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METHODS OF MEASURING VENTIL LEAKAGE OF HOUSES

No charge. Other reports to follow in due course when they are published externally.

by

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With Compliments

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SUMMARY

Two methods have been used at ECR
houses. The decay method permits s
very simply. The equilibrium conc
tubes for tracer gas distribution and
measurement. Both nitrous oxide an
tracer gases. Calibration procedures for the gas analysers and flowmeters are described.

A pressurisation test is used for measuring house leakage, with a fan installed in an outside door. The calibration procedures are given for flow measurement and assessment of effective leakage area. The use of a smoke puffer to locate leaks is also discussed.

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1. INTRODUCTION

Ventilation is the process of replacing air already in the house by fresh air from outside. In practice, the process is one of dilution since at least partial mixing of the incoming fresh air with the air already in the house takes place before this air is removed.

Methods used at ECRC for measuring the ventilation rate in houses are described.

The driving forces of ventilation are not discussed, only the ways in which the rate can be measured.

Under any given weather conditions, the ventilation rate will depend on how leaky the house is and also on where the leaks are situated. A technique is described for measuring and locating house leakage.

2. MEASUREMENT OF VENTILATION RATE USING TRACER GASES

Since ventilation is simply the process of contaminant removal by dilution, the change in concentration with time of a contaminant or tracer gas can be used to measure the ventilation rate.

The tracer gas would ideally have the same density as air, be readily obtainable, harmless and easily analysed. The choice of tracer gas has been discussed by Hitchin & Wilson (1). Carbon dioxide and nitrous oxide have been used at ECRC. Both are 50% more dense than air but, at the concentrations used, stratification does not appear to be a problem.

Carbon dioxide is harmless up to concentrations of at least 0.5% and relatively cheap equipment is available for measuring the concentration. The main disadvantage is that it is already present in the atmosphere at a slightly variable concentration around 0.03% and also the presence of people exhaling CO_2 disturbs the measurement and precludes occupation of the house during tests.

Nitrous oxide is more convenient because there is no background concentration in the atmosphere. Therefore much lower concentrations can be used and it is permissible to enter the house during tests. However, the infra-red analysers required to measure nitrous oxide gas concentration are fairly expensive.

are

the decay method and the equilibrium

2.1 The decay method

The tracer gas is first and distributed the at a which the analyser readily detect. The rate change of is then measured.

rate (

of V then the in tracer concentration in time interval dt is

the air ge rate, in house per unit time

dc

the air rate is equal to

The gas concentration must be uniform throughout the

In the ECRC test houses it was convenient to have the tracer gas supply tubing permanently installed. The gas supply cylinder is in an instrument space adjacent to the house and six 6mm bore PVC supply tubes pass from there into six main rooms. The tubes connect through individual taps to a manifold so that selective introduction of tracer gas is possible. All six tubes are the same length so that the individual pressure drops and therefore flows are equal. In the house, the free ends of the tubes terminate at the mixing fans. Gas flow is measured by a rotameter between the gas cylinder regulator and the manifold.

A satisfactory alternative method of gas distribution is by a long flexible tube attached through a needle valve and a flowmeter to a gas cylinder in the hall. By systematically walking round the house with the end of the tube and timing the gas input to each room proportional to its volume, a uniform gas concentration can be achieved throughout the house. An advantage of this system is the ease with which the gas cylinder and supply tubing can be completely removed from the house thus reducing the risk of accidental leakage of gas into the house during measurements.

The initial gas concentration aimed for is typically 0.1% CO_2 or between 100 ppm and 200 ppm of N_2O. With internal doors open and mixing fans running, a uniform concentration of tracer gas is attained throughout the house in 10 to 15 minutes. This is checked by individual room sampling.

