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PAPER S.1

THE PERFORMANCE OF VENTILATION IN AN UNTIGHT HOUSE

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INTRODUCTION

This paper is a companion to the one presented by Sandberg et al later in this conference (1). In contrast to that paper, this one deals with the flow of fresh air into, and the spread of point source contaminants around an untight 2 storey, multi-roomed house. The layout of the house is shown in figure 1. The house, owned by Segas, was built about 15 years ago when energy costs were not a major design constraint . It was designed for natural ventilation and was later subjected to some sealing of the larger sources of air inlet. In addition to the natural ventilation system there is a mechanical ventilation system that can act as supply or extract only and as a balanced unit. Figure 1 gives details of the supply and extract points.

Despite the best endeavours, the house still has a specific flow rate of 8 house volumes/h through the building envelope when pressurised to 50 Pa. This is about 10 times the leakage of the house described in (1). This is the rationale for the title of the paper.

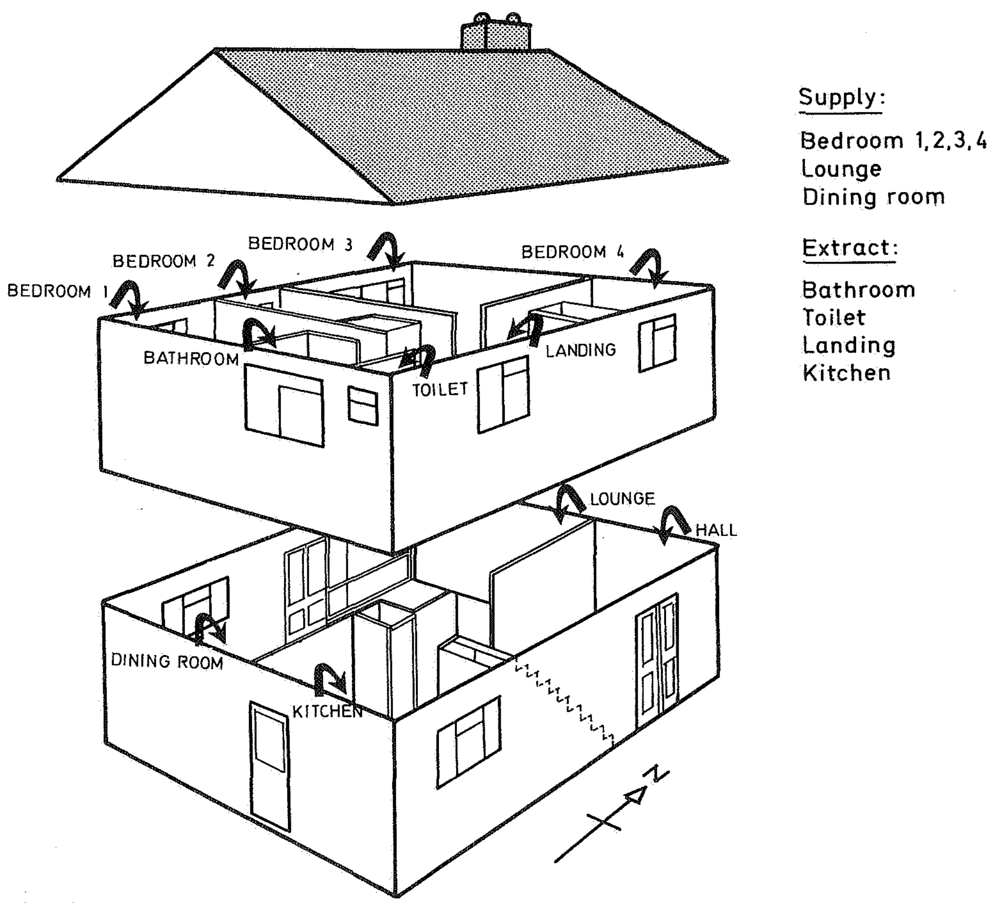

Fig 1

1. Experimental

The experiment we undertook was designed as a two-way comparison of the effects of ventilation systems and the apperatures of the internal doors on the local ventilation rates and the spread of a contaminant released in an extract or a supply room. Thirteen separate experimental runs are analyzed in this paper. Details of these runs are given in Table 1.

Table 1. Detail of experiments undertaken. ΔT is the temperature difference between indoor and outdoor.

