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MULTIPLE CELL AIR MOVEMENT MEASUREMENTS

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SYNOPSIS

The multiple tracer gas technique developed at UMIST has been applied to the measurement of roof-space ventilation rates and house to roof-space air movement, for various types and combinations of roof-space ventilation. It has been shown that ridge tile ventilators, whilst increasing roofspace ventilation rates at low wind speeds, also significantly increase house to roof-space airflows over the whole range of wind speeds. This has implications not only in terms of energy wastage, but, more significantly, in terms of increased moisture rates to the roof-space. Methods of reducing air leakage to the roof-space are briefly discussed. The use of a kitchen extract fan is shown to reduce airflow from downstairs to upstairs to between 10 and 30 m^3/hr. It is pointed out that in order to be able to gain a better understanding of air movement within the building envelope, it will be necessary to make use of three and four tracer gas measurements.

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1. INTRODUCTION

The energy crisis of the 1970's, and the resulting increase in the price of fuels, has shown that significant amounts of energy and money can be saved by the use of insulation. In the United Kingdom, approximately 30% of the total primary energy used is in the domestic sector[1], and it is clearly desirable that considerable savings are achieved here.

A popular method of energy saving has been the insulation of lofts. One of the effects of applying loft insulation is a general reduction of the structural roof temperature. The Building Research Establishment[2,3] have drawn attention to the danger of the occurrence of water vapour condensing in roof-spaces, with the consequent hazards of structural failure and ceiling damage. Sanders[4] has reported that typically, in still, cold conditions,30% of the air leaving a house does so through the roof-space. The increasing use of loft insulation, therefore, necessitates a greater understanding of air migration paths through the house and into the roof-space, which in turn provides indicators regarding the reduction of moisture transfer into the roof-space.

This paper briefly describes the multiple tracer gas technique used for ventilation and air movement measurements at UMIST for the case of two tracer gases, and its application to the determination of roof-space ventilation rates, house to roof-space airflows, and airflows between the upstairs and downstairs: in the latter case, the effect of a kitchen extract fan is demonstrated.

2. EXPERIMENTAL DETAILS

The multiple tracer gas ventilation and air movement measurement apparatus used at UMIST has been developed with three aims in mind: firstly, maximum portability and ease of use for site applications; secondly, rapidity of concentration/time data acquisition; thirdly, print-out of concentration/time data during the actual test period, so that any anomalies or faults can be noted and rectified immediately.

The apparatus used has been described in greater detail elsewhere[5]. Briefly, the system consists of a modified Analytical Instruments Model 505 gas chromatograph with electron capture detector. The chromatograph has been fitted (Figure 1) with two 4-port selector valves so as to permit the use of two matched chromatographic columns in parallel. This modification in effect doubles the number of samples that can be analysed in a given time, thus enabling air movement tests to be completed before recirculation of tracer gas becomes significant, and also minimises variations in data due to extraneous variables such as wind speed and wind direction. When used with two 8' long, 0.25" diameter 10% squalane separation columns, held at a constant 30^{o}C in a thermostatically controlled water bath, it is possible, for the case of two tracer gases, (Freon 12 and Freon 114) to analyse a sample in 30 seconds. By careful conditioning of the chromatographic columns, their responses can be matched to within 0.5% for a given tracer gas concentration: furthermore, the use of the water bath at 30^{o}C effectively eliminates problems previously encountered with baseline drift during ambient temperature use.

The concentration/time data obtained is analysed by the simplified analytical solution of the conservation of mass of tracer gas equations for two interconnected cells described in great detail in(5). This new analysis is superior to the Prony analysis previously used[6] on the grounds that it can cope more readily with random measurement errors, with the result that significantly less data has to be discarded as physically meaningless simply because of an inherent weakness of the mathematical analysis used. This is clearly of benefit in terms of efficiency.

The technique and new mathematical analysis have been validated in a series of tests carried out using two interconnected environmental chambers with controlled, measurable supply and extract rates[7]. The calculated inter-cell airflow values derived were within 10% of the measured values.

Site measurements were carried out in a three bedroomed, end-terraced council house of low energy design. (Figure 2). The house was built in 1981, and is of cavity brick/block construction, with insulation in the internal walls. The windows are double glazed. The roof is a 20 degree duopitch of cement tile and sarking felt underlay:

the ridge runs east-west. The roof-space of this house is insulated by 150 mm of loose-fill glass fibre insulation between ceiling joists. It is ventilated by a continuous 10 mm opening at the eaves level, (soffit ventilation) in combination with a ridge tile ventilator. (Figure 3). The bathroom, kitchen and lounge are fitted with extract fans. The house is heated by a solid fuel warm air heater.

3. RESULTS AND DISCUSSION

(a) Roof-space ventilation rates and house-roof airflows

Figure 4 compares the roof-space ventilation rates for the cases of all ventilators sealed, soffits only open, and soffits and ridge tile open, for the case of prevailing wind direction. For the case of soffit only open, the roof ventilation rate lies between 0.5 - 9.5 ach for wind speeds up to 5 m/s. Site observations show that soffit induced ventilation is relatively insensitive to changes in wind direction. In the case of the soffit/ridge tile combination, the presence of the ridge ventilator clearly has an effect on ventilation rate at low wind speeds (<2m/s): however, for wind speeds in excess of 6m/s, the roof ventilation rate tends to be the same value for both soffit only and the soffit/ridge combination.