For sampling six PVC tubes are used with inlets 1 metre above the floor in the centre of the main rooms (i.e. lounge, kitchen/diner, mid-stairs/hall, large front bedroom, back bedroom, landing). All these sampling tubes are the same length to ensure equal sampling rates at all points using one pump. The six sampling tubes lead into a mixing box, each through a tap to permit individual room sampling. A single tube leads from the mixing box to the gas analyser. The CO_2 analyser uses 6mm bore sampling tubes and a sampling rate of 100 cc/minute. The MIRAN N_2O analyser requires 12mm bore sampling tubes to enable the required sampling flow rate of 20 litres/minute to be achieved. A particulate filter, required by the MIRAN analyser, is situated in the mixing box.

The output from the gas analyser goes to an X-t recorder. The CO_2 analyser has a current output which is taken through a microammeter which converts it to a voltage signal and also permits zero suppression. The tracer gas concentration is recorded for 0.5 to 3 hours, depending on the ventilation rate. Wind speed and direction, inside and outside temperatures are also recorded.

Typical CO_2 and N_2O decay curves are shown in Figures 2 and 3. The air change rate is obtained by replotting the decay curve on log-lin paper and measuring the slope or by direct calculation of the slope of log (concentration) versus time.

When using CO_2, correction for the ambient concentration must be done before plotting the results.

2.2 The equilibrium concentration method

If tracer gas continuously flows into the house at a constant known rate, and mixes uniformly with the air in the house, the rate of loss of tracer gas in the ventilating air will eventually equal the rate of supply of tracer gas. A steady equilibrium tracer gas concentration will then be obtained.

Let q = rate of supply of tracer gas

v = ventilating air flow

c = equilibrium concentration of tracer gas

When the rates of supply and removal of tracer gas are equal:

$$q = (v + q)\,c$$

$$\therefore\ v = \frac{q - qc}{c} = q\left(\frac{1}{c} - 1\right) \approx \frac{q}{c}$$

If CO_2 is used as the tracer gas and is also present in ambient air at concentration c_a:

$$q + vc_a = (v + q)\,c$$

$$\therefore\ v = \frac{q - qc}{c - c_a} = q\left(\frac{1 - c}{c - c_a}\right) \approx \frac{q}{c - c_a}$$

The advantage of this method is that the ventilation rate can be continuously monitored. The main disadvantage is that the accuracy of the measurement depends on the absolute accuracy of the gas analyser and gas flow meter, whereas a constant percentage error in the gas analyser calibration does not matter when using the decay method.

2.2.1 Procedure

The gas supply and sampling arrangement is similar to that described for the decay method except that provision is made for maintaining and measuring a constant low flow rate of tracer gas into the house. The flow rate used in the ECRC test houses is 50 cc/minute of N_20 measured on a rotameter with a 'Flostat' to control the flow rate. The flow is monitored by the pressure drop across a constriction in the supply line measured by an electronic micro-manometer, the output being recorded on one channel of the X-t recorder used to record the gas concentration.

Since the time to reach equilibrium at the operating flow rate will be several hours, it is preferable to begin by charging the house with tracer gas as for the decay method to approximately the expected equilibrium concentration.

2.3 Gas analyser calibration

Most gas analysers require to be checked at 'zero' and at least one other known gas concentration. Some analysers claim to require only a zero check.

2.3.1 Carbon dioxide analyser

The Hampden Gas-0-Mat $C0_2$ analyser is comparatively inexpensive and has been used successfully at ECRC for decay and continuous measurements of ventilation rate. It has been found that a daily zero check and calibration is necessary, more frequently if the ambient temperature is varying.

'Carbosorb' in a glass U-tube is used to obtain air free of $C0_2$ for setting the zero. Commercially obtained cylinders of standard $C0_2$ in air mixtures are used to set the calibration span.

Measurement of the $C0_2$ concentration in ambient air is necessary at the beginning and end of each run, and gives an additional check that the calibration is approximately correct. Ambient air contains about 0.03% $C0_2$.

