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A STUDY OF THE VENTILATION CHARACTERISTICS OF A SUSPENDED FLOOR.

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A STUDY OF THE VENTILATION CHARACTERISTICS OF A SUSPENDED FLOOR

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ABSTRACT

The ventilation and leakage characteristics of suspended floors are not well documented. As part of a larger study of air flows in housing, the air flow through a suspended floor has been investigated under a number of conditions and methods of ventilation.

The leakage of the suspended floor and the space beneath it has been measured and is compared with the house leakage.

The infiltration to the underfloor space and also the infiltration to the house from the underfloor space through the suspended floor is investigated with natural ventilation and also with different modes of mechanical ventilation.

The leakage of the underfloor space was varied to assess its influence on the ventilation characteristics of the suspended floor and hence on the air quality in the house.

The results could also be of use in the investigation of infiltration of radon into dwellings with suspended floors.

1. INTRODUCTION

The importance of the influence of ventilation on energy conservation, safety, indoor air quality, thermal comfort and heating system design, is well known.

For example, reduced ventilation can have an adverse effect on indoor air quality [1], protective pressure techniques can exclude airborne pollutants [2], and there is also interest in the ingress of pollutants into a dwelling [3].

However, very little is known about leakage and ventilation of one important house component, the underfloor space and its influence on the whole house ventilation.

The Watson House Research Station of British Gas plc has developed methods to measure the leakage [4] and ventilation characteristics [5] of houses. The British Gas ventilation measurement system, Autovent, was adapted to measure house, underfloor and through-floor ventilation rates simultaneously.

The work was undertaken for two reasons. Firstly, more knowledge about underfloor ventilation was needed to assist in the verification of mathematical models of whole-house ventilation. Secondly, data was required giving the relative proportions of house infiltration from beneath a suspended floor due to stack and wind effects and the influence of different forms of mechanical ventilation. However, the data could also be of interest to those investigating the ingress of pollutants into houses.

2. THE TEST FACILITY

The work described in this report was carried out in the test house a view of which is shown in Figure 1. This detached house, which measures 9x6x5 metres contains nine rooms, four of which are bedrooms as shown in the plan of the house in Figure 2.

The construction is of brick and is part solid, part cavity wall. The ground floor is suspended and the house is well carpeted throughout. The house is equipped with a wet central heating system and a warm air system.

The Watson House Autovent [5] was installed in the dining room and was used to measure house ventilation rates and determine flows across the suspended ground floor.

2.1 The underfloor space

The underfloor space, shown schematically in Figure 3, covers a total area of $54m^2$. Its height is 0.94 metres to the joists and 1.1 metres to the suspended floor.

The floor of the space is concrete and the surrounding walls are unplastered concrete block. There is an irregularly shaped partition wall dividing the space into two unequal volumes. This wall, which is also built of concrete block, has holes in it at regular intervals, which allows air movement between the two sections.

The underfloor space is ventilated by seven circular ducts, each of which is 0.15 metres in diameter. There are four ducts in the west wall and three in the east wall. Apart from these ducts, there are no obvious ventilation pathways in the surrounding walls which are in good condition with sound cement work. Similarly, visual inspection of the suspended floor from underneath shows it to be also in sound condition with no obvious leakage paths.

Access to the space is via a trapdoor situated in the hall floor.

3. EXPERIMENTAL METHOD

3.1 Leakage Measurements

Two Watson House leakage testers, see Figure 4, were positioned in the hall and were connected to the underfloor space by a leak-tight seal in the trapdoor.

The leakage of the underfloor space was varied by progressive sealing of the seven vents. In this way, a series of eight sets of leakage measurements was made; the first with none of the vents sealed. Each successive set of measurements involved the sealing of an extra vent, until all seven vents were sealed.

Figure 5 shows how, for each stage of sealing, the leakage $Q(m^3/s)$ varies with the static pressure difference $\Delta P(Pa)$ between the underfloor area and the house.

The relationship between Q and ΔP is given by:-

$$\Delta P = AQ^2 + BQ + C$$

The curves in the graph have been fitted to the data, using a statistical quadratic curve fit [6].

The coefficients of the curve fits and Q50 the leakage at a pressure difference of 50Pa are shown in Table 1, which also shows the same information for the house leakage. Inspection of these values of Q50 shows that each vent contributes a similar amount of leakage and that UF1, the leakage across the suspended floor, is roughly equal to the additional leakage contributed by the seven vents (UF8 - UF1).

From Table 1 it is interesting to note that the Q50 for the total underfloor leakage with all the vents unsealed and the house have similar values of 1.03 and $1.13m^3/s$ respectively.

3.2 Ventilation Measurements

The Autovent, shown in Figure 6, was used in its dual tracer gas mode. N_2O was used as the primary gas, with which ventilation rates were measured using the constant concentration technique. The secondary gas, SF_6, was continuously injected in the underfloor space and was used to determine the fraction of ventilation air entering the house through the ground floor.

As mentioned, the underfloor space shown schematically in Figure 3, is divided into two unequal volumes by the partition wall. One section (UHAL) lies beneath the kitchen/hall area, the other section (UDIN) is beneath the lounge/dining room area. An injection line was installed in each section in an asymmetric manner in the NE and SW corners. Each injection line was connected to a desk fan which ensured adequate mixing in the sections.