Figure 5 shows the influence of different types and combinations of roof ventilator on house to roof air movement. With all ventilators sealed, 25 m^3/hr of house air escapes via the roof-space: this rate of airflow is relatively constant for wind speeds of up to 5 m/s. With a ridge tile open, the house-roof airflow lies between 25-60 m^3/hr for the same range of wind speeds. (It should be noted that the use of ridge ventilators with no openings at soffit level contravenes British Standard BS 5250: these results are included for experimental interest only). Ridge ventilators are highly sensitive to wind direction at low wind speeds. As wind speed increases, so the directional influence decreases, the velocity of the incident wind predominating.

House-roof airflows induced by soffit ventilators only can be seen to be between 16-34 m^3/hr for wind speeds up to 5 m/s: directional influences on soffit ventilators are generally small. For the same range of wind speeds, the use of the soffit and ridge ventilator combination gives rise to airflows that are between 45-80 m^3/hr.

Figure 6 shows the same data expressed as a proportion of the total amount of exfiltrated house air. This graph implies that the soffit and ridge ventilator combination induces 25% more exfiltrating house air to leave via the roof-space than would be the case when using soffit ventilators only. It is suggested that this increased airflow is due to a greater house/roof pressure differential being induced when the soffit and ridge combination is used. (Figure 7).

(b) Effect of kitchen extract fan on air movement between downstairs and upstairs

Figure 8 and 9 show the effect of using the kitchen extract fan on the airflows between upstairs and downstairs, for the case of prevailing wind direction. With regard to air movement from downstairs to upstairs, it can be seen that switching on the fan decreases the airflow from 130 - 178 m^3/hr to 10 - 30 m^3/hr. The airflows with the fan on do not seem to be particularly sensitive to increasing wind speed. Airflows from upstairs to downstairs, however, whilst not apparently affected significantly by the kitchen extract fan at low wind speeds, show a tendency to decrease with increasing wind speeds. It is suggested that this effect may be caused by increased air movement to the roof-space, and an increased tendency for "cross-flow" ventilation in the occupied dwelling space at higher wind speeds.

(c) Calculation of water vapour transfer rates

Using the calculation method described by Sanders[4], the rates of water vapour transfer (both by diffusion through the ceiling and by air movement) were calculated for the combinations of different ventilator types used, assuming uniform temperature distribution and moisture content within the occupied zone, for the purpose of preliminary assessment of the likely rates of water vapour transfer to the roof-space. This data is presented in Table 1. For comparison, data due to Sanders[4] is included. Table 1 shows that, depending on the type of roof ventilation used, moisture input to the roof-space varies from 61.2 - 143.5 g/hr. This means that the type of roof ventilator used can approximately double the vapour transfer rate to the roof-space. The water vapour transfer rates by air movement to the roof-space when ventilated by soffit vents and the soffit/ridge combination are 99.5 g/hr and 143.5 g/hr respectively. This implies that 44 g/hr of water vapour transfer into the roof-space can be ascribed to the ridge tile ventilator.

Water vapour transfer into the roof-space can be reduced by three principal methods. Firstly, by careful use of a vapour barrier at ceiling level, the water vapour input to the roof-space by diffusion could, in theory, be reduced to zero. In practice, however, there will be perforations in the vapour barrier caused by wiring and pipework entering the roof-space, and by poor jointing at the construction stage. Secondly, and most importantly, careful sealing of roof access hatches and pipework entries can reduce moisture transfer by air movement to the roof-space by as much as 75%. Finally, if the moisture generated in a dwelling can be removed at source using an extract fan, a lower house air moisture content is achieved. The decrease in pressure due to the fan also has the effect of reducing house to roof-space generally to below 10 m^3/hr.

4. CONCLUSIONS

Ridge tile ventilators, when used in combination with soffit ventilators, can be seen to increase roof-space ventilation rates by approximately 40% over the soffit only case at wind speeds of less than 2 m/s, when problems of roof condensation are most likely to occur. However, they also have the effect of inducing house to roof-space airflows which are approximately 25% greater. From the experimental work carried out so far, it is not possible to state categorically whether or not the benefit of the increased roof-space ventilation rate at low wind speeds is outweighed by the increased rate of moisture to the roof-space.

Current research involves the investigation of the effect of tile ventilators on roof-space ventilation and house to roof-space air movement rates, together with work on soffit vents in combination with more than one ridge vent. The new multiple tracer gas technique described in (5) and (7) has been refined and validated successfully for the case of three interconnected cells.[8] A mathematical analysis has been developed for the determination of ventilation and air movement rates between four interconnected cells. Calculations made from preliminary four tracer gas site measurements have been encouraging. These improvements in airflow measurement techniques will enable house to roof-space airflows to be expressed in terms of relative proportions of air drawn from different areas of the occupied space, particularly those of high moisture production such as the bathroom and kitchen. This will enable the influences of specific types and combinations of roof-space ventilators to be more precisely ascertained.