2.3.2 Infra-red gas analysers for N_20

Two models have been used. The MIRAN 1 is an all-purpose instrument which requires selection of wavelength and slit width, and then must be calibrated at those settings. The MIRAN 103 is much simpler to use since the 'factory calibrated' slit and scale appropriate to the gas in use are simply inserted in the instrument. It is claimed that standard gas mixtures are not required for the MIRAN 103. However, our tests showed inconsistencies in calibration and subsequent investigation showed that the meter scale on our instrument was wrong.

Figure 4 shows the method used to calibrate the MIRAN analysers. The inlet and outlet of the analyser are short-circuited giving a closed loop into which known volumes of gas are injected. The MIRAN 103 has an internal pump which can be used to circulate the gas in the loop; an external pump is necessary with the MIRAN 1.

Using a microlitre gas syringe, N_20 is injected 50 μ 1 at a time into the gas loop through a rubber septum. A calibration trace as in Figure 5 is obtained. Blockage of the syringe needle is indicated by discontinuities in the step size on the recorder trace. When this happens the loop must be flushed with N_20 free air and calibration repeated.

Calibration setting of these analysers has proved to be very stable and so a monthly calibration check is sufficient. The zero setting is also very stable but since it can be checked very quickly it is checked daily.

2.4 Flowmeter calibration

The equilibrium concentration method requires an absolute measurement of the tracer gas flow into the house. The flow is measured by a rotameter with 10-150 cc/minute air scale. For a given rotameter it is expected that $Q \sqrt{\rho}$ is constant where Q is the flow rate and ρ the gas density (2). Thus when using nitrous oxide the true flow should be 0.8 times the reading on the air scale. This was not confirmed by calibration.

Calibration of the rotameter was checked using the travelling soap film device shown in Figure 6. A vertical graduated tube of volume 500 ml is connected to the outlet of the rotameter. By squeezing a small rubber bulb containing soap solution at the base of the tube, a soap film is formed which is driven up the tube by the gas flow. The speed at which the soap film travels is measured by stop-watch.

The flow rate for N_2O was found to be 1.12 times the reading on the air scale. A calibration check with air gave the true flow as 1.04 times the indicated value. The anomalous behaviour with N_2O is not explained.

3. HOUSE LEAKAGE MEASUREMENT

Ventilation takes place through intentional and fortuitous gaps in the house envelope. The actual ventilation rate at any time depends both on the leakiness of the house and on the weather.

The house leakage can be evaluated by finding the pressure required to cause air to flow out through all the leaks at a measured rate.

The house is pressurised by a fan fitted to a substitute external door. The air flow Q through the fan is measured. At equilibrium the air flow into the house through the fan equals the total air leakage out of the house. If the pressure difference between inside and outside the house is Δp then (3)

$$Q = K A \quad \Delta p^m$$

where A is the effective leakage area

K and m are constants.

The value of m is given in the literature as 0.5 for a sharp-edge orifice and 0.63 for window cracks.

3.1 Procedure

The apparatus is shown in Figure 7. A centrifugal fan set into an adjustable plastic panel is fitted into the door recess. The remainder of the opening is blocked off by a sheet of 25 mm thick ICI 'Purlboard' or similar material. Obvious gaps are closed with adhesive tape.

The fan has a gauze screen across the outlet to achieve a sufficiently uniform air distribution for the flow to be reliably obtained from a single measurement of air speed using a vane anemometer. Calibration of the flow was carried out at indicated air speeds of 3 m/s and 6 m/s by traversing a pitot-static tube across the end of the duct at the intervals shown in Figure 8. The air speed was recorded against distance on an X-Y recorder and thence the average speed in each of the 24 equal rectangles could be found. When the vane anemometer read an air speed of 3 m/s the flow rate was 765 m^3/h i.e. 255 x air speed. The corresponding figures at 6 m/s were 1575 m^3/h and 263 x air speed. The mean value gives

$$\text{Flow } (m^3/h) = 259 \times \text{Vane anemometer reading } (m/s)$$

The output from the vane anemometer is connected to one channel of an X-Y recorder.

The pressure difference between inside and outside is measured by an electronic micromanometer, the output of which is connected to the other channel of the X-Y recorder.

