Introduction

The opening and closing of windows represents the most common way of controlling ventilation. However, ventilation in winter costs money because the cold fresh air from outside must take the place of an equal volume of warm air leaving the house and must itself be heated up to room temperature. The energy required to heat the fresh air is generally known as the 'ventilation heat loss', Q_V. If ΔT denotes the temperature difference between the inside and outside air, Cp the specific heat (993 J $kg^{-1}K^{-1}$) and ρ the density of the air (1.25 Kgm^{-3} at $10^{o}C$) then:

$$Q_V = (\text{mass flow rate of air in kg } s^{-1}) \times Cp \times \Delta T \quad \text{watts}$$

If the ventilation rate A is expressed in the usual units of air changes per hour and V is the house volume in m^3, then:

$$Q_V = \frac{1.25 \times 993 \times 24 \text{ VA } \Delta T}{3600 \times 1000} \quad \text{kWh per day}$$

$$= 0.00828 \text{ VA kWh per degree day}$$

For a typical house of volume 200 m^3, thermal insulation by readily available methods can reduce the heat loss by conduction through the walls, ceiling and floor to about 3 kWh per degree day. Under these circumstances the ventilation heat loss will exceed the fabric heat loss at air change rates greater than 1.8 per hour. Thus excessive ventilation can negate the effectiveness of thermal insulation.

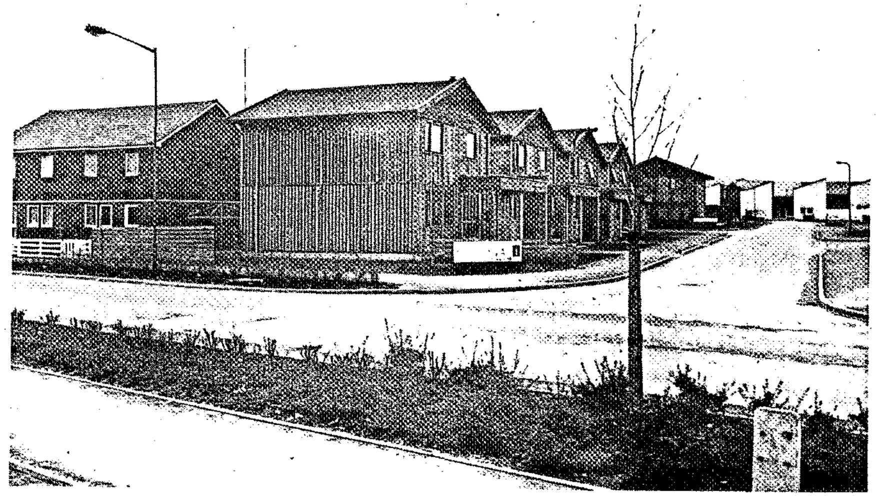
The ventilation rates arising from open windows have been measured in the two houses shown in figure 1.

House A is a well insulated detached wooden house with weather stripped wood framed windows hinged at the top. This house is not typical of the UK. The other, B, is a more conventional brick semi-detached house, with weatherstripped metal framed windows which are horizontally pivoted at the mid-points of the vertical sides. Details of the windows are given in figure 2.

