MEASUREMENTS OF VENTILATION RATES IN HOUSES WITH NATURAL AND MECHANICAL VENTILATION SYSTEMS

by M Guillaume and J Ptacek* and

P R Warren and B C Webb**

SUMMARY

This paper reports the results of measurements made jointly by BRE and the Centre Scientifique et Technique de la Construction, Belgium, to compare the performance of natural and mechanical ventilation systems in otherwise identical houses. Ventilation rates were obtained by tracer gas methods, and the available area for air leakage, and its distribution among the various components of the fabric were measured by pressurisation techniques.

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* Centre Scientifique et Technique de la Construction

** Building Research Establishment, Garston

1. INTRODUCTION

This paper reports the results of research on ventilation rates in dwellings, undertaken in collaboration by Centre Scientifique et Technique de la Construction, Belgium, and the Building Research Establishment, United Kingdom. The main aims of the work were,

(i) to compare the performance of natural and mechanical ventilation systems in identical dwellings, and

(ii) to compare the results for measurements of ventilation rate and in-situ measurement of component leakage, made using the methods employed by each Establishment.

The work formed part of the research programme of the Syndicat IC-IB*, entitled - 'Air Distribution - 1977/1978' - funded by the IRSIA* and carried out in collaboration by UBIC*, FABRIMETAL*, and CSTC. The programme has the following overall aims:

(i) to examine air change rates,

(ii) to define situations for the application of heat recovery,

(iii) to define methods for testing and the control of heat recovery devices.

The work also formed part of BRE research into the ventilation of modern dwellings, which has so far included the measurements of ventilation rates in some twenty-five dwellings, in co-operation with BSRIA*, with the ultimate aim of improving natural ventilation design.

The measurements by CSTC were carried out over a period of four months from February 1977 in newly-built houses on a site some 60km to the south of Brussels. The BRE measurements were made during the period March 1 to 24, during which a BRE Mobile Laboratory designed for the measurement of ventilation rates was brought over from England and set up at the test site.

2. THE TEST HOUSES

2.1 Description of the site

Figure 1 shows the general layout of the site. Six identical unoccupied houses, numbered 1 to 6 in the figure, were used by CSTC for measurements of ventilation and heating consumption. The houses are identical in layout orientation and construction, and differ only in the method employed for ventilation. The six houses were newly built and formed part of a development of about fifty single and two-storey dwellings at the edge of a small town, surrounded by flat open countryside.

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* CI-IB	-	Syndicat d'Etudes Interindustries - construction
IRSIA	-	Institut pour l'Encouragement de la Recherche Scientifique dans l'Industrie et l'Agriculture
UBIC	-	Union Belge des Installateurs de Chauffage et Conditionnement d'Air
FABRIMETAL	-	Federation des Enterprises de l'Industrie des Fabrications Metallique
BSRIA	-	Building Services Research and Information Association

(ii) Mechanical ventilation - extract only ('simple flux')

After sufficient measurements of natural ventilation rates had been made in House 1, the duct system for the natural ventilation of the kitchen, WC and bathroom was replaced by a mechanical extract system with outlets in each of these rooms. In view of the leakage areas in the building fabric, described in Sections 4.2 and 4.3, no special purpose-made openings were provided for the incoming replacement air. The total volume flow of the extract system was 215m^3/h at system pressure loss of 120 Pa. The pressure drop across the ceiling extract openings was 80 Pa.

(iii) Mechanical ventilation - input and extract system ('double flux')

Houses 2 and 5 were fitted with full input/extract mechanical ventilation systems, which were practically identical except for their heat exchangers. The positions of the extract and supply openings (all in the ceiling) are indicated on Figures 5 and 6. Suitable opening grilles were provided in the internal doors to allow free movement of air from supply to extract points. The design performance of the two systems are as follows:

House 2 : Supply fan : 215m^3/h at 180 Pa
Extract fan : 194m^3/h at 170 Pa
Pressure loss at extract openings : 70 Pa
Pressure loss at supply openings: 50 Pa

House 5 : Supply fan : 260m^3/h at 180 Pa
Extract fan : 215m^3/h at 160 Pa
Pressure loss at extract openings : 70 Pa
Pressure loss at supply openings : 50 Pa

3. EXPERIMENTAL TECHNIQUES

3.1 Tracer gas measurements

The methods employed by both CSTC and BRE were based upon the well known equation governing the variation of concentration, c, of some known contaminant, after time, t, in a space of volume, V, with an input rate of external air, Q :

$$|(c - c_e)| = |(c_o - c_e)| . \exp(-Qt/V) \qquad (1)$$

where: c_e is the concentration of the contaminant in the input air

c_o is the concentration of the contaminant at time, t = 0.

Provided c_e is known the ventilation rate (Q/V) may be determined by plotting log $|(c - c_e)|$ against time, t.

The CSTC and BRE methods differ in two main respects; the tracer gas employed, and the method of sampling when determining whole house ventilation rates.