5. REFERENCES

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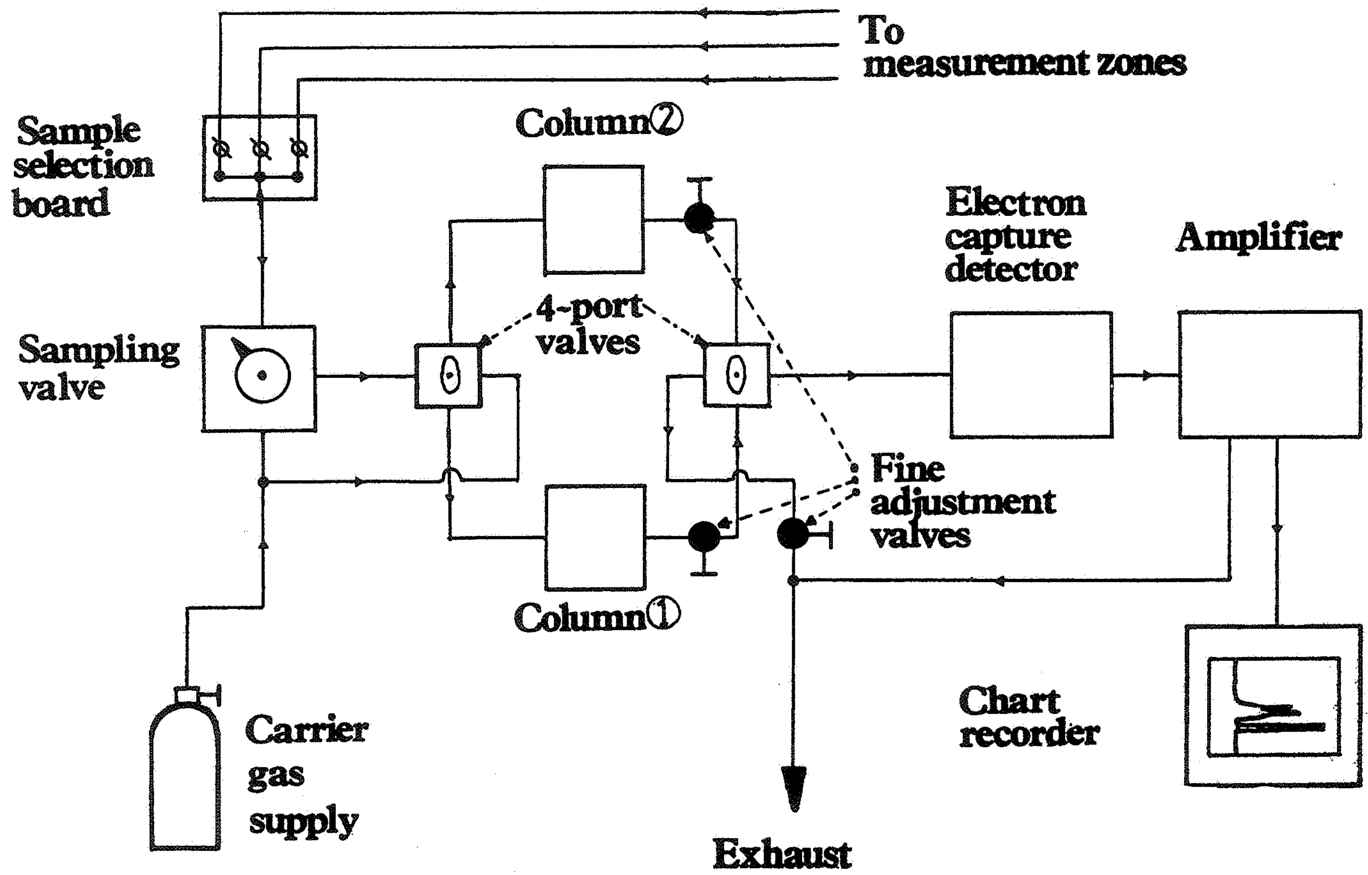
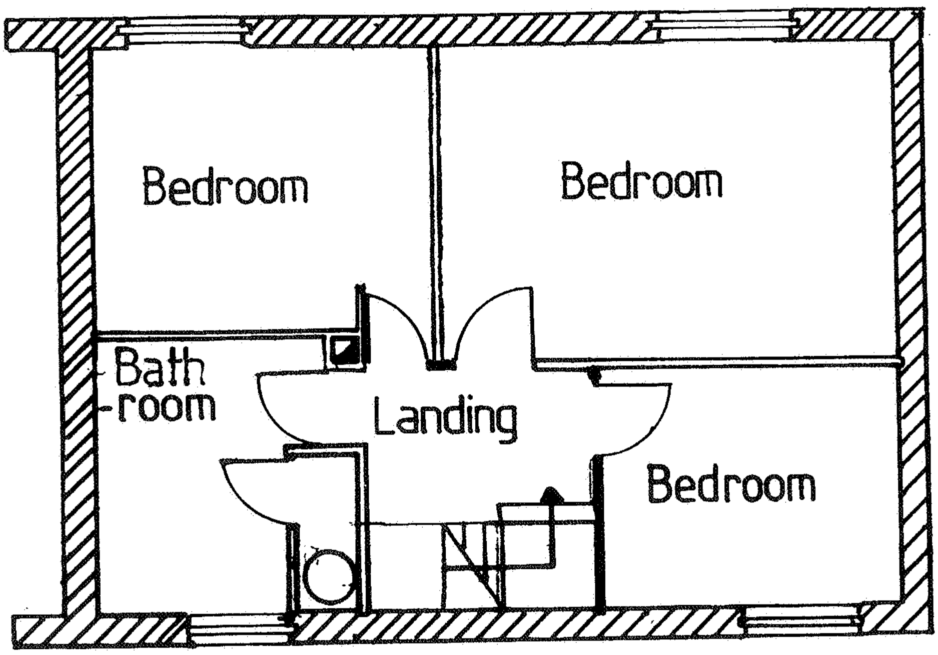
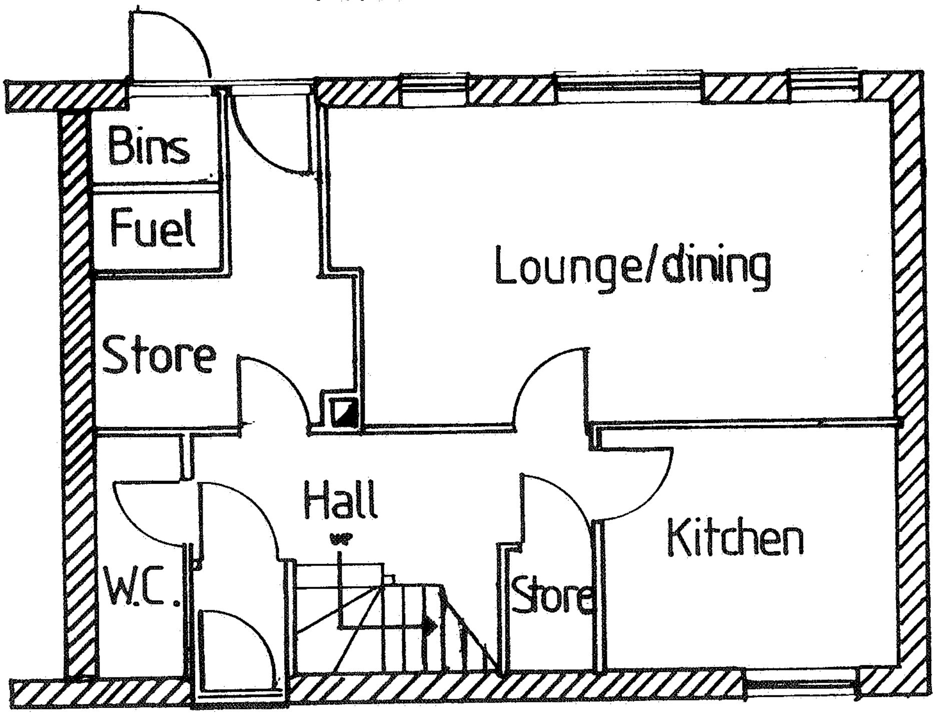