Ventilation system	Type of experiment	Apper ture of doors	ΔT (^oC)	Wind speed (ms^{-1})	Wind direction
Natural	Constant concentration followed by decay	Open	27	5.0	N
Extract	Constant concentration followed by decay	Open	26	3.0	N
Balanced	Constant concentration followed by decay	Open	19	2.4	W
Natural	Injection into bedroom 3	Open	25	1.7	W
Extract	Injection into bedroom 3	Open	22	3.3	W
Balanced	Injection into bedroom 3	Open	23	2.5	SW
Extract	Injection into bedroom 3	Closed	22	3.3	W
Balanced	Injection into bedroom 3	Closed	19	2.3	SW
Natural	Injection into the kitchen	Open	22	1.9	W
Extract	Injection into the kitchen	Open	23	2.1	W
Balanced	Injection into the kitchen	Open	25	2.0	SW
Extract	Injection into the kitchen	Closed	21	2.8	S
Balanced	Injection into the kitchen	Closed	18	3.0	S
			22 ± 3	2.7 ± 0.9	

The experiments were made possible by the 'Autovent', computer controlled ventilation system (2). This equipment was designed around proprietory components and with programmable logic provided through a micro computer. It can inject gas or sample the atmosphere in 12 rooms. The 'Autovent' could easily be programmed to perform constant concentration measurements followed by decay or to follow the concentration history of a contaminant released in a room.

In these experiments nitrous oxide was used as the tracer gas. It was detected with a Leybold-Hereus infra-red analyser.

For decay and contaminant release experiments no mixing was used, except in the initial dosing of the source room. For constant concentration experiments a small mixing fan was deployed in each room.

The experiments took place in the spring and high stack effects were achieved by the operation of a gas fired heating system with the thermostats set at 30°C. Table 1 gives the stack effect parameter for each run together with the wind speeds and directions. The means and standard deviations reveal a reasonably comparable set of conditions so that detailed comparisons between ventilation systems are justified. Time prevented a fuller experimental programme of more natural ventilation tests with the doors closed and repeat runs of all experiments.

Where conditions were repeated, the agreement between results was acceptable.

2. Theory

The framework for analysing these results is presented in detail in (1). The methods of reducing the experimental measurements to useful parameters have been described in (3). In examining the spread of a contaminant around a house the parameter which best characterises the effectiveness of the ventilation system is the ratio D_p/D_s. The time integrated exposure in a particular room, D_p, divided by the integrated exposure in the source room, D_s. This parameter is relevant when the major consideration is the ability of a ventilation system to deal with a contaminant. If, on the other hand, the major concern is to judge the way in which fresh outdoor air is provided by the ventilation system and stale air is removed from the house, then the parameters q_m/q_m^t and $\bar{\tau}_p/\langle\bar{\tau}\rangle$ are indicated. The flow of outdoor air to each room, q_m, expressed as a proportion of the total flow, q_m^t, is a simple way to reflect the distribution of air entry points to a house. The variation of the ratio with ventilation system provides some indication of the effect of the system on the incoming air distribution.

The mean age of the air in each room, $\bar{\tau}_p$, divided by the average mean age of the air in the whole house, $\langle\bar{\tau}\rangle$, gives a measure of the relative time taken to replace (exchange) the air in a room.

3. Results and Analysis

3.1 Relative flow rate

Figure 2 shows the results of the analysis of two ratios determining the relative values of fresh air intake and air replacement times for each of the three ventilation systems. Limitations of experimental time meant that only internal doors open cases were considered.

