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Consequences of air movements in buildings

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Introduction

Investigation and research into the so-called "sick building" phenomenon has been steadily increasing during the past 10 years, partially due to the emergence of the energy crisis of 1973. Hundreds of detailed case studies in residential and commercial buildings have been carried out in Europe, the U.S.A., Canada and Japan. However, very few results in the literature can give definite or clear answers for the cause of the sickness; or an effective method to prevent the problem. It has been shown that energy conservation with its tight building techniques and consequentally decreasing ventilation rate, plus the introduction of new building materials and equipment have all played important roles in the sickness syndrome.

The demand for improved indoor air quality as well as reducing energy costs has focused more attention on the modelling of infiltration and indoor air flow in buildings. A common characteristic of most existing buildings is that they have floor plans and internal partitioning, which makes the single-cell model redundant. Many multi-room models have been developed. A review of the literature shows that most of these programmes are not available to the public, especially the programmes which can suit specific needs, such as energy cost analysis and indoor air quality analysis. The difficulties in developing such a model are how to determine the parameters of input data, such as the wind pressure distribution, leakage distribution, etc, see The COMIS Group (1989). How to validate the model by the experiment is another problem, see Feustel et al (1985), and Feustel (1989).

The work carried out here was to simulate infiltration, and indoor air movement and its interaction with the mechanical ventilation in multi-room buildings. A multi-room indoor air quality prediction model was combined with the multi-room indoor air flow model. The multi-room indoor air flow model is called MIX (*m*ulti-room *i*nfiltration and e*x*filtration). The single-cell version of MIX is called SIX (*s*ingle-cell *i*nfiltration and e*x*filtration). The program MIX was employed to study a series of indoor air quality problems. These consisted of smell transfer, tobacco smoke spreading, radon concentration, and the moisture content in buildings. The influences of infiltration on the operation of an exhaust ventilation system, balanced ventilation system, and the mechanical ventilation system in high-rise buildings, were also investigated. Lastly, a new combined method of natural ventilation and mechanical ventilation was developed by using MIX. A description of the model and the results will be published in several different papers, see Li et al (1990) and Li (1990a-1990g). A general discussions now follows.

Multi-room Model MIX

The building surfaces and indoor partitions contain openings, either large or small, which permit the air to flow through them whenever there are pressure differences across the openings. The pressure differences may be due to naturally occurring wind, indoor-outdoor temperature differences, or the operation of mechanical ventilation. MIX considered the multi-room building as a complicated interconnecting system of flow paths, and can be used to predict air flow rates between rooms, across the outside envelopes, and through the mechanical ventilation system. As well as predicting room pressures and indoor pollutant transfer. For the theoretical background of MIX, see Li et al (1990).

To run MIX, the following data are required.

- o Building description by:
  - number of rooms
  - volume of each room
  - height of each room
  - flow path interconnections
- o Flow description by:
  - type of ventilation system
  - initial ventilation flow rate
  - leakage area of each flow path
  - k_t values and exponent
  - flow resistence of the ventilation system
  - fan characteristics
  - chimney temperature and height

- o Environmental description by:
  - external and internal air temperature
  - wind speed and direction
  - shielding and terrain conditions
  - atmospheric pressure
- o Pollutant description by:
  - source and sink of pollutant
  - initial concentration for dynamic case

For the comparison between the measurement of the houses and the prediction of indoor air flow by MIX, two measurement data sets are chosen from AIC mathematical model validation data, see AIC (1981). The houses used in the experiment are called HUDAC upgraded house and HUDAC standard house. The ranges of ventilation conditions of each data sets are listed in Table 1.

Table 1. List of validation data.

House	Country	Time	U	$\Delta\theta$	n
HUDAC upgrad	Canada	Summer,79 Winter,79	1,0-10,6	- 7,9-40,6	0,05-0,32
HUDAC standard	Canada	Winter 78-79	1,0-10,6	6,3-40,6	0,15-0,42

where

U = wind speed, m/s
$\Delta\theta$ = indoor-outdoor temperature dofference, ^{o}C
n = infiltration rate, ach

Table 2. Values of leakage cofficient k_t.