To
measurement zones
Sample
selection
board
Column②
Sampling
valve
4-port
valves
Electron
capture
detector
Amplifier
Fine
adjustment
valves
Column①
Carrier
gas
supply
Chart
recorder
Exhaust

FIGURE 1



FIRST FLOOR



GROUND FLOOR

FIGURE 2

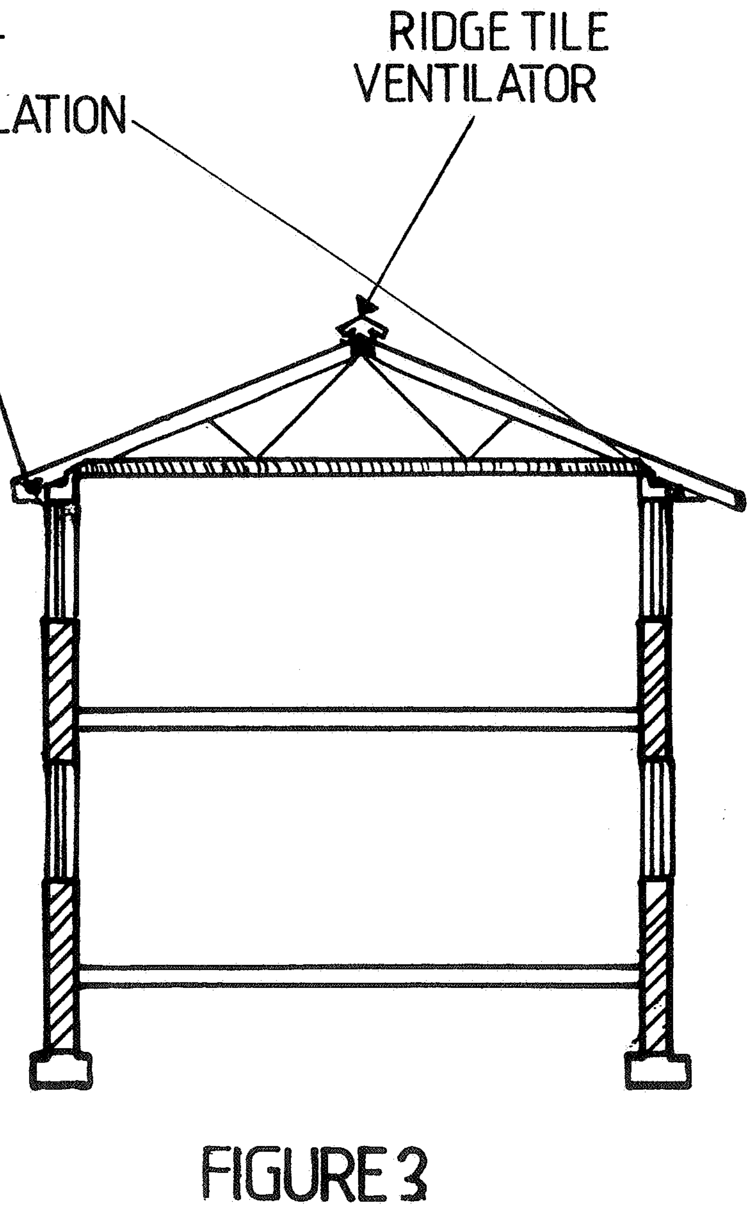