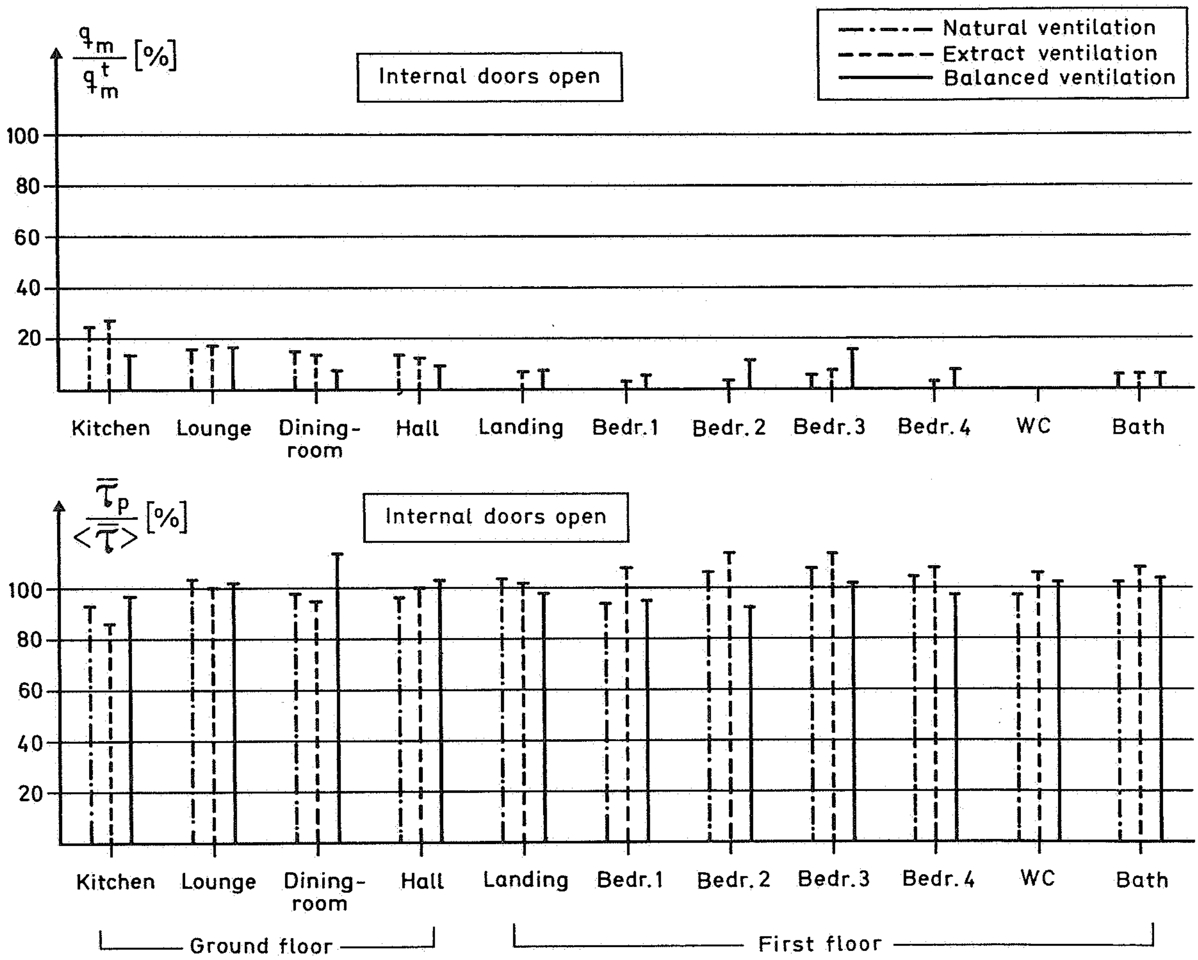

Fig 2

The ratio q_m/q_m^t shows that for natural ventilation most of the incoming fresh air enters on the ground floor and very little on the upper floors. This is the classical stack effect in operation. When the combined ventilation system is operated, however, fresh air enters all the supply rooms and there is some modification of the stack effect dominated ventilation pattern.

The relative air replacement rate for each room is almost constant for each room under each ventilation system. From this result one could conclude that the exposure to a passive homogeneous pollutant, such as Radon, would be the same throughout the house. The house is behaving very much like a leaky box with sources of leakage well distributed over its surface. The paper by Sandberg el al (1) demonstrated the contrast with a tight house where the leakage is concentrated to a few places.

3.2 Pollutant spread from the kitchen

Figure 3 shows the ratio D_p/D_s, the room exposure to a pollutant divided by the source room exposure. For this case the source room was the kitchen on the ground floor of the building