(i) CSTC method

The tracer gas used was oxygen, and its concentration was determined using its para-magnetic properties. Nitrogen was introduced into the space under test in order to reduce the concentration of oxygen to approximately 4.0 per cent below the prevailing level in the external around the component and, using a centrifugal fan, air was extracted from the enclosure, creating a flow through the component and a pressure drop across it. Measurements of flow rate were made over a range of applied pressure, up to about 400 Pa by BRE, and up to 750 Pa by CSTC. Measurements were made on days with low wind speed to avoid any interference with the measurements. The CSTC rig consisted of rigid wooden box screwed to the external surface using threaded holes specially provided in the wall for this purpose, and sealed by a mastic. The advantage of the rigid enclosure of being able to apply both suction and positive pressures, and hence being able to investigate the effect of flow direction through the component, was offset by the limited applicability of the rig. The BRE rig consisted of an aluminium framework, adjustable to the overall size of the component under consideration, which supported a polythene sheet sealed to the surface surrounding the component. Only suction pressures could be applied. Checks for leakage were continuously made with smoke tube tracer during the BRE measurements.

3.4 Whole house leakage tests

Measurements were made of the leakage under a uniformly applied pressure difference of the external 'shell' of the house, using equipment developed at BRE, Princes Risborough Laboratory, and described by Skinner (2): Figure 7 shows the general arrangement of this equipment which consists of a wooden false door designed to be sealed into the main doorway opening. This false door supports a variable speed axial flow fan, to which is connected a short length of duct, containing at its centre a vane anemometer, pre-calibrated to give volume flow rate through the fan. The fan could be arranged both to pressurise and depressurise the house with respect to external air static pressure. The overall characteristic of the house shell could therefore be determined by simultaneously measuring applied pressure and flowrate. By sealing various components in turn the distribution of leakage amongst components could be estimated.

4. RESULTS

4.1 Ventilation rates

(i) CSTC measurements

Measurements were made in House 1, with both natural and simple extract ventilation, and in Houses 2 and 5 with full supply/extract systems, and the results are summarised in Table 2. In the mechanically ventilated houses the air flow rate at the supply and extract grilles was measured using a calibrated, hooded vane anemometer.

(ii) BRE measurements

Measurements were made in House 1, with natural ventilation only, and in House 2, with full supply/extract system. In the latter case a limited number of measurements were made with the mechanical system switched off. The results for Houses 1 and 2 are summarised in Tables 3(a) and 3(b) respectively. (The gaps in the test numbers relate to individual room measurements which were also made and which will be reported elsewhere).

mechanical system turned off, the ventilation rates, due only to wind and temperature difference, are close to those of House 1. The CSTC results for House 2 are also plotted on Figure 11. These are lower than the BRE results but again generally substantially in excess of the measured mechanical ventilation flow rates. Unlike the results shown in Figure 9 for the naturally ventilated house, those in Figure 11 cover several wind directions and this may be a contributory factor to the differences between the two measurement methods. It would appear that the houses are insufficiently well-sealed to take advantage of the mechanical system. This is further confirmed by the results for House 5 listed in Table 2, where again the measured whole house rates are considerably in excess of the flow rate from the mechanical system . The excess flow rate due to infiltration is sufficient to remove any savings in ventilation heat loss due to the inclusion of a heat recuperator.

5.2 Leakage rates

It is clear from Figures 8(a) to 8(d) that there is considerable variation in the leakage characteristics of nominally identical components fitted to identical houses by the same builders. It was not possible to determine quantitatively what proportion of the leakage took place through the perimeter gaps around opening parts, and what proportion resulted from leaks at the juncture of frames and the walls. One test was made however to obtain an estimate of the leakage through the drain holes situated in the base of each window frame. In order to present the results more succinctly, use has been made of the following equation, derived from dimensional analysis:

$$Q = d.F(\,Re^*,\ \text{crack geometry}\,)\sqrt{\frac{2\Delta p}{\rho}} \qquad (3)$$

where Re^* is a Reynolds Number, defined as $\left[\frac{d}{\nu} \cdot \sqrt{\frac{2\Delta p}{\rho}}\right]$

Q is the volume flow rate per unit length of crack

d is the mean crack width

Δp is the applied pressure difference.

An examination of published work (3,4,5) on flow through typical component cracks shows that as Reynolds Number is increased, ie as the applied pressure difference is increased, the function F tends to a constant value. Thus plotting $Q/(2\Delta p/\rho)^{\frac{1}{2}}$ against, say, $(\Delta p)^{\frac{1}{2}}$ enables the product (d.F) to be determined. The actual value of F will lie close to the theoretical value for sharp-edged orifices of 0.61, when the length of the opening is relatively small in comparison with the width, d, but will increase to values nearer 1.0 as the length increases, and will then gradually decrease with length as frictional effects begin to dominate the overall pressure loss. For purposes of comparison, in this instance the value of F has been arbitrarily taken as 0.61 to give a notional equivalent width to the various components examined. It must be remembered that this applies at high values of Δp only and a knowledge of the variation of F is required to predict flow rates at lower values, such as those typically produced by the wind and stack effect in buildings.

