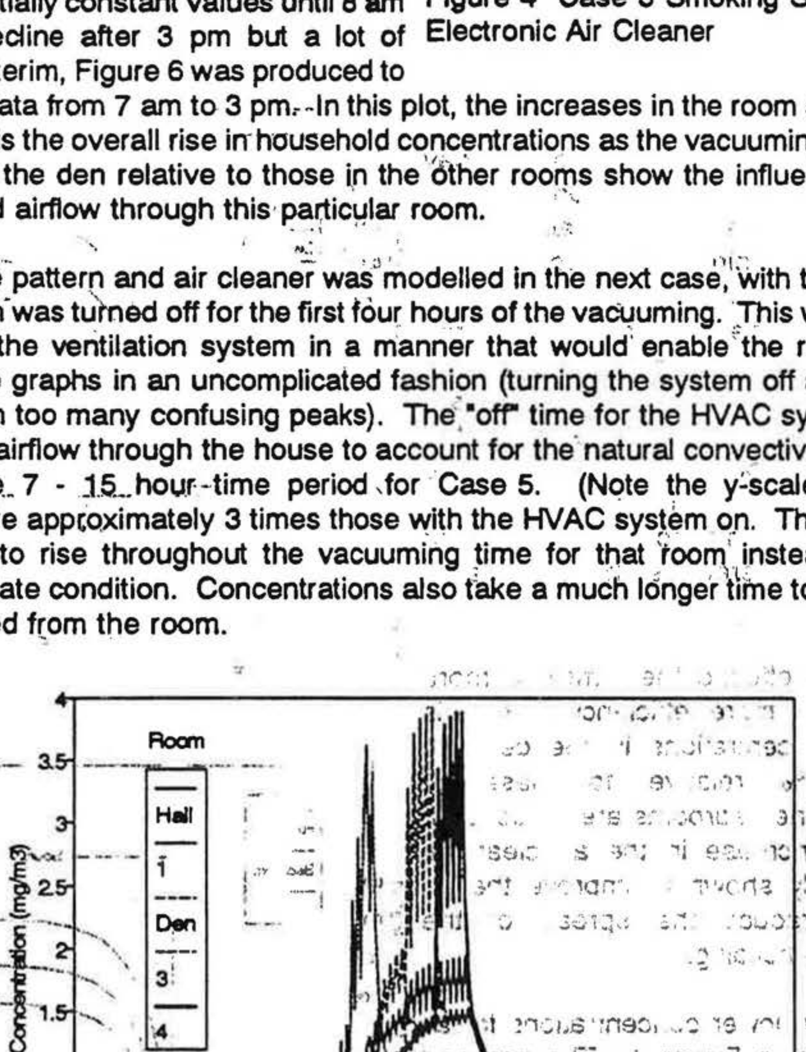

Figure 5 Case 4 Vacuuming Simulation with Furnace Filter

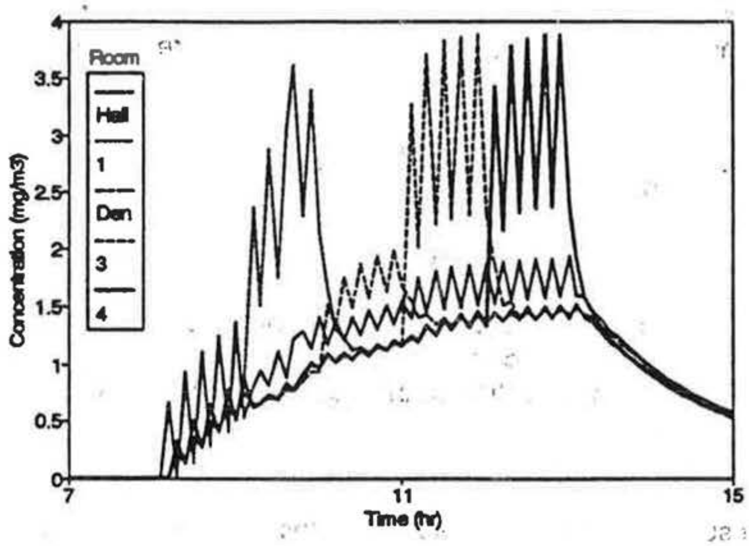

Figure 6 Expanded View of Vacuuming Simulation

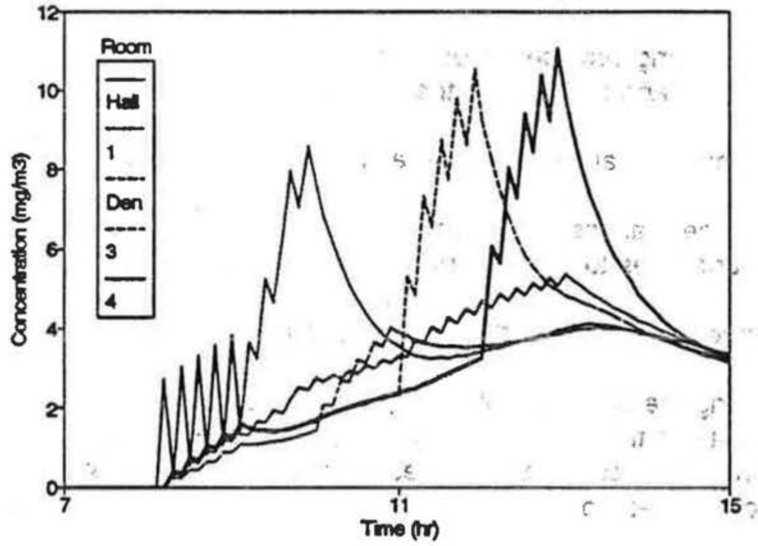

Figure 7 HVAC System Influence on Vacuuming Concentrations

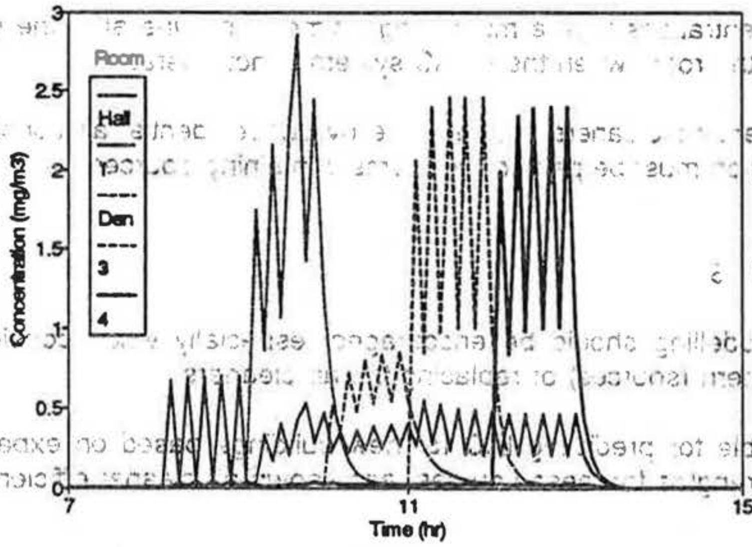

Figure 8 Case 6 Vacuuming Simulation with Electronic Air Cleaner

Figure 8 shows Case 6, where the schedule is the same as in Case 4 but the much more efficient electronic air cleaner is used. Clearly the concentrations are lower overall, but the current room still reaches a rather high concentration, and those in the hall remain elevated as long as the vacuuming continues in any location. Again, the hall and the den show the influence of having higher air flowrates than the other rooms. Very efficient air cleaners will keep the overall residential air clean, but attention must be paid to the rooms containing sources (smoking, vacuuming, painting, burning, etc.).

All of these cases show the influence of several variables on the indoor concentrations and the power of modelling as applied to indoor air. Much more elaborate cases can be developed. The results of simulations such as this may allow builders, owners, and/or occupants to determine the types of ventilation systems and air cleaners that are needed for their expected uses or to determine the effect of source modification of the quality of their air supply.