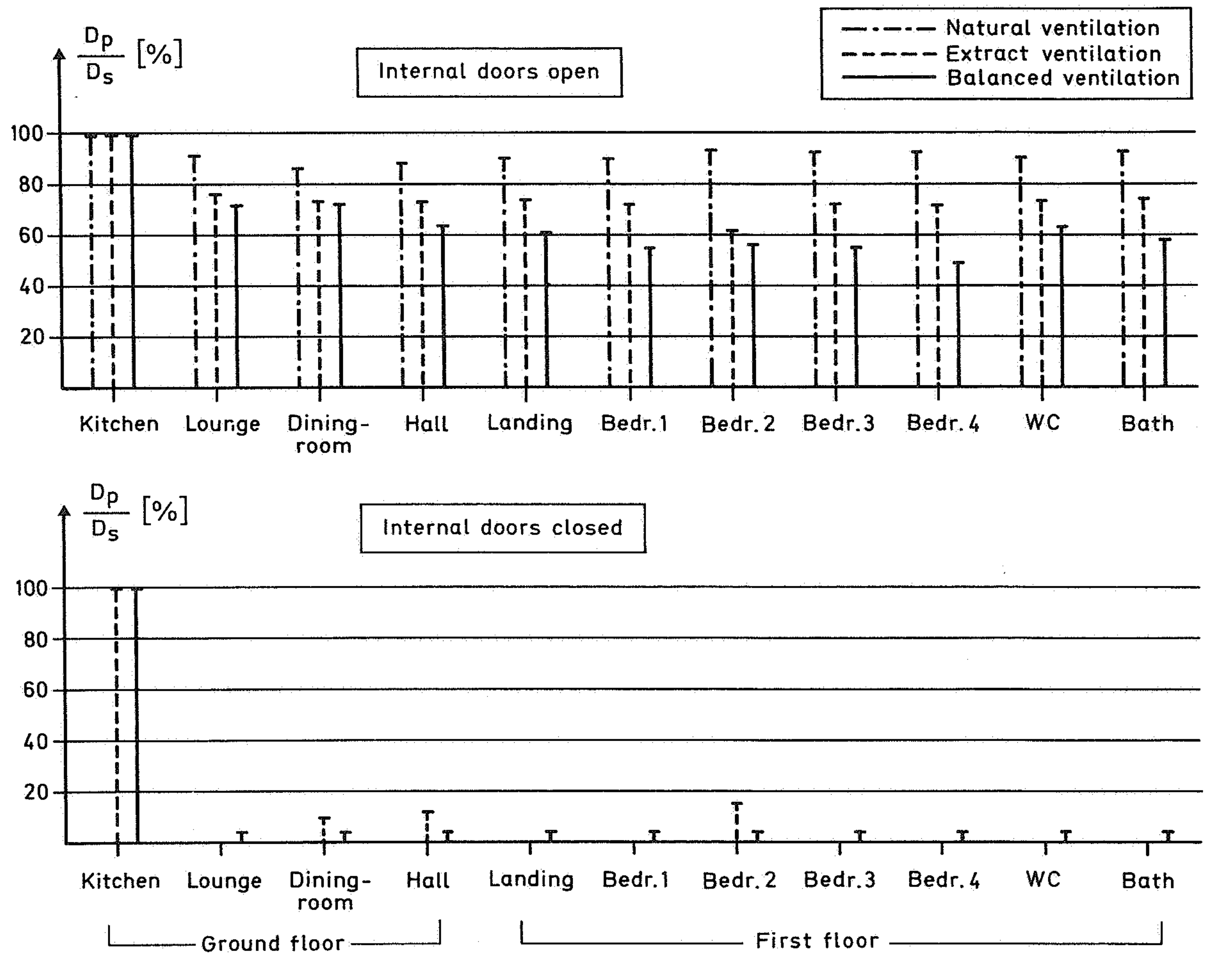

Fig 3

The first contrast to make is between doors open and doors closed cases. For the former the relative exposure is much more even than for the latter, where the source exposure is, at least, six times that for any other room.

For natural ventilation and open doors the most even pattern is observed. The explanation for this is in the driving force of the stack effect, which carries air from the ground to the first floor and sets up recirculation patterns between the floors, particularly in the open stair well. When the extract system is used with doors closed the relative exposure in all rooms decreases. The kitchen is an extract room and so the pollutant is removed at source. Other extract points are in the bathroom, toilet and the landing. These three rooms have the highest relative exposures, presumably due to a small net increase in flow of air to these rooms as a result of the operation of the mechanical extract system. With the balanced system in operation, the combined effects of extract and supply mean that relative exposures are the lowest for this ventilation system. It is also noticeable that relative exposures on the first floor are slightly lower than those on the ground floor. This is also attributable to the effects on air being supplied to all the bedrooms and countering the stack effect to some extent.

3.3 Pollutant spread from bedroom 3

Figure 4 shows a similar set of relative exposure data for the case of the pollutant source room being on the first floor of the house. A comparison of the doors open and closed results reveals the same pattern as for the kitchen as source room, namely a fairly even exposure with open doors and a distribution biased to the source room for door closed.

In this case the effect of closing the door is less marked. This could be a function of the tightness of the internal doors and of the communication between bedroom 3 and the adjacent rooms as well as the location of the source room. Under natural ventilation and with open doors the relative exposures of the ground floor rooms are less than those of the first floor. This is as would be expected under stack effect dominated ventilation. With the extract system operating and doors open the same conclusion applies. Even in the kitchen, a major extract point, the relative exposure is not significantly different from other ground floor rooms. With the balanced system in operation, the ground floor relative exposures increase and approach those of the first floor. This result is somewhat unexpected and is attributed to the effect of air supply to the bedrooms opposing the stack effect and pushing pollutant air out onto the landing and into the hall. When the doors are closed, the relative exposures are greater than when the pollutant was injected into an extract room. For the extract only system, bedroom 4 has a high exposure. Bedroom 4 is adjacent to bedroom 3 and could possibly have a large intercommunication. With the balanced system we again observe an increased relative exposure on the ground floor due to the effect of air supply to the source room and other bedrooms.