Table 6 lists the values of equivalent width for the components examined. Since the windows had opening lights with similar cross-sections through the sashes, these represent the largest group for comparison. The range in values of d is large and values of the mean for the CSTC and BRE measurements are 0.31mm and 0.26mm respectively. Simple statistical but nevertheless implies a limitation on the ability to predict with accuracy the natural ventilation of houses from the nominal performance characteristics of windows and similar components.

4. From the combined results of leakage measurements on individual components and whole house leakage tests an indication was obtained of the distribution of the leakage areas. Only about 40 per cent was accounted for by those components generally regarded as the main source of infiltration, doors and windows. Of the remaining proportion 25 per cent could be identified with openings such as trap doors, and in this case gaps between the ceiling plasterboarding. The remaining 35 per cent could not be identified, but probably included gaps at the juncture of the ceiling and walls. Such a distribution must be treated with some caution, since under real conditions the pressure differences are not evenly distributed and are generally lower than those used for the tests. Nevertheless, this further underlines the errors likely to be associated with predictions of ventilation performance based upon the characteristics of windows, doors and other purpose-made openings alone.

5. There are too few results to make an accurate comparison of the two different methods of measuring ventilation rates employed by BRE and CSTC, nevertheless the results obtained were consistent. There was no significant difference between the results obtained from the two methods of measuring in-situ leakage performance of components.

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House No.	U_{10} (m/s)	ϕ	T_e (°C)	R (ach)	R_m (ach)	ΔR (ach)
1	2.0	E	20.0	0.20	--	--
	2.0	SE	14.0	0.45	--	--
1*	2.0	E	13.0	1.13	0.94	0.19
	3.5	N	12.0	0.96	0.96	0.00
2	2.0	E/SE	14.5	1.28	0.93	0.35
	2.0	SW	8.0	1.29	0.93	0.36
	3.8	S	12.0	1.05	0.94	0.11
	5.0	SW	15.5	1.74	0.94	0.80
	5.0	SW	15.0	1.58	0.94	0.64
5	2.6	SW	9.0	1.01	0.94	0.07
	2.8	SW	8.0	1.20	1.10	0.11
	4.6	SW	14.0	1.49	1.09	0.40
	7.0	SW	12.0	1.79	1.09	0.70

R - Whole house ventilation rate
R_m - Mechanical ventilation system flow rate
ΔR - Excess of R over R_m
T_e - External air temperature
ϕ - Wind direction
U_{10} - Wind speed, measured at height of 10m

Table 2 Whole house ventilation rates - Houses 1,2 and 5 CSTC measurements

Test No.	U_{10} (m/s)	ϕ (deg)	T (°C)	R (ach)	Notes
1	2.6	197	12.1	1.75	With mechanical system in operation
2	2.9	191	12.0	1.64	
3	3.2	208	11.6	1.72	
4	4.6	225	11.0	1.85	
6	2.8	189	10.0	1.69	
7	1.1	183	12.0	1.57	
16	1.9	062	12.7	1.56	
17	2.6	058	12.8	1.63	
2	2.3	055	12.1	1.57	
28	1.6	047	12.6	1.56	
31	0.7	178	10.5	1.57	
33	2.8	059	12.2	1.59	
34	3.3	050	12.0	1.68	
5	3.9	216	9.9	0.54	With mechanical system off
29	1.2	047	12.8	0.40	
32	0.0	---	11.4	0.34	

Symbols as defined for Table 3(a) overleaf

Table 3(b) Whole house ventilation rates - House 2 BRE measurements

No. of opening (Table 1a)	House 1 (BRE) A_2 (cm^2)	House 1 (BRE) d (mm)	House 2 (CSTC) A_2 (cm^2)	House 2 (CSTC) d (mm)	House 5 (CSTC) A_2 (cm^2)	House 5 (CSTC) d (mm)
1	5.9	0.16	8.3	0.23	14.3	0.39
2	34.1	0.40	60.2	0.71	68.7	0.81
3	20.9	0.29	17.8	0.25	23.6	0.33
4	109.0	1.77	96.5	1.57	444.0	7.21
(4')	-----	----	(90.1)	(1.46)	(304.8)	(4.95)
5	12.2	0.34	9.6	0.26	7.4	0.20
5*	10.9	0.30	----	----	----	----
6	24.4	0.34	35.2	0.49	17.8	0.25
7	12.5	0.17	18.0	0.25	30.1	0.42
8	147.3	2.43	199.4	3.29	139.7	2.31
(8')	----	----	(172.7)	(2.85)	(119.4)	(1.97)
9	62.5	2.60	----	----	----	----
10**	70	2.7	----	----	----	----

' -- result for flow out through opening

* - result with drain holes sealed off

** - result obtained from whole house leakage tests

Table 6 Notional equivalent area and crack width of main openings

No. of Opening	House 1	House 2	House 5	Calculated using NBN B 62-001
1	15	22	35	20
2	97	140	125	60
3	54	50	64	40
4	286	298	---	36
5	31	22	18	20
6	32	92	47	40
7	95	47	70	40

Results underlined indicate those with values less than prescribed by NBN B 62-001