An additional injection line was installed in the UDIN section, through which the second tracer gas was injected at a constant rate. The resultant gas concentrations were monitored in both UDIN and UHAL, and the two values were found to be very similar, thus showing that there was good mixing in the underfloor space.

The initial tests investigated how the air flow through the suspended floor was affected by natural and mechanical ventilation, house pressurisation and depressurisation, wind speed, stack effect and different degrees of underfloor leakage. There are inevitable gaps in the measurements caused by the unpredictability of weather conditions.

House pressurisation was provided by an air supply unit situated in the ceiling of the landing. The unit provided up to $200m^3/h$ of air. Depressurisation was provided by an extract unit (0.25 metres diameter, $300m^3/h$) situated in a window in the kitchen. The results of the tests are shown in Table 2.

In order to isolate the effect of a particular parameter, the data has been selected for consistency of wind speed/direction and stack effect.

From analysis of the data the ratio R, has been obtained. R is the ratio of the flow of air entering the house through the suspended floor to the total airflow leaving the house and its derivation, in detail, is shown in Figure 7.

4. RESULTS

4.1 Ventilation Results

An example of how stack and wind speed affect ventilation rate in the house and the underfloor space is shown in Table 3. The effect of doubling the stack while keeping wind speed/direction approximately constant, is to increase the house ventilation rate by a factor of 1.5 and to double the underfloor ventilation rate.

The effect of doubling the wind speed while keeping the wind direction and stack approximately constant, is to increase the house ventilation rate by a factor of 1.6 and the underfloor ventilation rate by a factor of 1.4.

4.2 Natural Ventilation and Pressurisation

For natural ventilation, Table 2 shows that under the prevailing weather conditions with seven underfloor vents unsealed, the total ventilation rate of the house is 0.19 air changes per hour, 60% of this entering via the underfloor space. When the underfloor vents are sealed, the reduction in air change rate is relatively small, from 0.19 to 0.15, but the percentage of air entering the house from the underfloor space reduces significantly to only 18%. However, it was not possible to obtain a matched pair of results and the wind speed and temperature for the sealed vent test were lower than desired.

When the house is pressurised under similar weather conditions, the increased house ventilation rate is roughly the same at 1.08 and 0.99 air changes per hour, with the underfloor vents unsealed and sealed respectively. The proportion of the ventilation air entering the house from the underfloor space is reduced from 60% to 37% with the underfloor vents unsealed and from 18% to 2.7% with the underfloor vents sealed, virtually eliminating any infiltration through the suspended floor.

Under these conditions, and for natural and pressurised house ventilation respectively, the ventilation rates of the underfloor space were 95m^3/h and 112m^3/h with the vents unsealed, reducing to 41m^3/h and 22m^3/h with the underfloor vents sealed.

4.3 Natural Ventilation and Depressurisation.

Using a kitchen extract fan to depressurise the house resulted in an increase in house ventilation rate from 0.56 to 3.5 air changes per hour. The flow rate through the suspended floor decreased from 75% to 52% of the house ventilation. When the underfloor vents were sealed, the house ventilation rate increased to 3.8 air changes per hour. Some of the variation was due to a larger contribution by stack driven ventilation, although the wind speed was lower, but the proportion entering through the suspended floor reduced to 15%. The underfloor ventilation rates after house depressurisation and underfloor vent sealing changed from $263m^3/h$ to $136m^3/h$ during the test.

In this set of measurements, an intermediate sealing stage was measured with results in between the extremes presented in Table 2. With four vents unsealed, the depressurised house ventilation rate was 3.3 air changes per hour, 44% of which entered from the underfloor space.

4.4 Natural and Mechanical Ventilation.

The final results in Table 2 show the influence of a balanced mechanical ventilation system. With no mechanical ventilation, and a house airchange rate of 0.76, 0.5 air changes (65%) infiltrates through the suspended floor. When the balanced mechanical ventilation system is switched on, the total air change rate increases to 1.76, 0.86 air changes (49%) coming through the suspended floor.

5. DISCUSSION

The results support the expected behaviour of the ventilation performance of the suspended floor, but they also demonstrate some interesting interrelationships between the ventilation characteristics of the house and its underfloor space.

Air infiltration through the suspended floor provided on average, two-thirds of the house natural ventilation, when the underfloor vents were unsealed. All the forms of mechanical ventilation used decreased the proportion of ventilation entering the house through the suspended floor while increasing the total house ventilation rate. In every case, however, the volume of air entering the house from the underfloor space increased.

House pressurisation and depressurisation increased by a factor of 4 the volume air flow entering the house through the floor, while the house air change rates increased by a factor of 6. Thus, the proportion of air entering the house through the suspended floor decreased.

Balanced mechanical ventilation had less impact, as would be expected. The flow through the floor increased by a factor of 1.7, while the house ventilation increased by a factor of 2.3. Whereas some of the increased air flow from the underfloor space is probably due to an increased stack effect at the time of measurement, not all can be attributed to this. Therefore, the underfloor space must have been acting as an air flow pathway between rooms.