House	Wall 1	Wall 2	Wall 3	Wall 4	Ceiling
HUDAC u.	0,000172	0,000172	0,000172	0,000069	0,000082
HUDAC s.	0,000232	0,000232	0,000186	0,000093	0,000112

where

k_t = leakage coefficient, m^3/s at 1 p_a.

Table 3. The c_p distribution on envelope.

Direction	Wall 1	Wall 2	Wall 3	Wall 4	Roof	Roof
N	0,4	-0,4	-0,4	-0,1	0,0	-0,3
NW	0,5	-0,3	-0,5	-0,3	-0,3	-0,3
W	0,0	0,5	-0,3	-0,3	-0,3	-0,3
S	0,4	0,0	-0,3	0,1	0,0	-0,3
E	-0,2	-0,2	0,2	-0,3	-0,3	-0,3
NE	0,5	-0,3	-0,4	0,1	-0,3	-0,3

where

c_p = the pressure coefficient

The single-cell version, SIX, was adopted to predict the air infiltration rates. This is because the internal flow paths in the previous measuremental houses are very difficult to specify due to the limited description in the present publications. The values of major parameters used in the corresponding calculation are listed in Table 2 and Table 3.

The differences between calculated and measured air infiltration rates for a HUDAC upgraded house and a HUDAC standard house are illustrated by Figures 1 and 2 respectively. After analysing the sources of error and sensitivity of the infiltration models to the sources, Etheridge (1988) concluded that the error in the calculated infiltration rate could be expected to be less than $\pm$25 % at best. Hence, calculations within $\pm$25 % of measurement were regarded as satisfactory. For a HUDAC upgraded house, and a standard HUDAC house, 42 of 49 calculations and 28 of 32 calculations were within $\pm$25% of measurement, respectively.

To compare the measurement and the prediction of indoor air quality by MIX, the experimental data from Charles et al (1974) was chosen. Again, the single-cell version SIX was adopted to predicted the concentration of ozone vs. time. The values of major parameters used in the corresponding calculation were the same as in Charles et al (1974). The result is shown in Fig. 3 and Fig. 4.

Fig. 1 to Fig. 4 indicate a good agreement between the calculation by MIX(SIX) and the measurement of both indoor air flow and indoor air quality. Unforturnately, a complete comparison for individual rooms is not available. Nevertheless the results using MIX are encouraging.

Tightness and indoor air flow

It was found that both the indoor air flow and air flow direction have considerable influence on the concentration of pollutants produced in buildings, and could be used effectively to control the accumulation of such pollutants. The tightness of a building is an important factor in influencing the air flow rate, and sometimes, also the air flow direction. For example, a change in the distribution of leakage or an opening can result in a different air flow rate and direction.

From the point of view of the operation of a mechanical ventilation system, the air flow through a leakage or opening of a building is an uncontrolled flow, because of the driving force related to an uncontrolled climate. This uncontrolled flow may possibly result in the unstable operation of the mechanical ventilation system, or at least, the unsteady supply of fresh air. There will also be little control over the pattern of air movement within the building.

Heating cost and building construction cost are two other factors which influence tightness. What is the correct tightness? It is a question of balancing economics and living standards, to produce an optimum living environment.

One point is clear, that is the level of tightness of a building should be chosen according to the type of ventilation system. A building with a balanced ventilation system must be tighter than an exhaust ventilation. A building without any mechanical ventilation must have more leakage than one with. Generally, if a building is not tight, there is no need for a mechanical ventilation system. If the building is very tight, a mechanical ventilation system must be installed, see Fig. 5.

It should be noted that in Fig. 5, the figures are only approximately estimated from practical experience. They are included for convenience and comparison. The k_t-values were then translated approximately into air change rate values at normal conditions and at 50 Pa. The values in Fig. 5 are not so important here, The important points are that, firstly, there is some type of relationship between the installation of the mechanical ventilation system and tightness of the building. Secondly, there probably exists a range of k_t-values, when natural ventilation alone is not adaquate, however the external influences may still be too great to allow the normal operation of a mechanical ventilation system. This is the worst situation, and should be avoided.