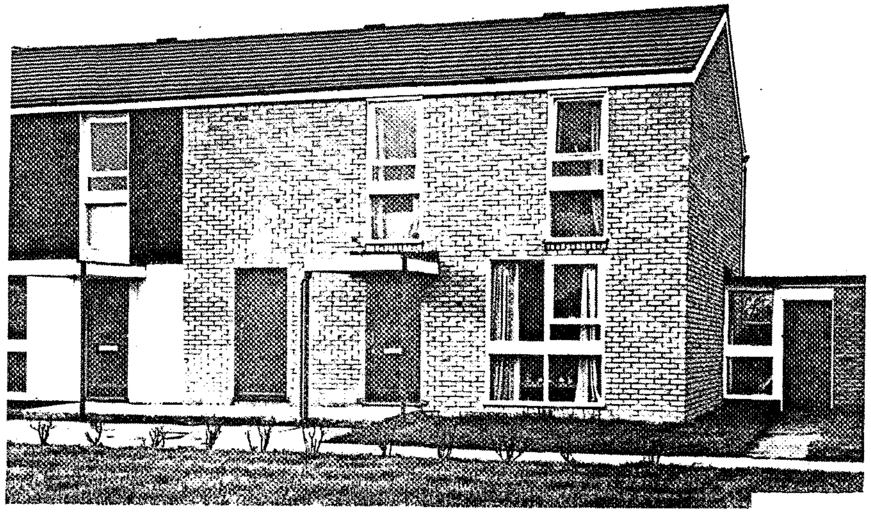
Ventilation needs

Ventilation is required mainly to remove objectionable odours and excessive moisture (1). Water vapour is associated with washing and cooking and requires intermittent high local ventilation for its removal. Odour removal in an average size room (30 m^3) with three or four people in it requires more than 2 air changes per hour of fresh air, but if the room is intermittently occupied one-third to one-half of an air change per hour will probably be sufficient to avoid discomfort.

Thus, in a domestic environment it is necessary to vary the fresh air ventilation rate from time to time between about one-third of an air change per hour and 3 to 4 changes per hour.

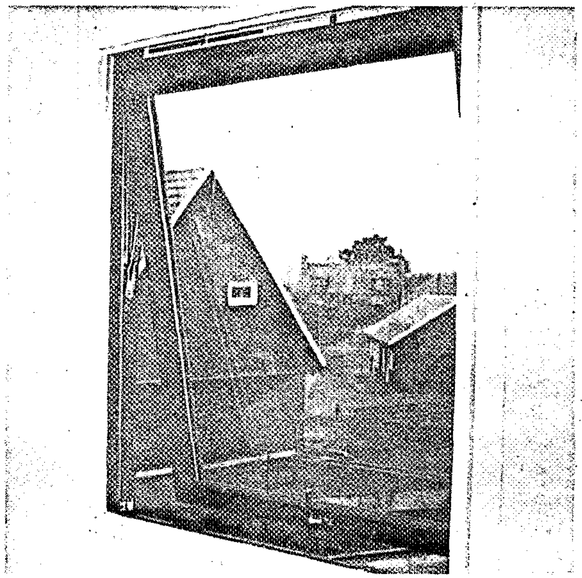


House A. Well insulated wooden, facing east, volume 260m^3

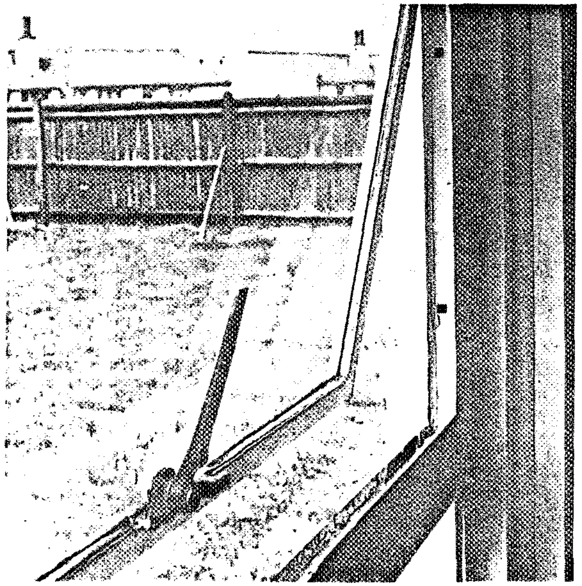


House B. Brick semi, facing south east, volume 200m^3

Figure 1. The houses in which measurements were carried out



House A. 875 x 980 mm. Open 8°



House B. 700 x 900 mm. Open 3° and 12°

Figure 2. Window details

Weather influence

Even if all windows and external doors are closed, a house is ventilated through fortuitous cracks in the structure. The house pressurisation technique (2) has been used for measuring and locating this leakage. Leaks occur at joins in the structure, particularly between brick walls and wooden components, less than one-third at openable parts of windows and doors.