Thus, the use of mechanical ventilation systems resulted in a reduced proportion of the house ventilation air entering via the suspended floor. This was largely due to the increase in infiltration through the exterior fabric of the house and not through a reduction in flow rate through the floor. Air flows into the house via the suspended floor increased unless the underfloor vents were sealed. If the underfloor vents were left unsealed, this would result in reduced concentrations of any products entering the house via the underfloor space. If the vents were sealed, concentrations in the underfloor space would increase, with a possible increase in house pollutant concentrations.

The effect of sealing the underfloor vents resulted in a decreased ventilation rate in the underfloor space and reduced air flows through the suspended floor. When the house was naturally ventilated, the flow through the suspended floor reduced from 60% to 18% of the house total infiltration rate, while the underfloor ventilation rate reduced from $95m^3/h$ to $41m^3/h$.

With sealed vents, using a pressurised ventilation system, the air flow rate entering through the suspended floor was unchanged, although the house's ventilation rate increased by a factor of 7. The underfloor ventilation changed from $41m^3/h$ to $22m^3/h$, which would result in an increased rate of pollutant infiltration.

Depressurisation of the house with the underfloor vents sealed resulted in air flow rates through the floor similar to the natural ventilation condition, although the house's total air change rate increased by a factor of 7. When the house was depressurised and the vents were sealed, a small increase in the house ventilation rate occurred due to an increased stack effect. Under these conditions, the sealing of the underfloor vents caused the proportion of air from the underfloor space to decrease by a factor of 3.

6. CONCLUSIONS

The house used for the tests had approximately the same leakage values (Q50 = $0.5m^3/s$) for the outer fabric, the suspended floor and the underfloor vents. This resulted in typical house infiltration rates of 0.5 air changes per hour and underfloor infiltration rates of 5 air changes per hour. Approximately 65% of the house ventilation entered via the suspended floor. Sealing the vents in the underfloor space reduced this contribution by a factor of 3 for natural and depressurised mechanical ventilation, and by a factor of 14 when the house was provided with pressurised mechanical ventilation.

The ventilation method had more influence on the contribution of infiltration through the floor when the underfloor vents remained unsealed.

For the weather conditions measured, the most effective way of reducing the concentration of any pollutants entering this house via the underfloor space would appear to be depressurised ventilation with the underfloor vents sealed, i.e. a 'tight' underfloor space. In this situation there was a low proportion of underfloor air entering the house, but a relatively high underfloor ventilation rate. This was mainly due to the high house ventilation rates induced by depressurisation.

Pressurised ventilation with the underfloor vents sealed provided a similar performance, but with a much lower underfloor ventilation rate than in the depressurised case.

7. ACKNOWLEDGEMENTS

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RS/BP/WP2
11.8.88.

TEST NAME	LEAKAGE STATUS	COEFFICIENTS FOR $AQ^2+BQ+C=\Delta P$			Q50 (M^3/S)
		A	B	C	
UF1	V1 TO V7 SEALED	66.4	59.3	-0.6	0.53
UF2	V2 TO V7 SEALED	54.8	36.7	-0.3	0.68
UF3	V3 TO V7 SEALED	51.4	33.7	-0.7	0.72
UF4	V4 TO V7 SEALED	51.9	26.1	-0.4	0.77
UF5	V5 TO V7 SEALED	39.6	28.9	-0.3	0.82
UF6	V6 TO V7 SEALED	23.3	36.8	-1.3	0.89
UF7	V7 SEALED	26.7	27.9	-0.7	0.95
UF8	ALL UNSEALED	22.3	26.2	-0.9	1.03
HL1	HOUSE LEAKAGE	29.4	11.4	-1.1	1.13

TABLE 1.
LEAKAGE CHARACTERISTICS OF THE UNDERFLOOR SPACE AND THE HOUSE.

	VENTILATION CONDITIONS	WIND SPEED M/S	WIND DIR. DEG	STACK °K^0.5	UNDER FLOOR VENT. M^3/H	SUSPENDED FLOOR VENT. AC/H	TOTAL HOUSE VENT. AC/H	R
SEVEN VENTS UNSEALED	NATURAL	2.88	191	2.19	95	0.11	0.19	0.600
	PRESSURISED	2.83	191	2.25	112	0.43	1.08	0.370
	NATURAL	1.86	175	3.44	264	0.42	0.56	0.750
	DEPRESSURISED	1.61	182	2.72	263	1.82	3.50	0.520
	NATURAL	2.46	322	1.60	200	0.50	0.76	0.650
	BALANCED MECHANICAL	2.57	317	2.60	306	0.86	1.76	0.490
SEVEN VENTS SEALED	NATURAL	1.90	172	0.77	41	0.027	0.15	0.180
	PRESSURISED	2.50	170	2.00	22	0.027	0.99	0.027
	DEPRESSURISED	1.00	167	4.00	136	0.57	3.80	0.150

TABLE 2
TEST RESULTS

WEATHER PARAMETER VARIED	WIND SPEED M/S	WIND DIR. DEG	STACK °K^0.5	HOUSE VENT. AC/H	UNDER FLOOR VENT. AC/H
STACK	1.76	296	3.3	0.27	4.00
	1.46	279	1.8	0.18	2.10
WIND SPEED	3.69	324	3.3	0.45	5.68
	1.76	296	3.3	0.27	4.00

TABLE 3.
EFFECT OF STACK AND WIND SPEED ON VENTILATION RATE.