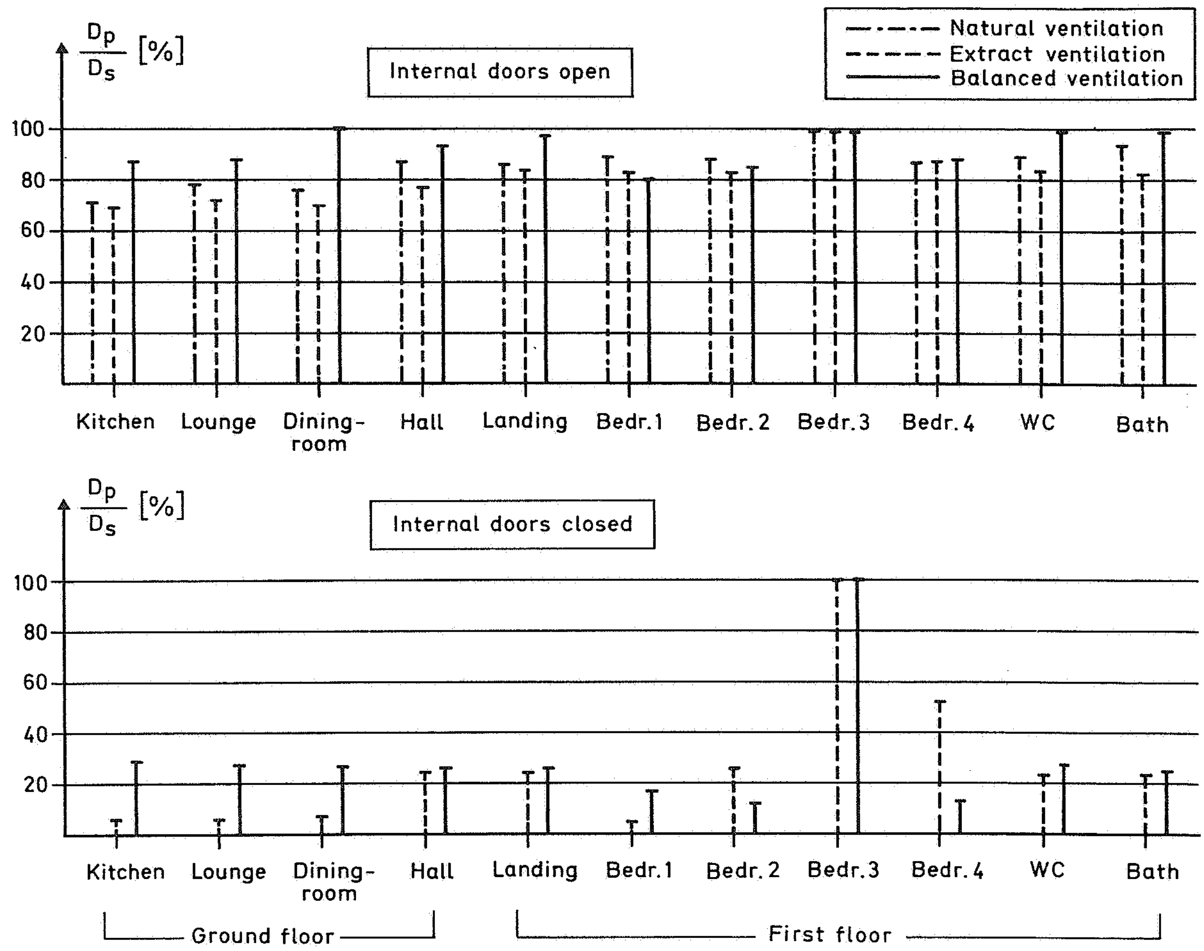

Fig 4

4. CONCLUSIONS

For an untight house a mechanical ventilation system has very little virtue. These results have demonstrated some small effects in the redistribution of pollutant from a source room but have also demonstrated that the natural, stack dominated ventilation pattern is not overcome by the mechanical system. The mechanical system does offer the assurance of a minimum flow rate to the supply rooms and a minimum exhaust rate from the extract rooms. It does not,

however, guarantee a predictable distribution of air supply to the rooms of an untight house.
The differences between relative exposures when the source is on extract or a supply room lend weight to the viewpoint that investment in extraction facilities in pollutant source rooms is much more cost beneficial than investment in complex balanced systems.

5. ACKNOWLEDGEMENTS

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