CONCLUSIONS

- The results of simulations such as this may allow builders, owners, and/or occupants to determine the types of ventilation systems and air cleaners that are needed for their expected uses or to determine the effect of source modification of the quality of their air supply.
- IAQ modelling provides a quick method for examining the effect of air cleaner efficiencies and sources on the concentrations in a building.
- Indoor concentrations increase as long as a source emits.
- The concentrations in a room directly connected to the source room increases faster and rises to a higher maximum than the other non-source rooms.
- A source in one part of the house does affect the remainder of the rooms.
- Improving the efficiency of the air cleaner can very effectively improve the indoor air quality of the residence. However, source removal or reduction will also be effective. Also cost of the air cleaner and electricity must be considered in making air cleaner decisions.
- For a given source strength, a larger room or one with more airflow will have lower concentrations.
- Concentrations take a much longer time to decline after the source is removed from the room when the HVAC system is not operating.
- Efficient air cleaners will keep the overall residential air concentrations low, but attention must be paid to the rooms containing sources.

RECOMMENDATIONS

The use of IAQ modelling should be encouraged, especially when considering changing a building's usage pattern (sources) or replacing the air cleaners.

Modelling is advisable for predicting IAQ for new buildings based on expected sources (and knowledge of the strengths for these sources) and known air cleaner efficiencies.

REFERENCES

1. Caceres, T., H. Soto, E. Lissi, and R. Cisternas (1983). "Indoor House Pollution: Appliance Emissions and Indoor Ambient Concentrations," Atmospheric Environment, 17(5):1009-1013.

2. Budiansky, S. (1980). "Indoor Air Pollution," Environ. Sci. & Technol. 14(9):1023-28.

3. Leaderer, B. P., W. S. Cain, R. Isseroff, and L. G. Berglund (1984). "Ventilation Requirements in Buildings - II. Particulate Matter and Carbon Monoxide From Cigarette Smoking," Atmospheric Environment, 18(1):99-106.

4. Owen, M. K., P. A. Lawless, T. Yamamoto, D. S. Ensor, and L. E. Sparks (1989). "IAQPC: An Indoor Air Quality Simulator," In: Proceedings of IAQ '89, April, San Diego, CA.

5. Yamamoto, T., D. S. Ensor, P. A. Lawless, A. S. Damle, M. K. Owen, and L. E. Sparks (1988). "Fast Direct Solution Method for Multizone Indoor Model," In: Proceedings of Building Systems: Room Air and Air Contaminant Distribution, Dec., University of Illinois.

6. Owen, M. K., P. A. Lawless, D. S. Ensor, and L. E. Sparks (1989). "Indoor Air Quality Simulation: IAQPC," In: Proceedings of the IBPSA Building Simulation Conference, June, 1989b, Vancouver, BC.

7. Lawless, P. A. and M. K. Owen (1991). "IAQPC Indoor Air Quality Simulator for Personal Computers: Program, Volume 1. Technical Manual, and Volume 2. User's Guide" (NTIS PB91507871).

8. Sparks, L. E., M. D. Jackson, and B. A. Tichenor (1988). "Comparison of EPA Test House Data With Predictions of an Indoor Air Quality Model," In: Proceedings of IAQ '88, American Society of Heating, Refrigerating and Air-Conditioning Engineers, April, Atlanta, Georgia.

9. Smith, D. D., R. P. Donovan, D. S. Ensor, and L. E. Sparks (1990). "Quantification of Particulate Emission Rates from Vacuum Cleaners," In: Proceedings of the Indoor Air '90 Conference, August, Toronto.

10. Ensor, D. S., A. S. Viner, J. T. Hanley, P. A. Lawless, K. Ramanathan, M. K. Owen, T. Yamamoto, and L. E. Sparks (1988). "Air Cleaner Technologies for Indoor Air Pollution," In: Proceedings of the ASHRAE Conference IAQ'88, April, Atlanta, Georgia.