Summary

MIX is a model of indoor air flow for multi-room buildings, taking into account: mechanical ventilation, tightness of the building, terrain and shielding conditions, and climate conditions. It can be used to predict air flows between the rooms, air flows across the envelopes, air flows through the mechanical ventilation system and indoor pollutant

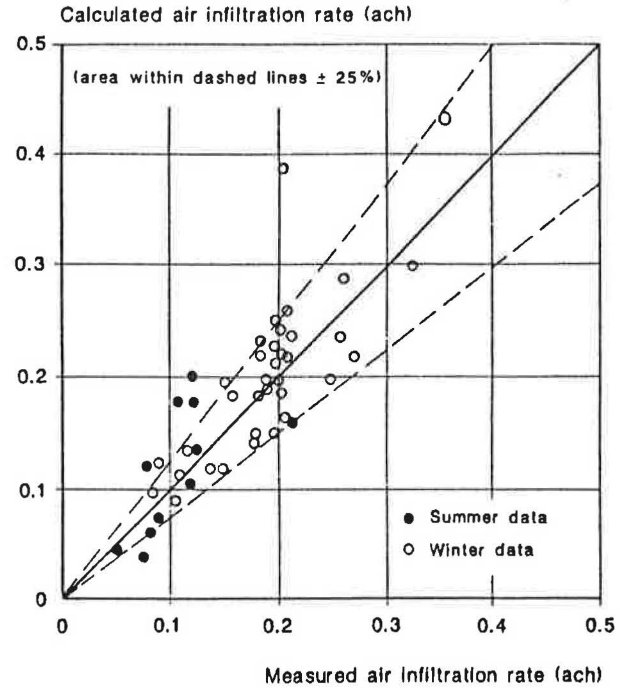

Fig. 1. Comparison between calculated and measured air infiltration rates (HUDAC upgraded house).

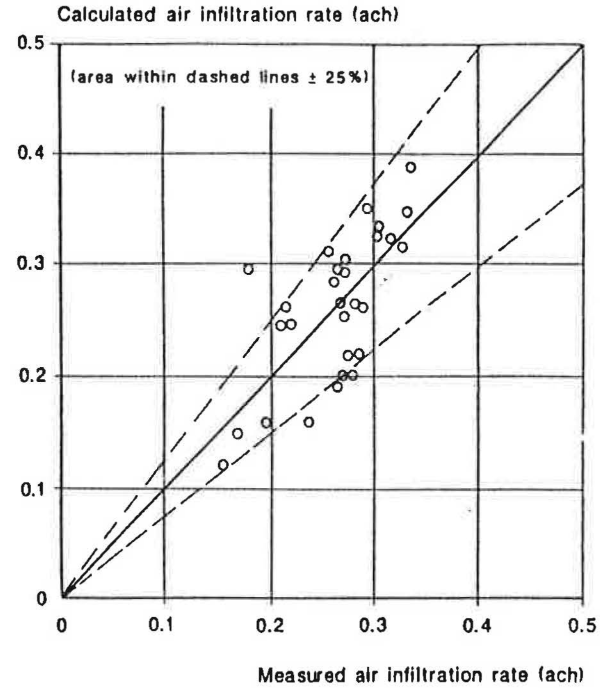

Fig. 2. Comparison between calculated and measured air infiltration rates (HUDAC standard house).