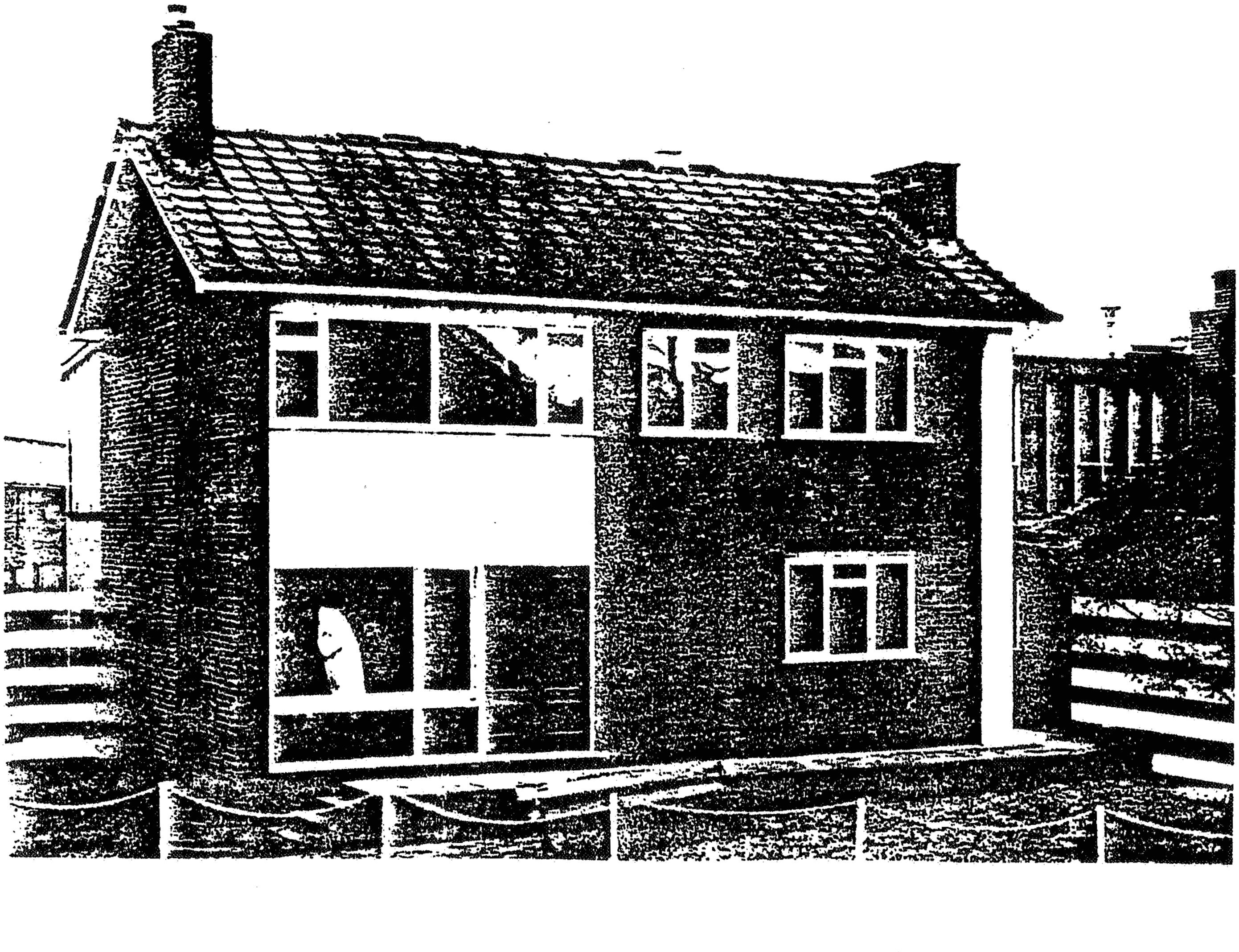


Fig. 1. VIEW OF THE TEST HOUSE SHOWING WEST FACE