FIGURE 3

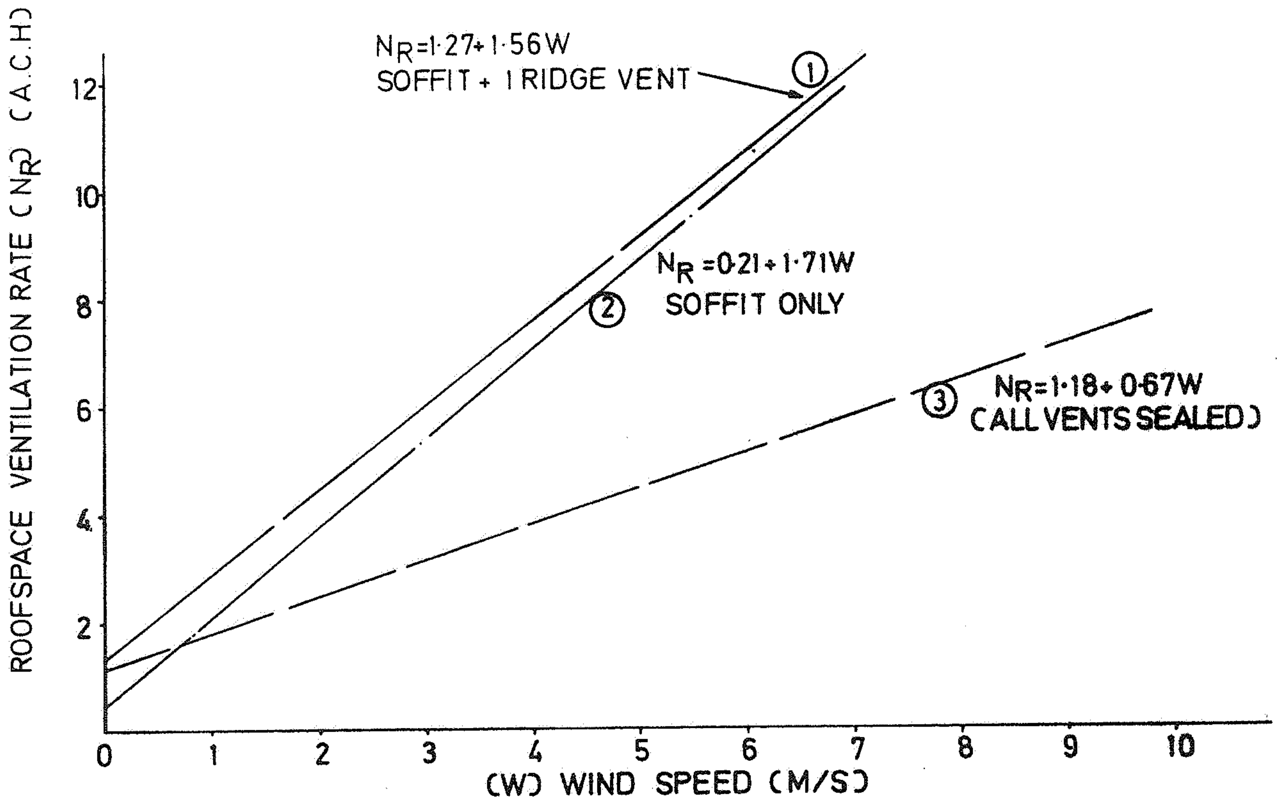


FIGURE 4 ROOFSPACE VENTILATION – SOFFIT AND RIDGE VENTS

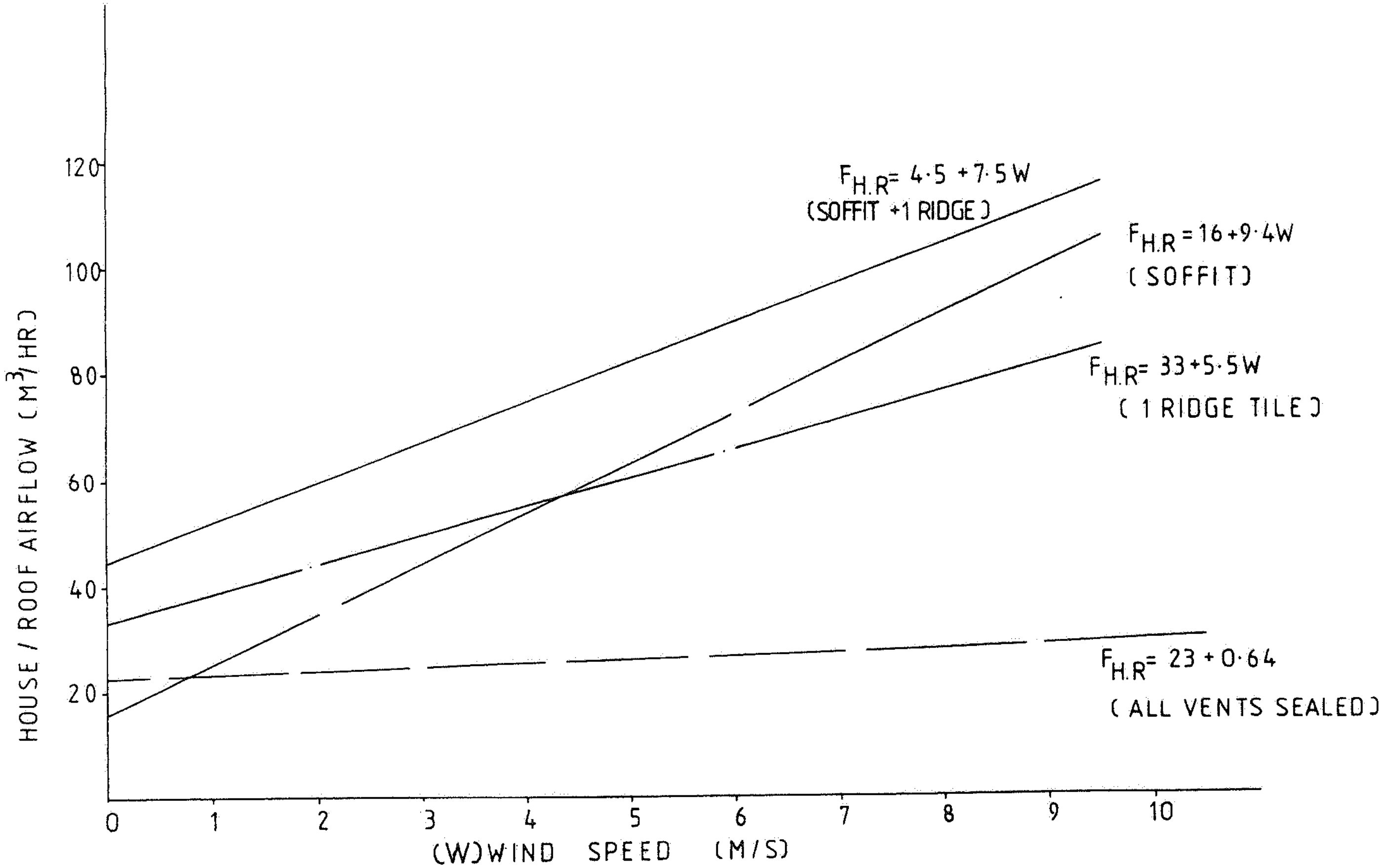


FIGURE 5 HOUSE TO ROOF AIRFLOW USING DIFFERENT ROOF VENTILATORS

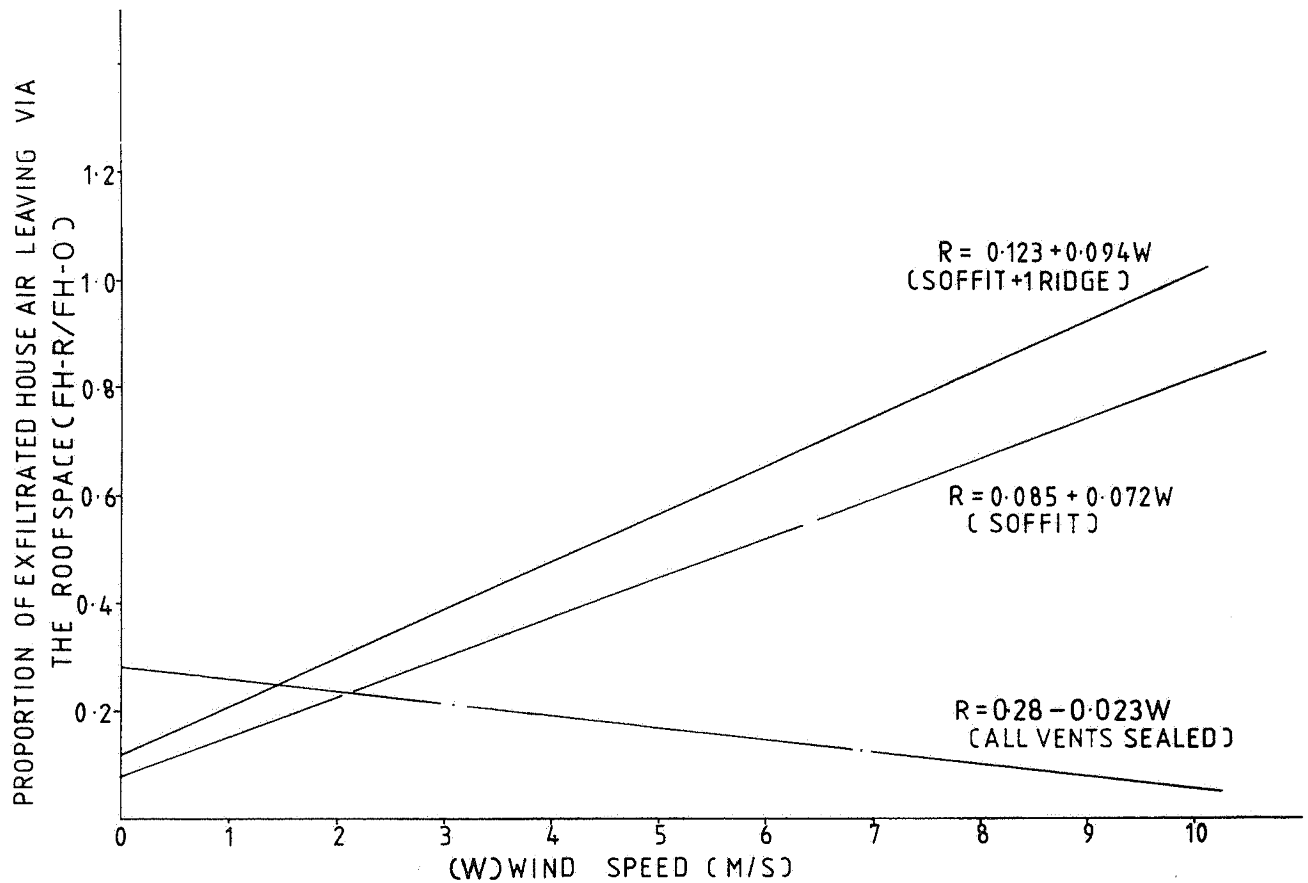