The driving forces for ventilation are wind and temperature difference between inside and outside acting in such a way that (in a two storey house) cold fresh air from outside enters downstairs windward rooms and warm stale air leaves upstairs leeward rooms. The air flow in and out of upstairs windward and downstairs leeward rooms will depend on the relative magnitudes of the wind and temperature effects. However, at wind speeds greater than about 2 metre/second wind effects are dominant except in very cold weather.

The ventilation rates in these houses (as measured by tracer decay) are shown in figure 3. Both these houses would be classed as 'tight' and neither has a flue. Under average conditions the background natural ventilation rate is less than 0.5 air changes per hour in both cases.

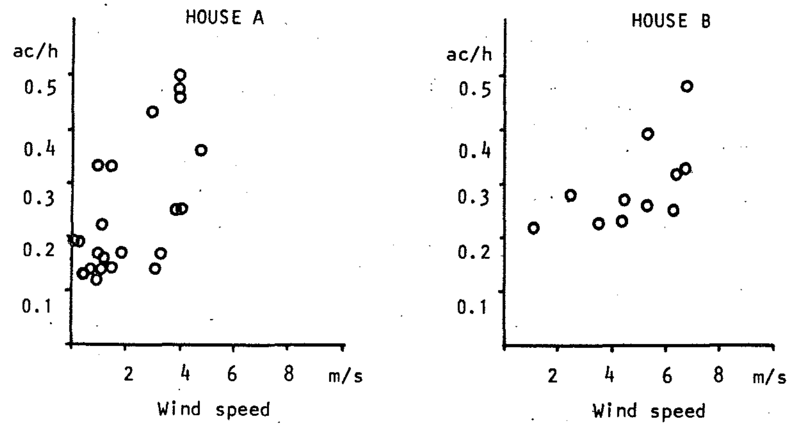


Figure 3. Measured ventilation rates with windows and external doors closed

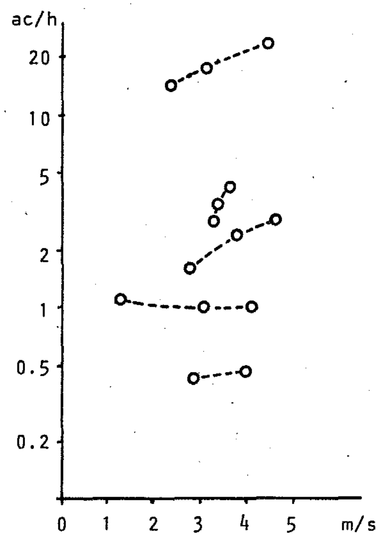
Experimental methods

Tracer decay methods were used to measure ventilation rates in individual rooms during various weather and open window conditions. Both carbon dioxide and nitrous oxide have been used as tracers. A Hampden Gas-O-Mat and Miran-103 Infra Red gas analyser were used respectively. The decay rate was calculated from a chart recorder trace of gas concentration versus time.

A uniform tracer concentration was first established throughout the house, with the assistance of mixing fans mainly in the internal doorways. The fans were then switched off, the appropriate window opened and the decay rate in the chosen room was measured. Internal doors were open throughout and the houses were heated electrically to 19°C.

Ventilation rates floor by floor

Surveys have shown that upstairs (bedroom) windows are most commonly left open for long periods. The resulting measured ventilation rates are shown in figure 4, for House A.



open windows	measured ventilation
all upstairs	upstairs
upstairs windward	upstairs
all upstairs	downstairs
upstairs leeward	upstairs
none	whole house

Figure 4. Ventilation rates floor by floor with upstairs windows open

With a wind of 3 to 4 metre/second directly onto the front of the house and with an inside to outside temperature difference of about 10°C it was found that, compared with the ventilation with windows closed, opening two leeward upstairs windows doubled the ventilation upstairs. When instead the two windward upstairs windows were opened, the upstairs ventilation increased eightfold to about 4 air changes per hour. When all the upstairs windows were opened, through-ventilation of about 20 air changes per hour occurred upstairs and also 2 to 3 air changes per hour downstairs (where the windows were closed).