Table 7 Comparison of measured leakage rates (m^3/h) at an applied pressure of 100 Pa with those prescribed for components by Belgian Standard NBN B 62-001

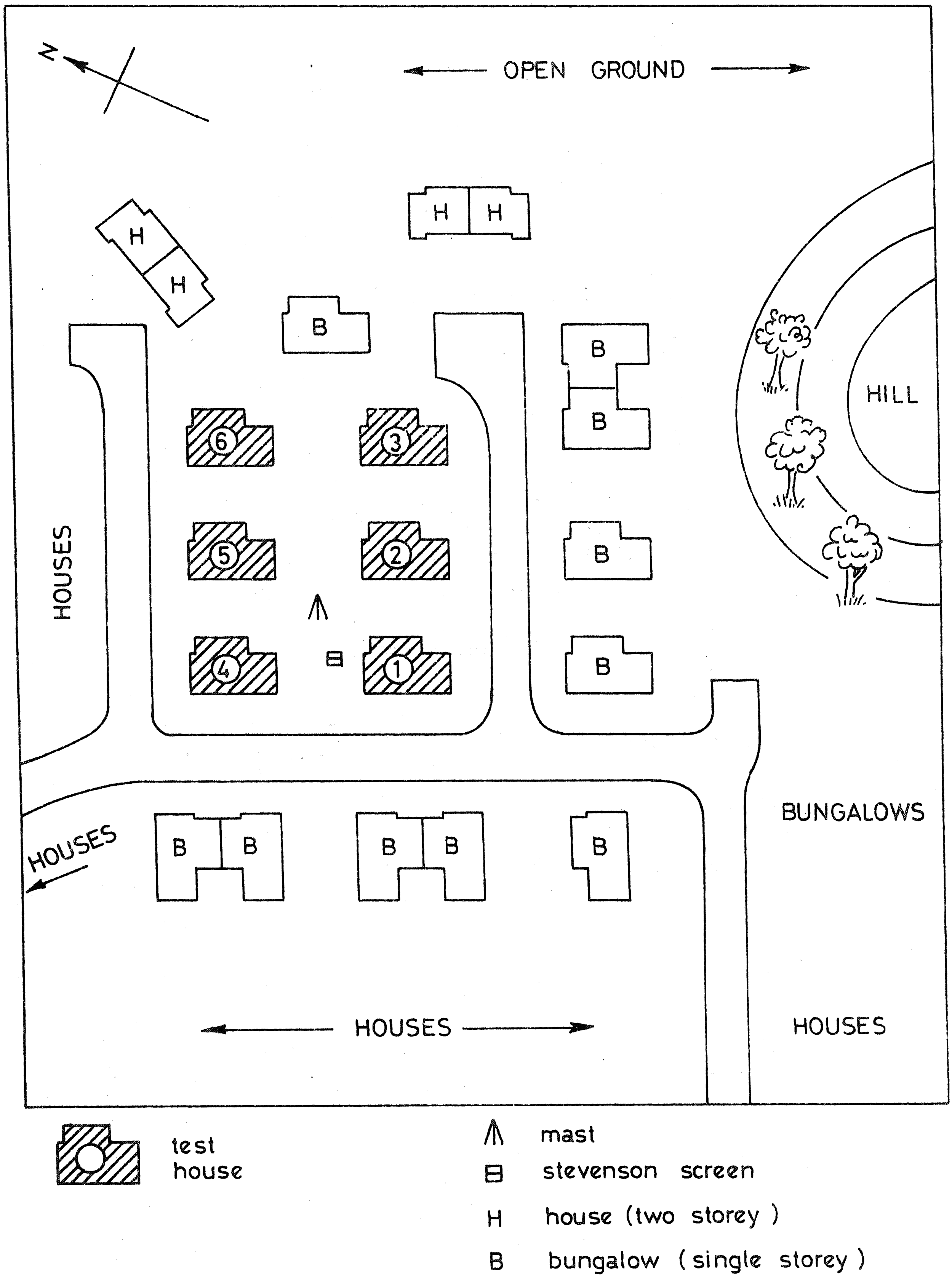

FIGURE 1 SITE LAYOUT SHOWING POSITION AND ORIENTATION OF TEST HOUSES