A motorised thyristor controller is used to slowly increase and decrease the fan speed so that flow versus pressure difference is plotted directly on the X-Y recorder. The fan speed is increased from minimum to maximum in 5 minutes; coincidence of the traces for increasing and decreasing fan speed indicates that pressure equilibrium is achieved at each flow rate. This can also be checked by holding the fan speed steady at any intermediate value.

In low wind conditions, very reproducible smooth traces are obtained as in Figure 9.

3.2 Interpretation

The results of 40 measurements in 26 houses gave values of m between 0.61 and 0.75 as shown in Table 1. The mean value is m = 0.66.

The proportionality constant K was found by using calibrated leaks. First the house leakage was reduced as much as possible by closing and sealing all the internal doors except that of the W. C. The fan was installed in the front doorway. So that the leakage could be increased by known amounts, the W. C. window was replaced by a panel with an 8 x 50 cm hole in it. Figure 10 shows the flow versus pressure curves for the three conditions:

(1) Background leakage only (= A m^2)
(2) Background + 8 x 25 cm hole (= A + 0.02 m^2)
(3) Background + 8 x 50 cm hole (= A + 0.04 m^2)

These curves satisfy respectively:

(1) $V = 0.245 \quad \Delta p^{0.697} \approx 0.278 \quad \Delta p^{0.66}$

(2) $V = 0.490 \quad \Delta p^{0.624} \approx 0.434 \quad \Delta p^{0.66}$

(3) $V = 0.740 \quad \Delta p^{0.596} \approx 0.596 \quad \Delta p^{0.66}$

Hence (1a) $0.278 = K A$

(2a) $0.434 = K (A + 0.02)$

(3a) $0.596 = K (A + 0.04)$

From (1a) and (2a) $K = 7.8$

(1a) and (3a) $K = 7.95$

(2a) and (3a) $K = 8.1$

giving a mean value of $K = 8$

We now have $V = 8 A \quad \Delta p^{0.66}$ where V is the vane anemometer reading in metre/second. From this family of curves, Figure 11, the effective leakage area can be immediately obtained.

3.3 Leak location

When the house is pressurised the places where the air is escaping can be located by using the smoke puffer, Figure 12. Occasionally the leaks can be seen more easily when the pressure inside is reduced, by reversing the fan.

Alternatively, selected leakage paths can be sealed with adhesive tape and their contribution to the house leakage found by difference.

4. REFERENCES

(1) Hitchin, E. R. & Wilson, C. B. A Review of Experimental Techniques for the Investigation of Natural Ventilation in Buildings. Building Science, 2, 59-82, Pergamon (1967).

(2) Ower, E. & Pankhurst, R. C. The Measurement of Air Flow. Pergamon (1977), p. 296.

(3) IHVE Guide, Section A4: Air Infiltration (1976)

Table 1 : Values of exponent in pressure dependence for different houses

No. of Houses	House	Type	Value of m for Flow p^m				Mean value of m
1	Test House No.10, ECRC	Semi-detached, modern	0.629	0.631	0.623		0.628
1	Test House No.10, part	Semi-detached, modern rooms sealed off	0.703 0.677 0.747	0.712 0.633 0.750	0.705 0.715	0.723) 0.642)	0.700
1	Test House No.16, ECRC	Semi-detached, modern frame wall	0.677	0.680	0.666	-	0.674
1	Test House No.18, ECRC	Solid wall, semi-det.	0.660	0.644			0.652
9	Detached, Kemnay	Well insulated, wooden	0.689 0.712 0.643	0.695 0.643	0.711 0.667	0.721) 0.743)	0.692
2	End terrace, Kemnay	Well insulated, wooden	0.671	0.707			0.689
6	Bebington Solar Houses	With solar wall	0.662 0.666	0.645 0.626	0.677	0.629))	0.651
5	Bebington Traditional	As above without solar wall	0.612 0.584	0.617 0.597	0.674		0.617
			OVERALL MEAN				0.663