Individual room ventilation

The effect of opening one window was investigated in both houses under various conditions. It is convenient to consider four categories of room as follows:

Wind →

Upstairs windward	Upstairs leeward
Downstairs windward	Downstairs leeward

The results are summarised in figure 5. Internal doors were open. An open windward window frequently results in local ventilation greater than 10 air changes per hour. Leeward open windows gave rise to local ventilation rates up to 4 air changes per hour at average windspeeds. There was considerable scatter in both sets of results.

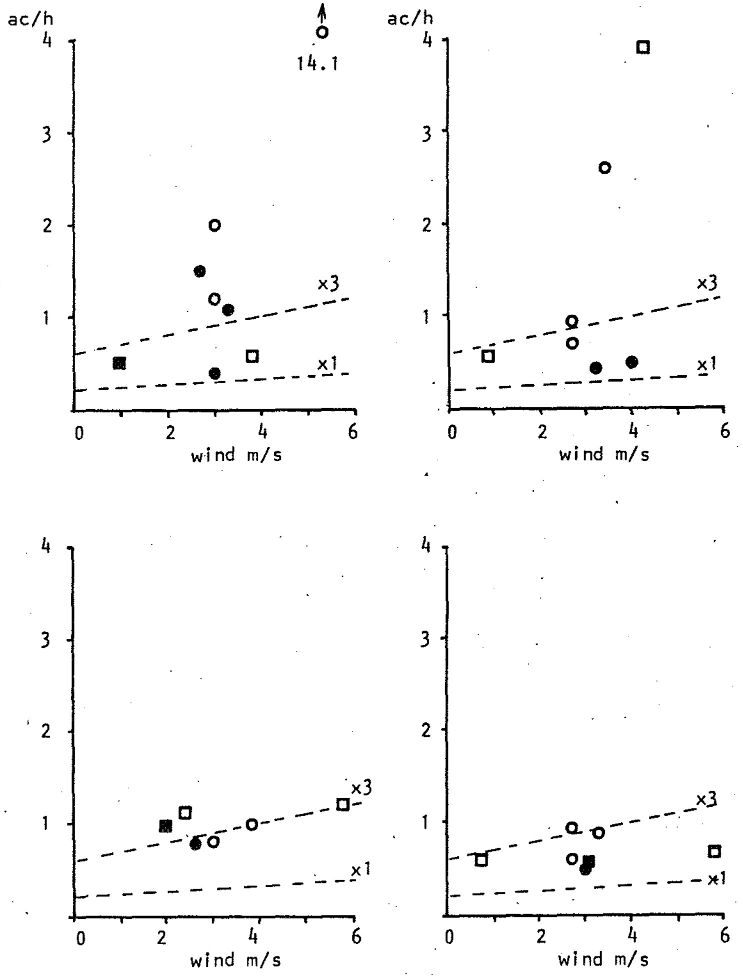
Opening of any upstairs window increased the ventilation rate downstairs approximately threefold (slightly more on the windward side, less on the leeward side).

Flow patterns between rooms

The flow from room to room within the house through open doorways was investigated with smoke. It was found that even when a room had an open window a two-way flow existed at the doorway, out of the hotter room at the top and out of the colder room at the bottom. A typical air speed distribution with a temperature difference between the rooms of 1°C is shown in figure 6 for a windward room with window open. Even if the rooms are initially at the same temperature, the opening of a window will soon result in non-uniform temperatures between rooms. These findings agree with Bouwman who predicted an air flow each way of 350 m^3/h when the temperature difference is 1°C, i.e. more than 10 air changes per hour.

The flow between rooms on account of temperature differences thus can be much greater than the air flows caused directly by ventilation.