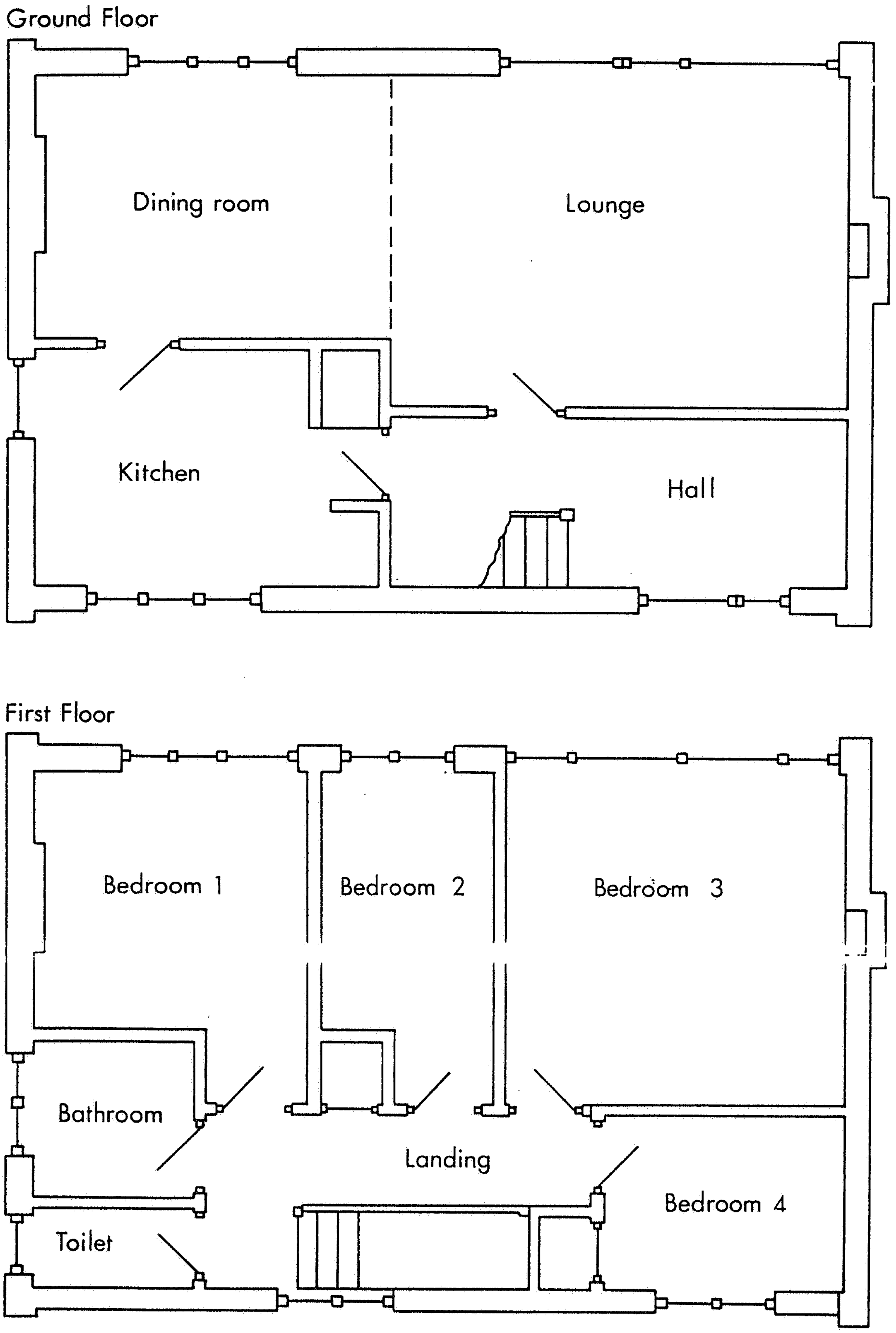
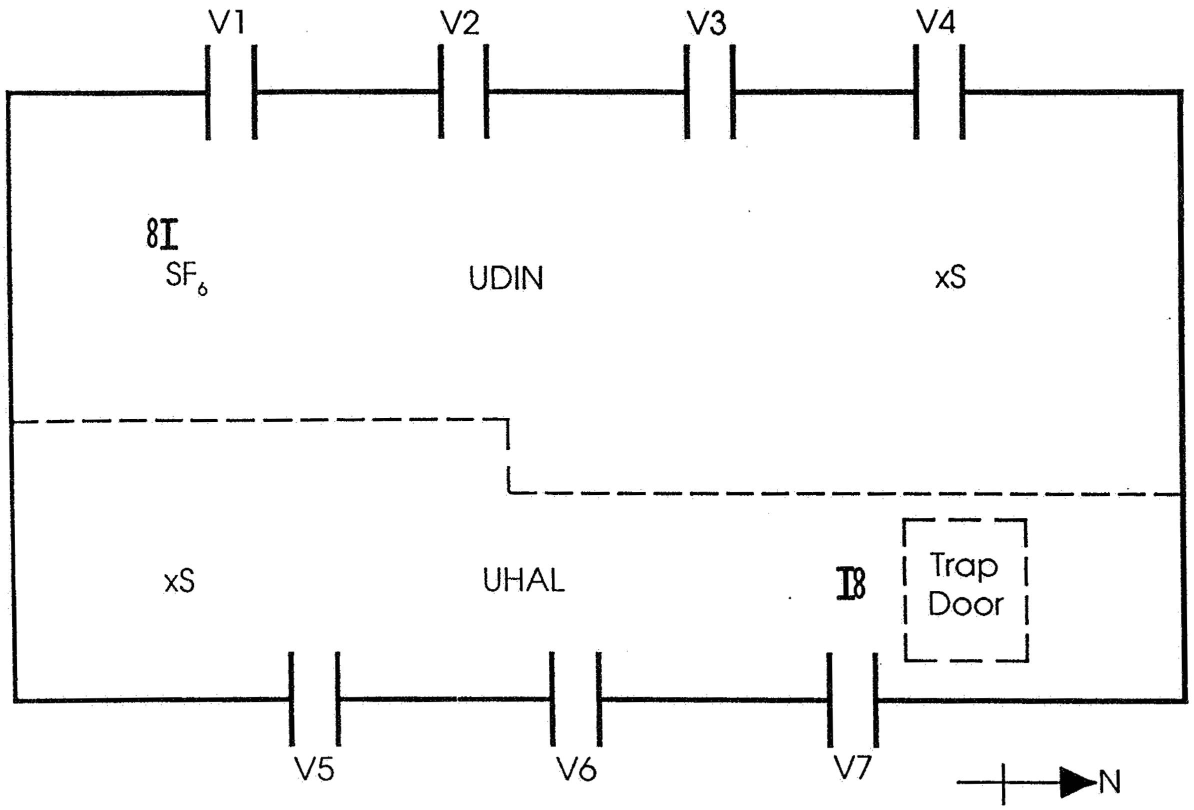