FIGURES

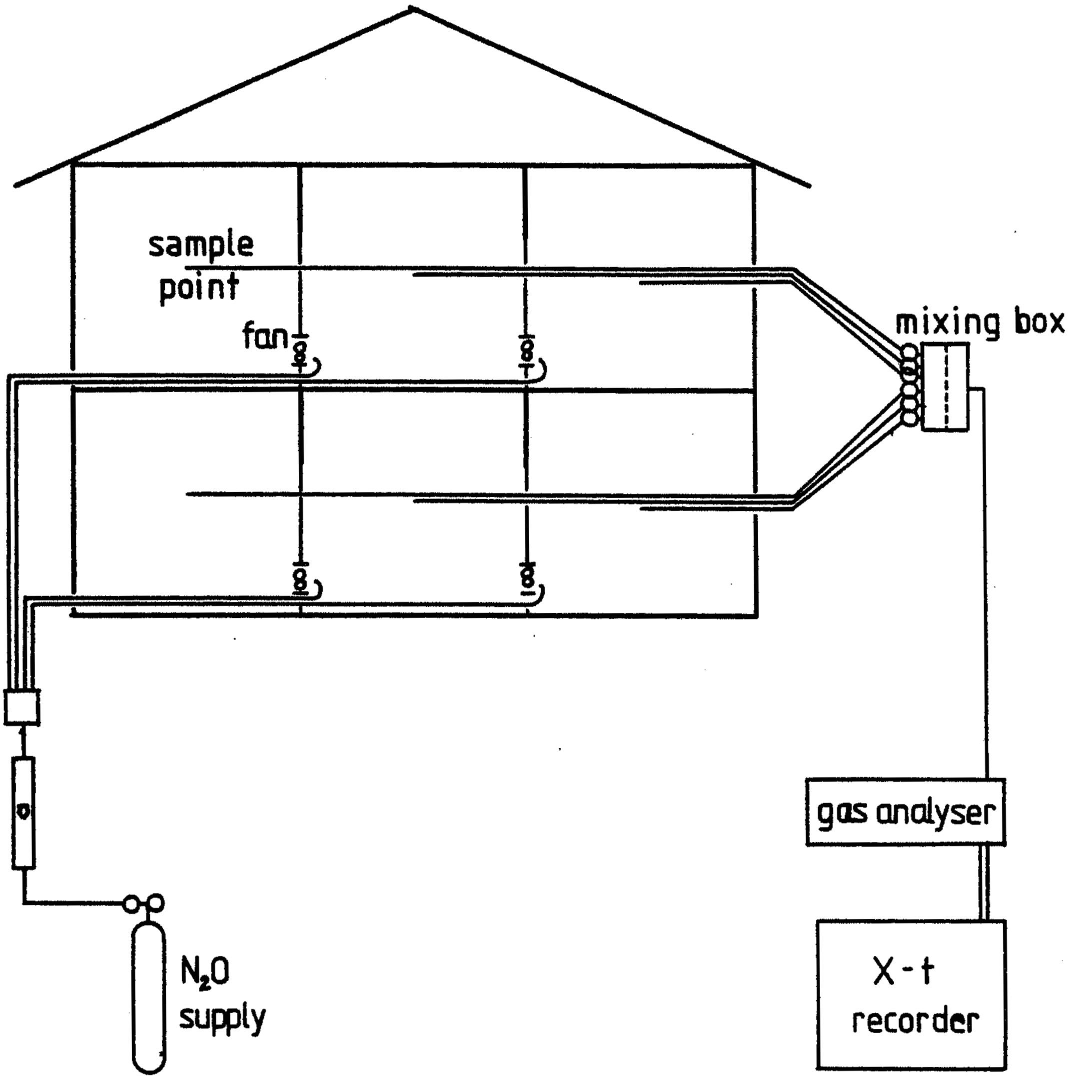


Figure 1.   Apparatus for measuring