A similar situation was observed on stairs with cold air flowing downstairs at stair level and a corresponding warm air flow upstairs at ceiling level. This explains why the influence of an open window is felt very quickly throughout a house whether the window is leeward or windward. This was confirmed by tracer gas tests in which gas released in leeward rooms spread to windward rooms within 10 minutes. Thus even against the



Key: □ leeward window open upstairs

○ windward " " "

■ ● } 3°   □ ○ } 8° or 12°

-----x1 all windows closed

-----x3 three times all windows closed ventilation rate

Figure 5. Individual room ventilation rates

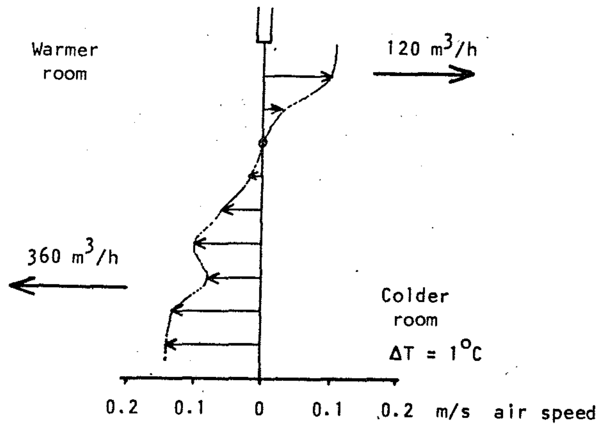


Figure 6. Air flow through internal open doors

wind direction, contamination will spread throughout a house. However, the closing of internal doors has a significant effect and considerably reduces inter-room mixing if the doors are well fitting.

<u>Flow within rooms</u>

Air flow within rooms having an open window was investigated with smoke. On the windward facade the wind pressure is such that air enters through small openings. However, since the wind blows along the outside wall surface the detailed air flow at an open window will be influenced by the aspect the open window presents to the air flow. In particular, a window which when open protrudes beyond the outer wall surface may cause both inward and outward flow. This contributes to the very high local air change rates occurring in a room with an open windward window. Such high air change rates do not represent air flow through the house of this magnitude as was confirmed by measuring the ventilation rates in other rooms, and so two-way flow must take place at the open window.

In a windward upstairs room the cold fresh air came in at the bottom of the window and immediately ran down the inner wall and into the room along the floor, while the warmer air at ceiling level escaped through the top of the window. But conditions were never steady and air would from time to time flow in at the top of the window and also in and out across the lower half of the open window.

On the leeward side of the house, there is suction outwards at any opening drawing air out of the house. On the outside, the air is turbulent, with eddies but the air flow through the open window is very smooth. However if the wind is feeble, temperature effects may dominate giving a flow out at the top and in at the bottom of the open window, resulting in an enhanced cold downdraught, similar to the windward case, and a draught into the room along the floor of typically 0.3 metre/second.

Conclusions

The results indicate that openable windows can successfully provide the variable ventilation required in a house. The same data also show that excessive ventilation may easily occur, resulting in the ventilation heat loss exceeding the fabric heat loss.

Leeward windows should be opened rather than windward ones for moderate ventilation; one open leeward window upstairs will ventilate a whole house if internal doors are open.

Two-way air transfer occurs between rooms as a result of temperature difference, 1^{o}C giving rise to air interchanges exceeding 10 air changes per hour. This dominates any ventilation air flows, and results in rapid fresh air (or contaminant) dispersal throughout a house, unless internal doors are closed.

References

1. Ventilation requirements, Building Research Establishment Digest 206, (1976).
2. Stricker, S. Measurement of Air Leakage of Houses, Ontario Hydro Research Quarterly, Fourth quarter 1974, pp. 11-18.
3. Bouwman, H.B. Air flow through an open door, OA Trans. No. 1761.

Discussion

B.A.Børresen, University of Trondheim, Norway:

Ordinary dwellings/houses are ventilated by window opening at high indoor temperatures.

For calculations on summer conditions, is it reasonable to use an air change rate of for instance 5 times per hour?

Dickson:

Our ventilation measurements so far have been confined to winter conditions. However, the results indicate that in a conventional house with one or more windows open by about 100 mm, internal doors open, and $\Delta T = 10 \pm 5$ ^{o}C, an air change rate of 4 ± 2 air changes per hour would be likely. Extreme through-ventilation resulting from wide open windows on both sides of the house may result in higher ventilation rates.