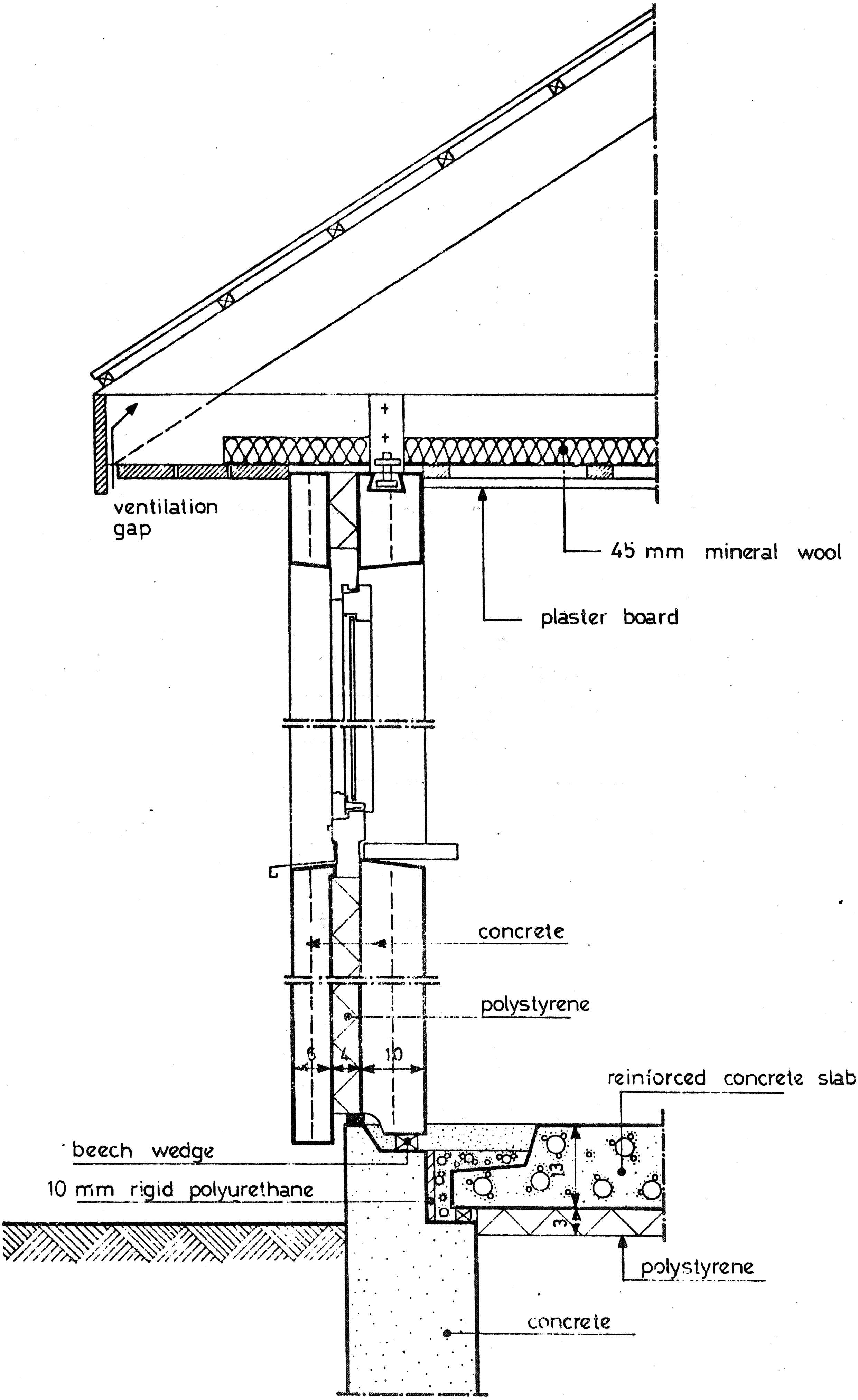

FIGURE 3 SECTION THROUGH OUTER WALL

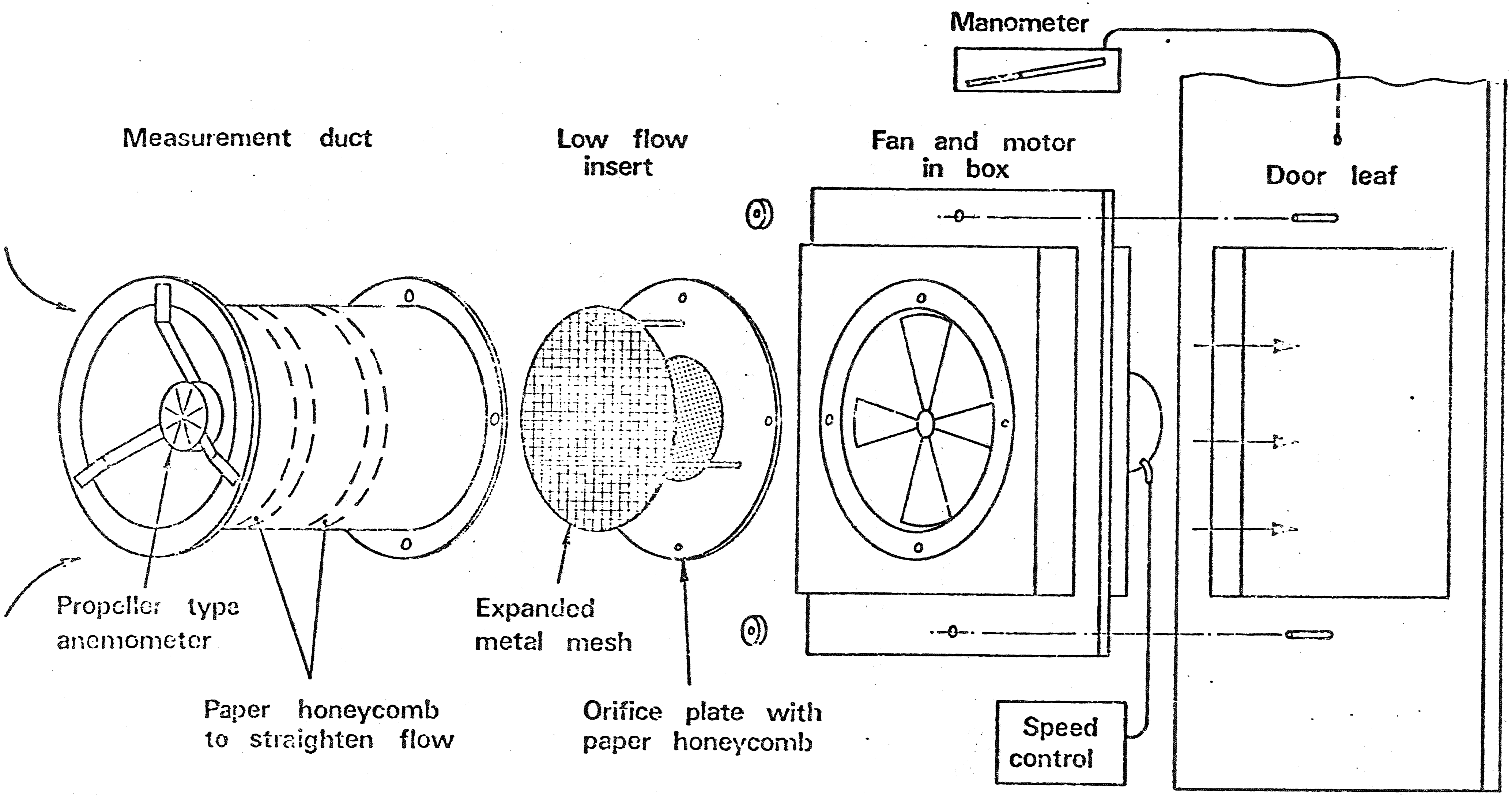

FIGURE 7 EQUIPMENT FOR MEASUREMENT OF WHOLE HOUSE LEAKAGE (after Skinner (Ref. 2))