the ventilation rate

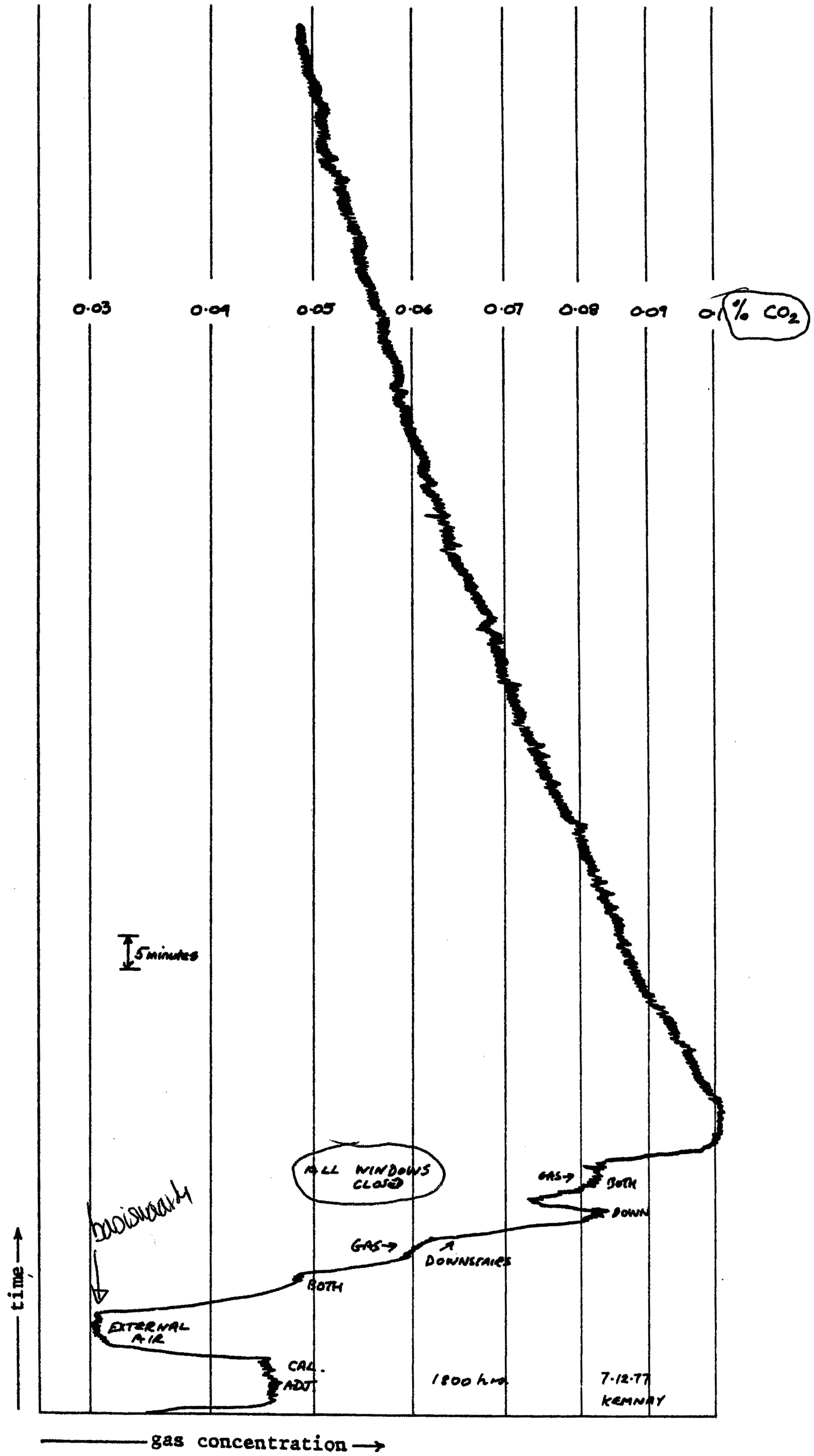


Figure 2. CO_2 