FIG 2 PLAN OF THE TEST HOUSE



V - 0.15m vent

I - Injection point

8 - Mixing fan

xS - Sample point

UDIN - Space under dining room and lounge

UHAL - Space under hall and kitchen

Fig.3. THE UNDERFLOOR SPACE

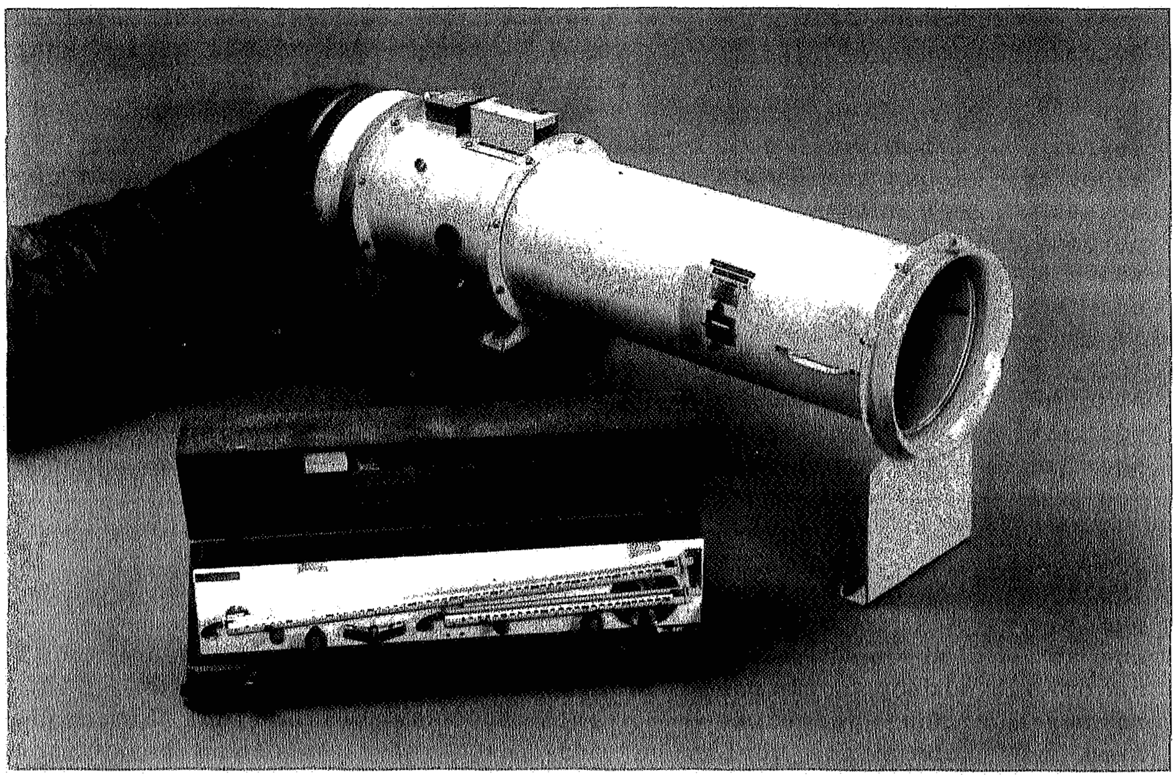


Fig. 4. THE LEAKAGE TEST EQUIPMENT

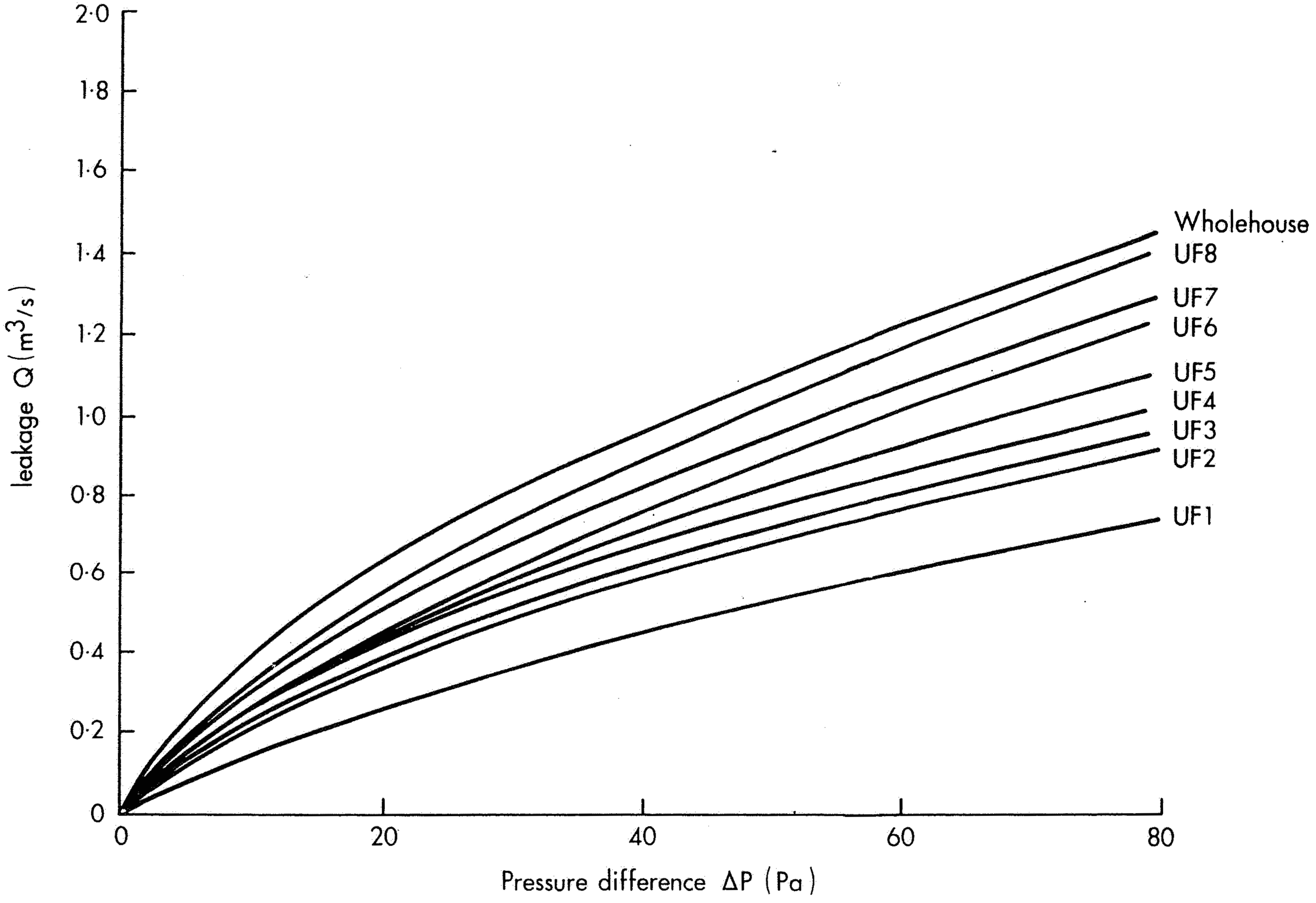