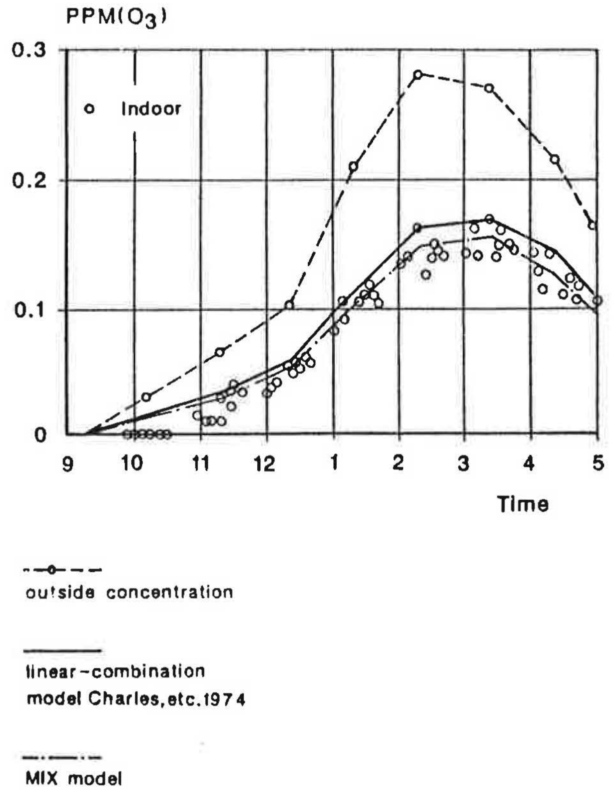

Fig. 3. Concentration of ozone vs. time for hallways in Noyes Lab, October 16,1973.

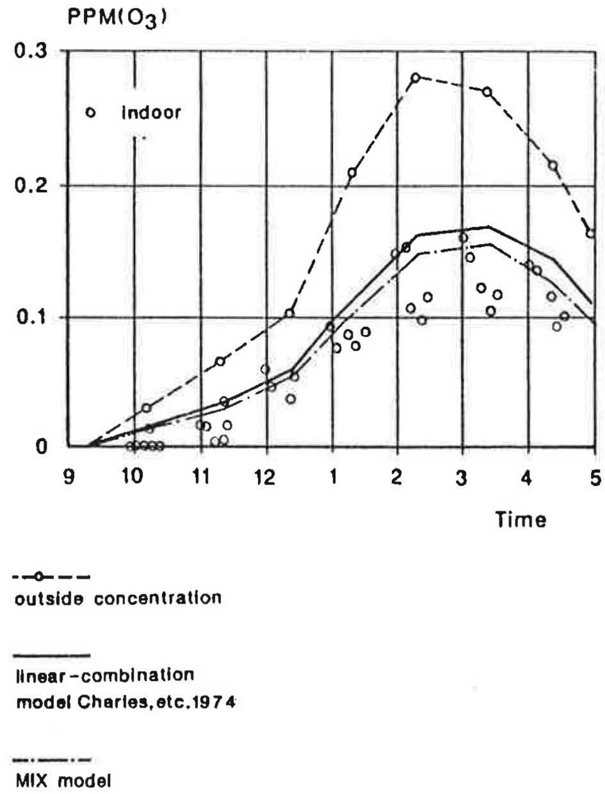

Fig. 4. Concentration of ozone vs. time for various rooms in Noyes Lab, October 16, 1973.