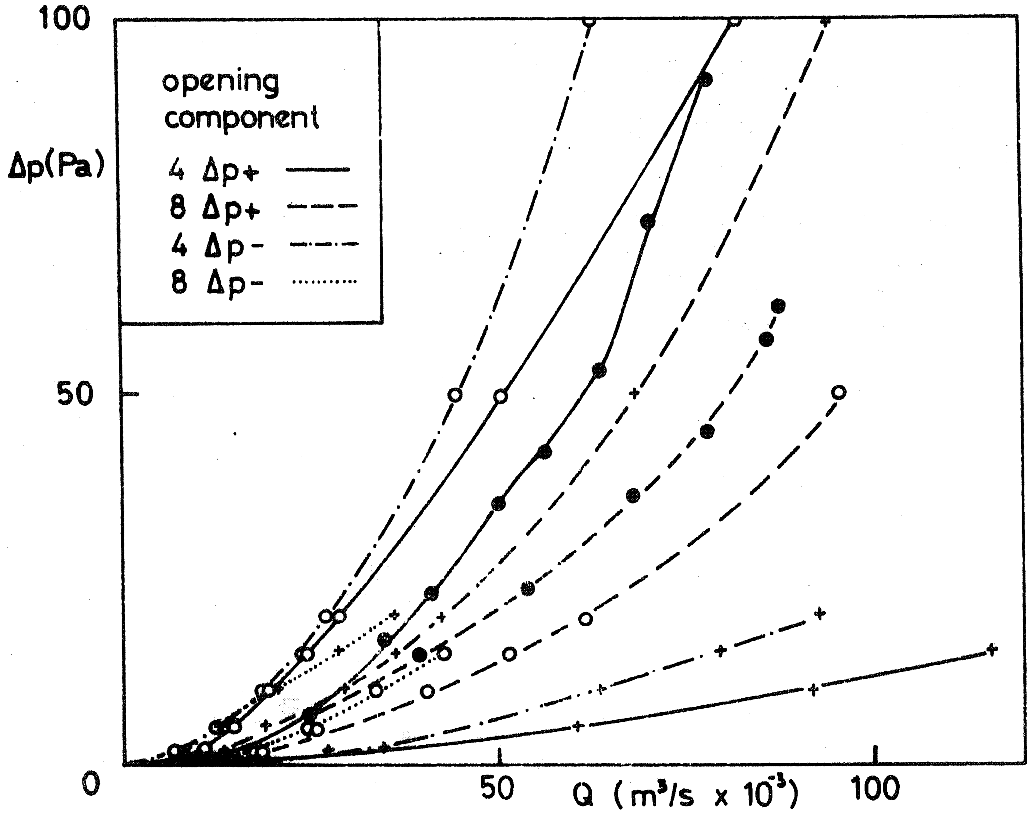

FIGURE 8(c) LEAKAGE CHARACTERISTICS OF DOORS

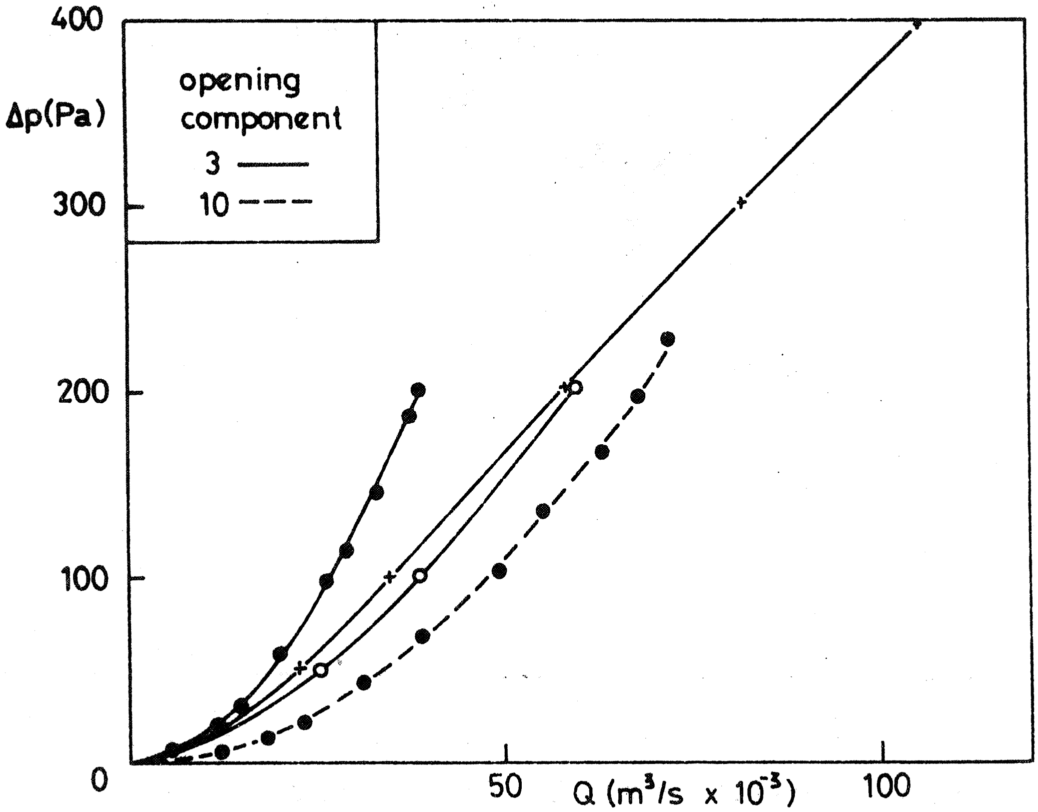