FIG 5 LEAKAGE MEASUREMENTS FOR THE UNDERFLOOR SPACE AND THE HOUSE

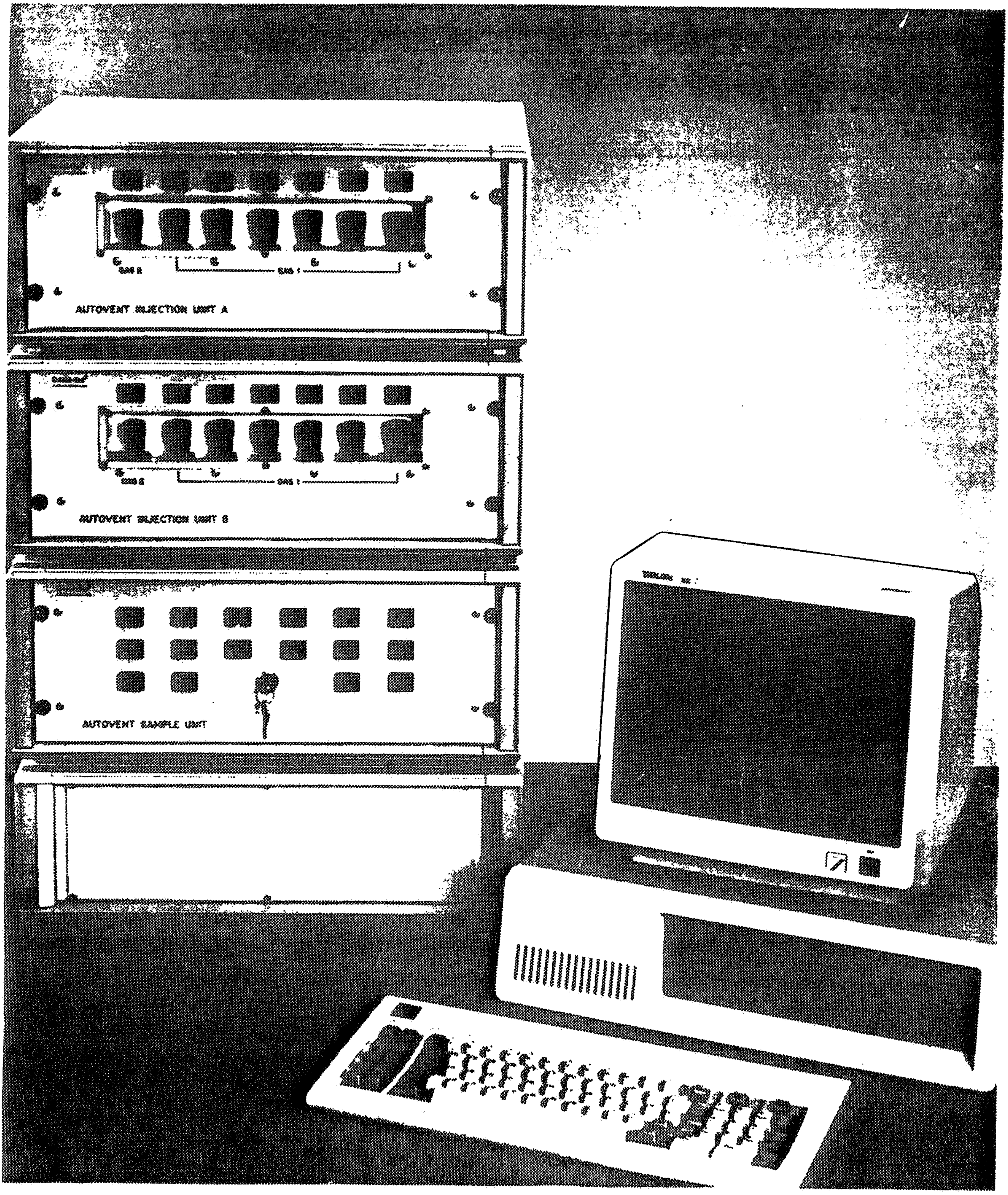
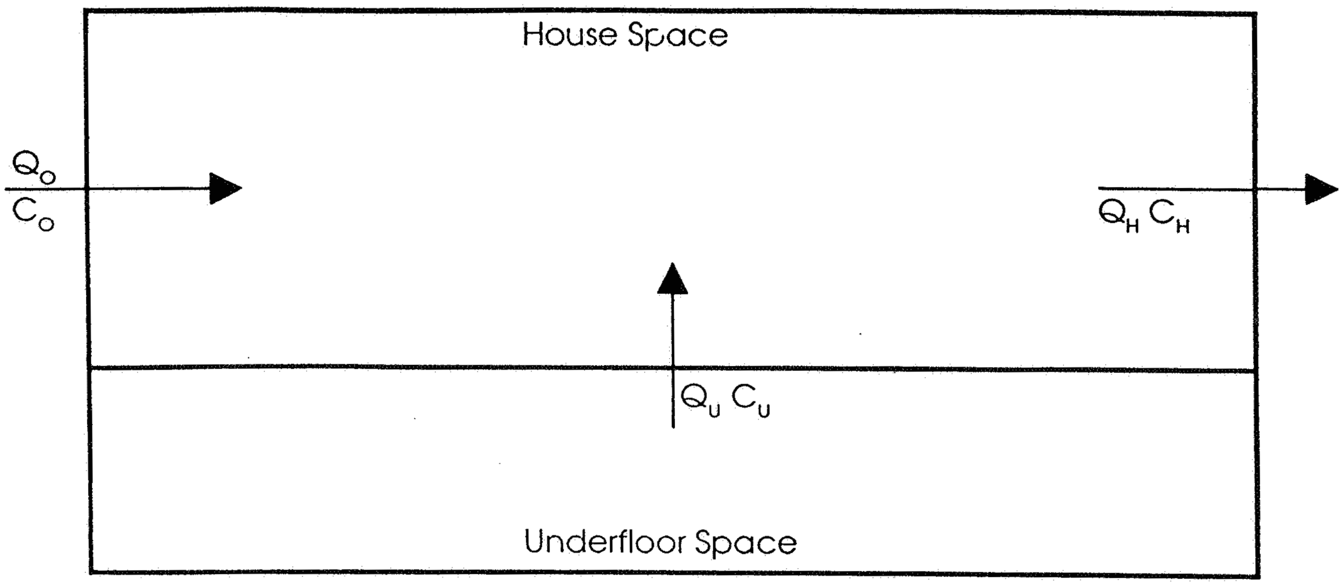


Fig. 6. THE BRITISH GAS AUTOVENT



C denotes SF_6 concentration
Q denotes air flow rate
U denotes underfloor
H denotes house
O denotes outside

The air flow rate within the house is made up of two components, air infiltrating from the underfloor space and from outside

$$Q_H = Q_O + Q_U$$

Also at equilibrium

$$Q_H C_H = Q_O C_O + Q_U C_U$$

But outside air does not contain SF_6 ie $C_O = 0$

$$\text{and } Q_H C_H = Q_U C_U$$

$$\text{or } R = \frac{Q_U}{Q_H} = \frac{C_H}{C_U}$$

Fig.7. DERIVATION OF R