FIGURE 6 HOUSE TO ROOF AIRFLOW – EFFECT OF DIFFERENT ROOF VENTILATORS

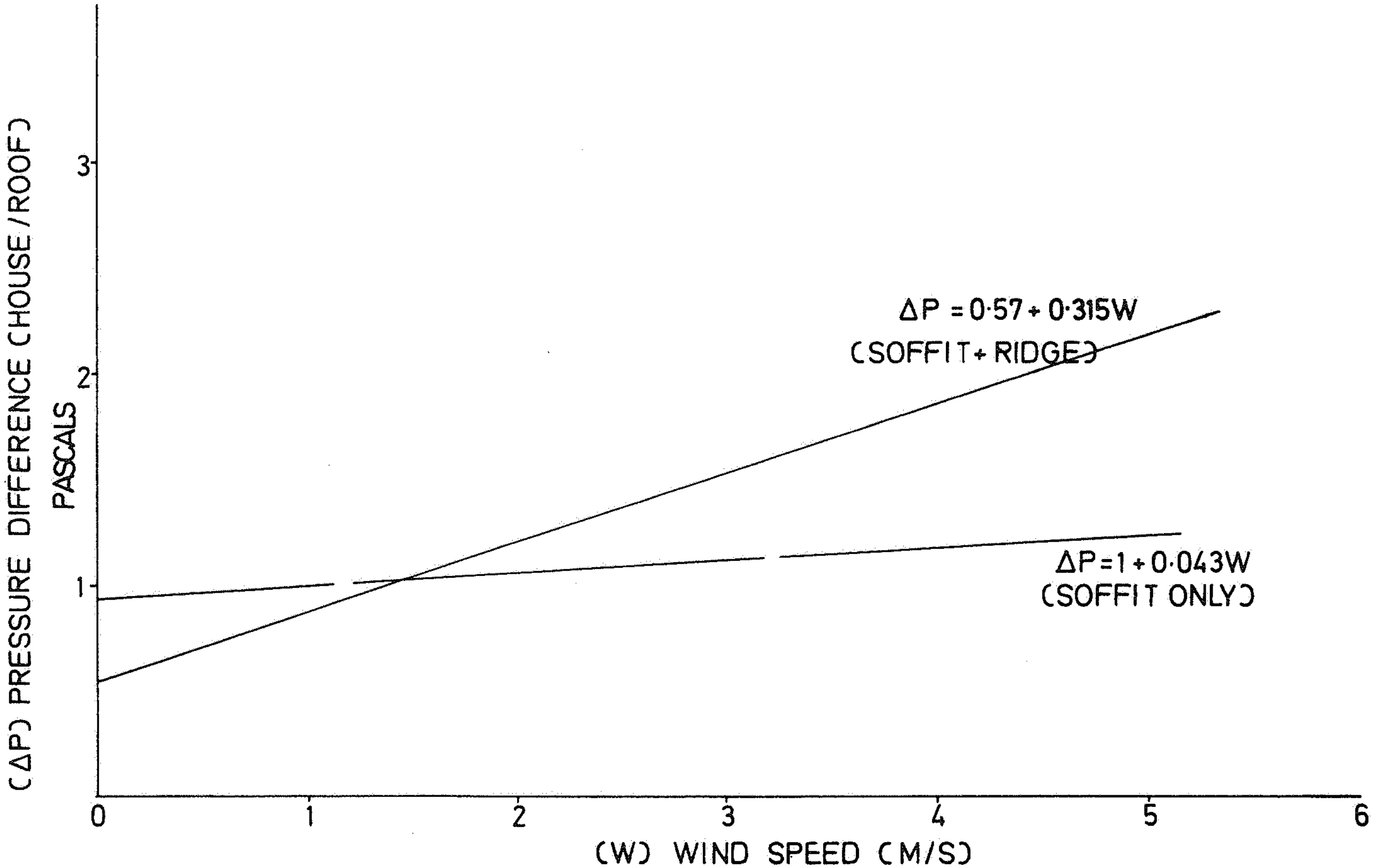


FIGURE 7 PRESSURE DIFFERENCE HOUSE / ROOF

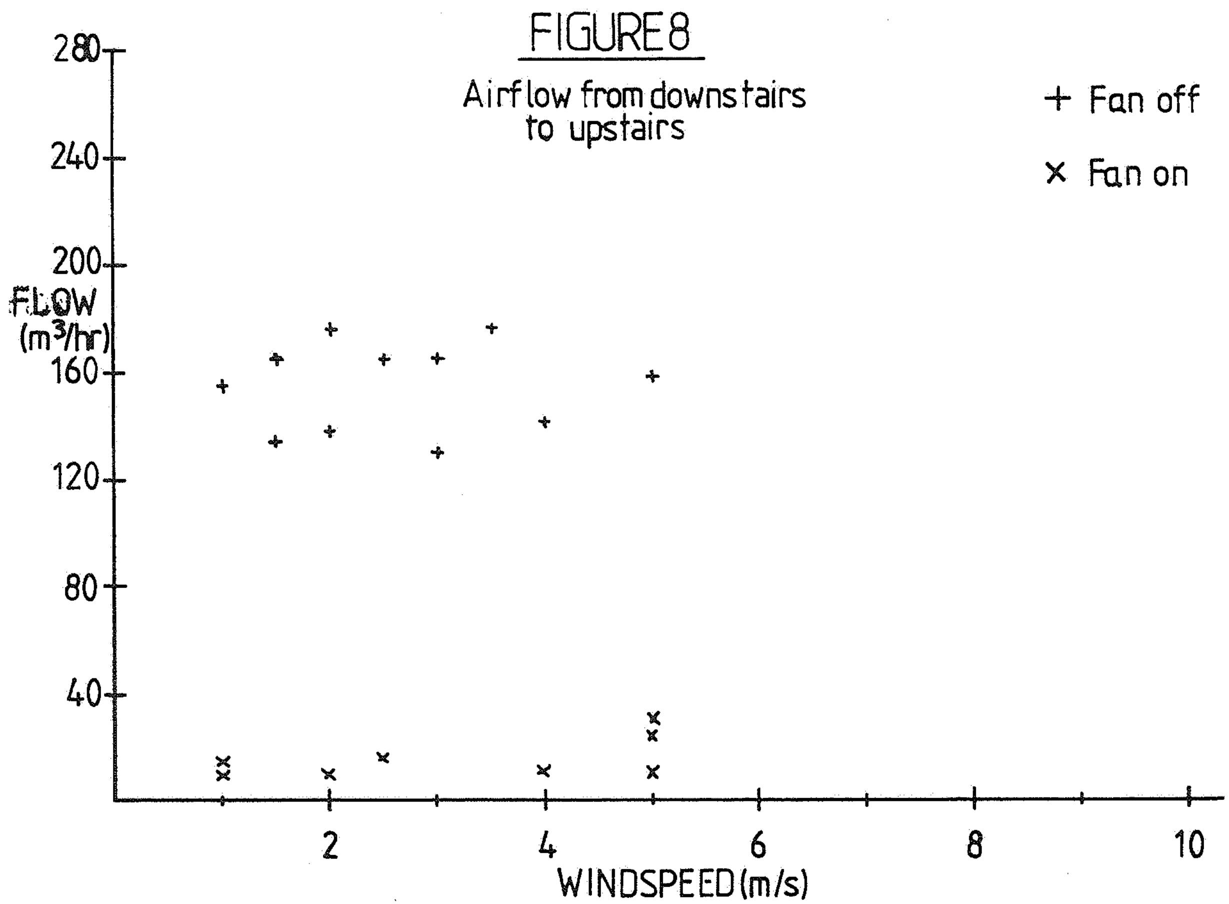
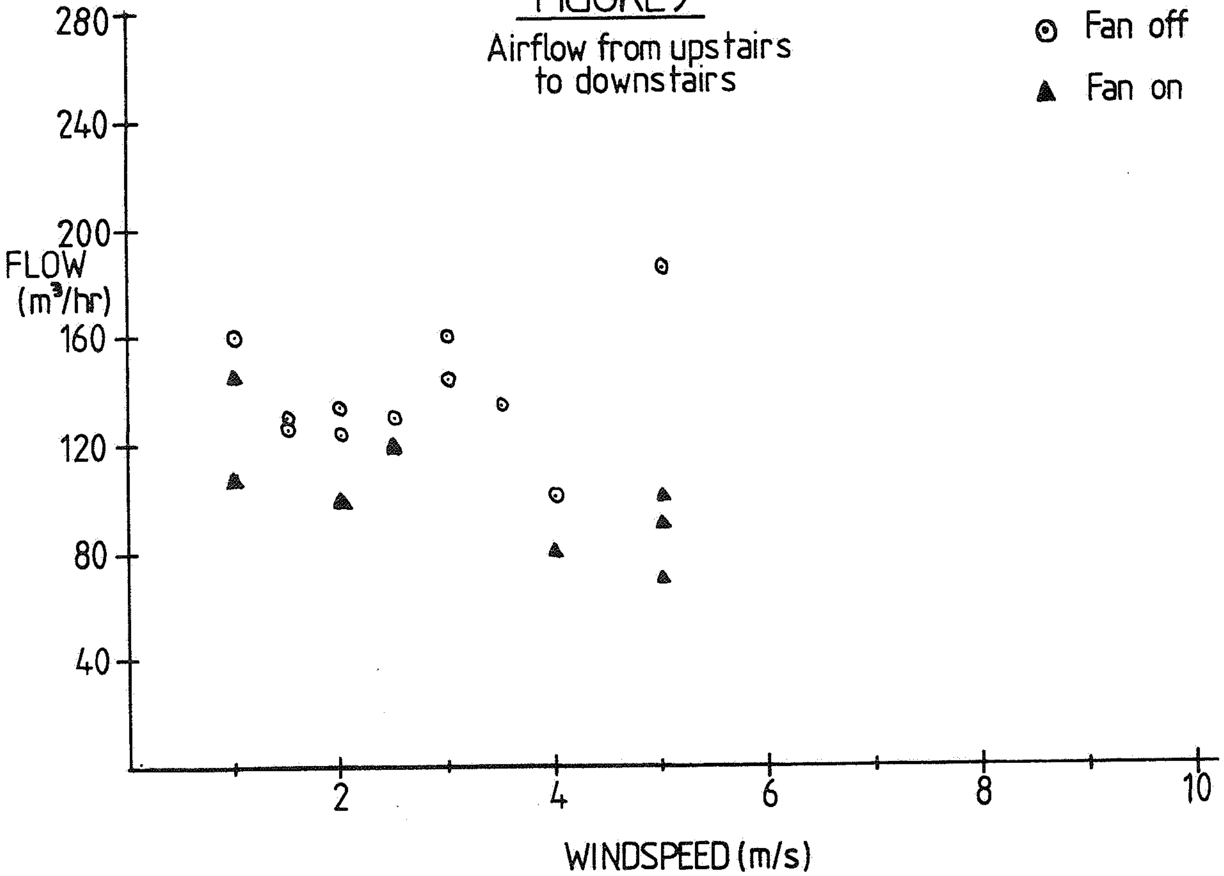


FIGURE 8
Airflow from downstairs to upstairs
+ Fan off
× Fan on
FLOW (m³/hr)
280
240
200
160
120
80
40
2
4
6
8
10
WINDSPEED (m/s)

FIGURE 9

Airflow from upstairs to downstairs



TYPE OF ROOF VENTILATION	HOUSE TO ROOF AIRFLOW (m^3/hr)	ROOF VENTILATION RATE (ACH)	WATER VAPOUR TRANSFER BY DIFFUSION (g/hr)	WATER VAPOUR TRANSFER BY AIR MOVEMENT (g/hr)	TOTAL WATER VAPOUR TRANSFER (g/hr)
All ventilators sealed	25	2.8	13.3	61.2	74.5
1 Ridge Tile	47	4.5	12.7	110.6	123.3
Soffit ventilators	40	4.5	13.5	99.5	113.0
Soffit + 1 Ridge tile	70	5.1	11.0	143.5	154.5
Unknown*	30	2.0	22.7	64.0	86.7

* BASED ON INFORMATION IN REF (4)

TABLE1