FIGURE 8(d) LEAKAGE CHARACTERISTICS OF FRENCH DOORS AND LOFT HATCH

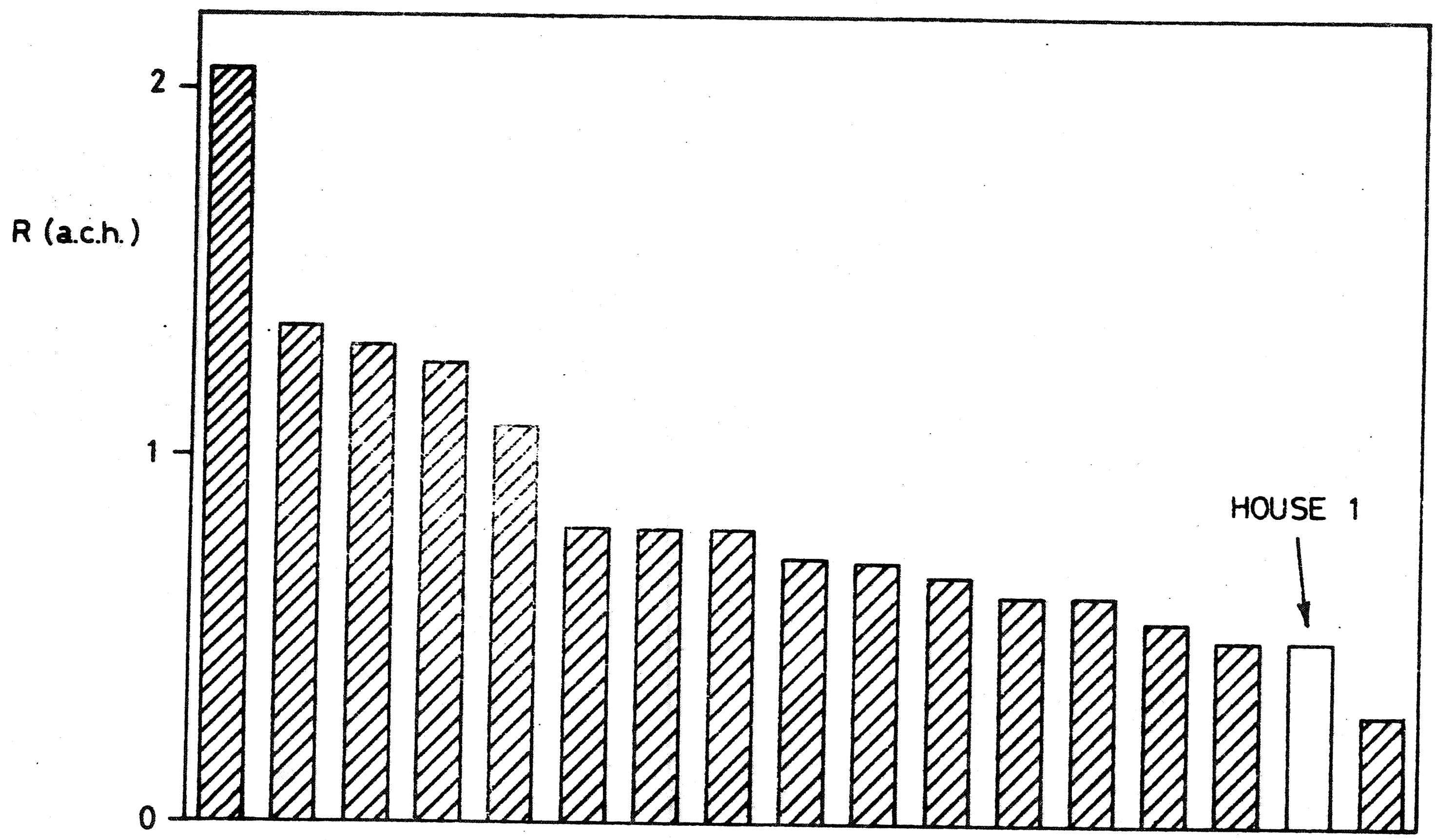

FIGURE 10 RANGE OF NATURAL VENTILATION RATES IN MODERN HOUSES