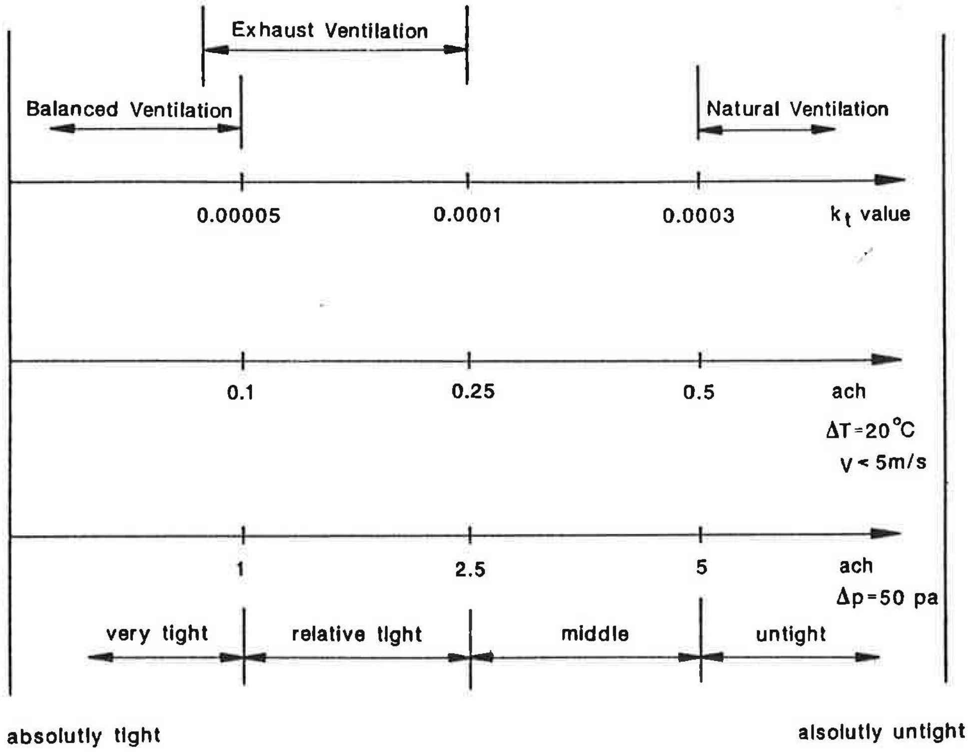

Fig. 5. Tightness and ventilation type.

transfer. The single-cell version of MIX, which is SIX, show a good agreement between calculated, and experimental values both in terms of indoor air flow and indoor air quality.

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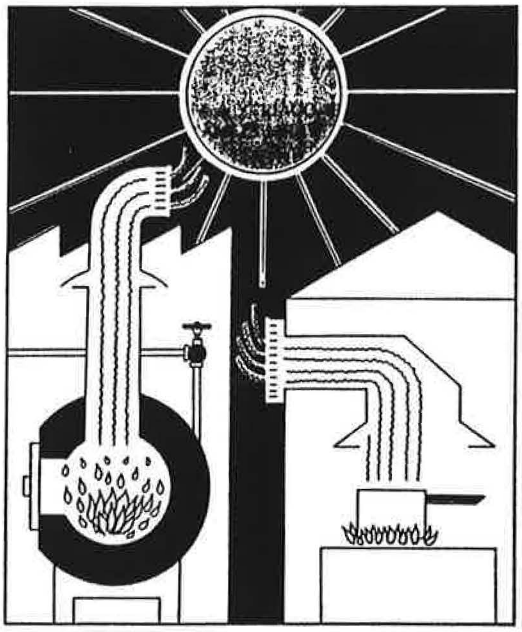

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AIMS

With problems of indoor air quality becoming increasingly apparent, it is essential to have a far more detailed and fundamental understanding of the occurrence of specific chemicals in indoor air, and of their mechanisms of interaction and modes of dispersion. These are heavily influenced both by building design and construction materials as well as building ventilation and maintenance. Little attention has been paid to these problems in warm climates where building design can be substantially different from that in colder climates and where alternative systems are in use for cooling and ventilating. Occupational and domestic exposure to specific chemicals from a wide number of sources including cooking, cleaning, building materials and smoking all need careful evaluation as do such problems as 'sick building syndrome' which has recently attracted considerable attention in many countries. The importance of architectural and service design is widely acknowledged, and many innovative changes are needed for the future in both the developed and developing world.

Accordingly, the conference will centre on the scientific, engineering and health aspects of indoor air quality and ventilation in warm climates whilst concentrating upon the following major themes:

- *Specific Chemicals, their Interaction, Dispersion and Modelling*
- *Sources of Pollutants - Influence of Indoor and Ambient Air Chemistry*
- *Climatic Effects with respect to Heating and Ventilating of Buildings*
- *Indoor Air Quality Implications of Domestic Heating and Cooking Processes*
- *Airborne Bacteria in Warm Climates*
- *Environmental Tobacco Smoke and its Effects under Different Climatic Conditions*
- *Occupational Exposure to Specific Chemicals in the Indoor Environment*
- *Direct and Indirect Effects of Pollutants on Human Health including Risk Assessment*
- *Architectural Design Concepts*
- *Analytical Methodology*
- *Ventilation and other Control Strategies - Technological and Economic Implications*

Both state-of-the-art reviews and original research papers will be presented as will specific case studies and field evaluations.