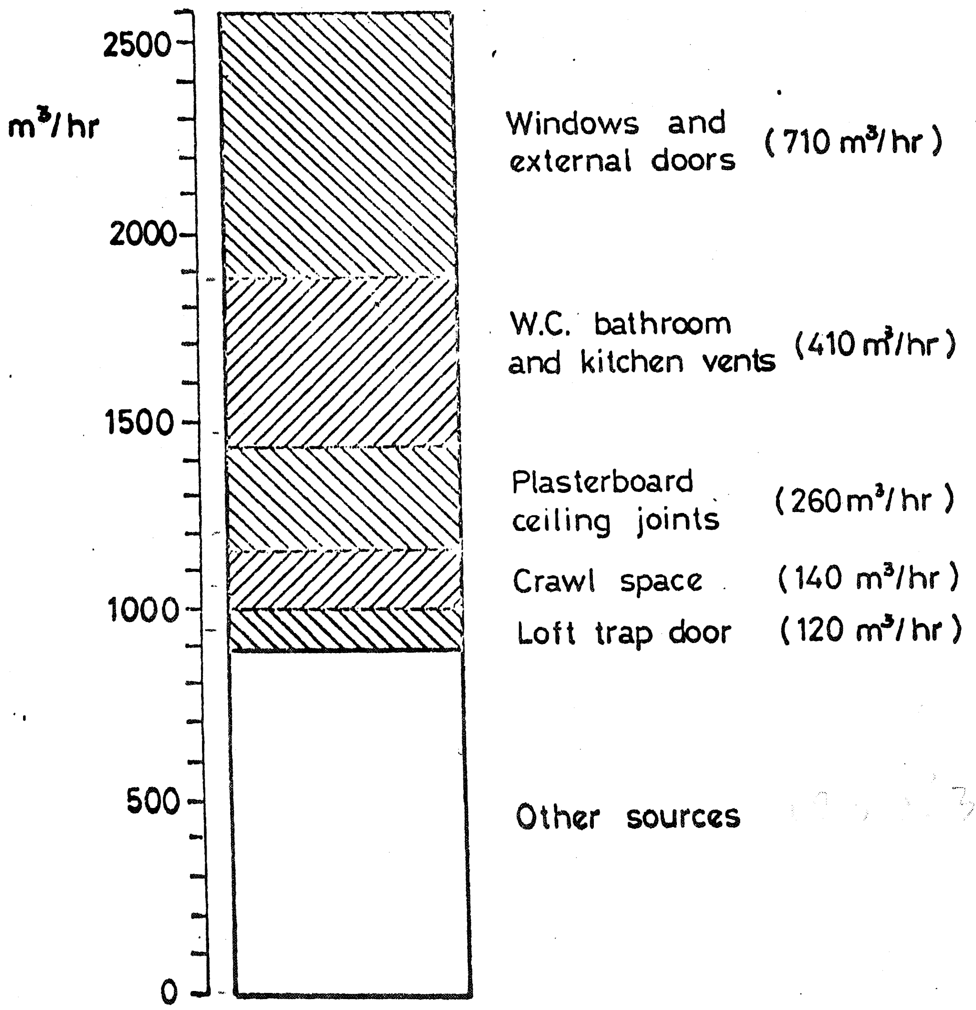

FIGURE 12 DISTRIBUTION OF WHOLE HOUSE AIR LEAKAGE FLOWS AT AN APPLIED PRESSURE OF 50 Pa