decay trace

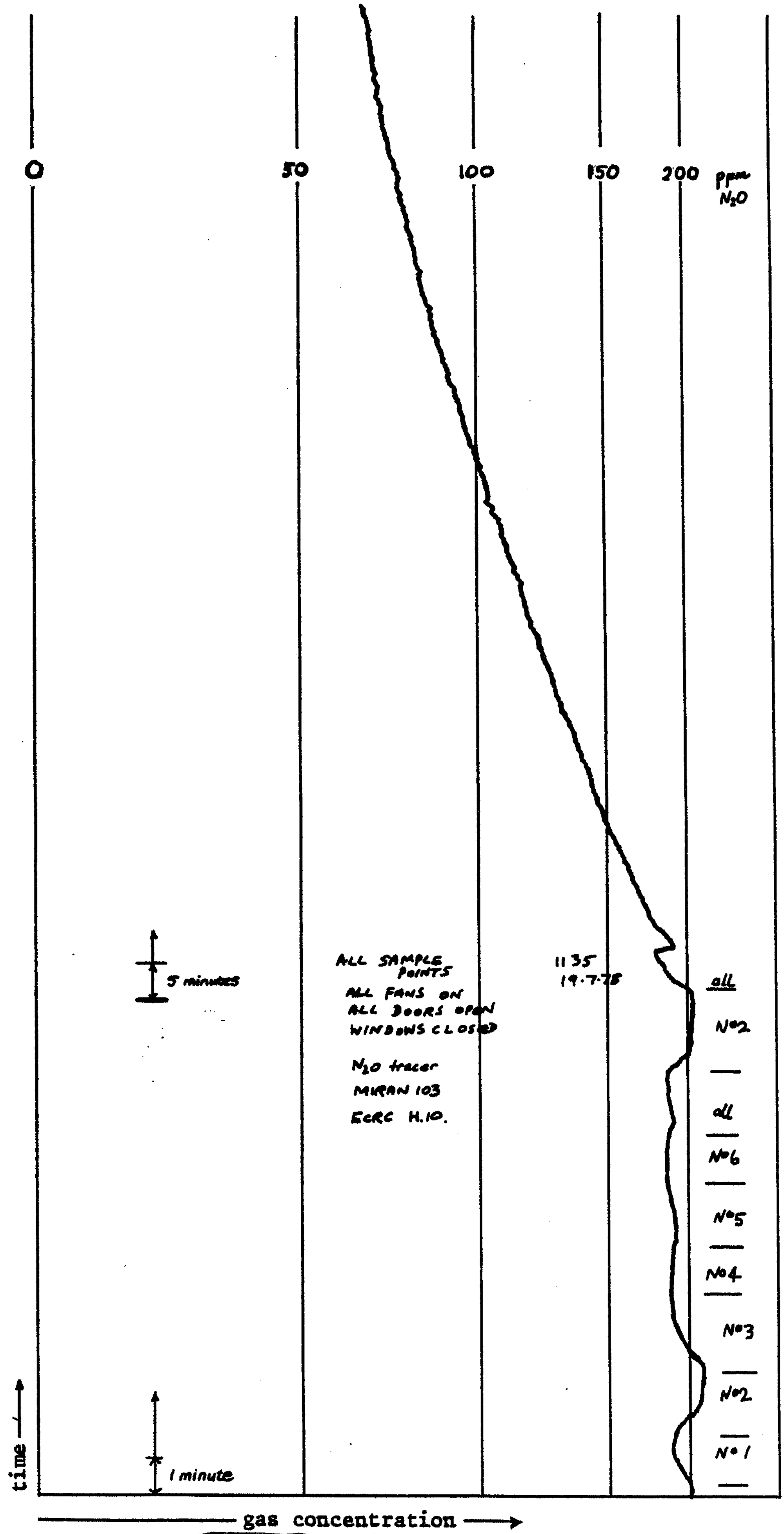


Figure 3. N_2O decay trace

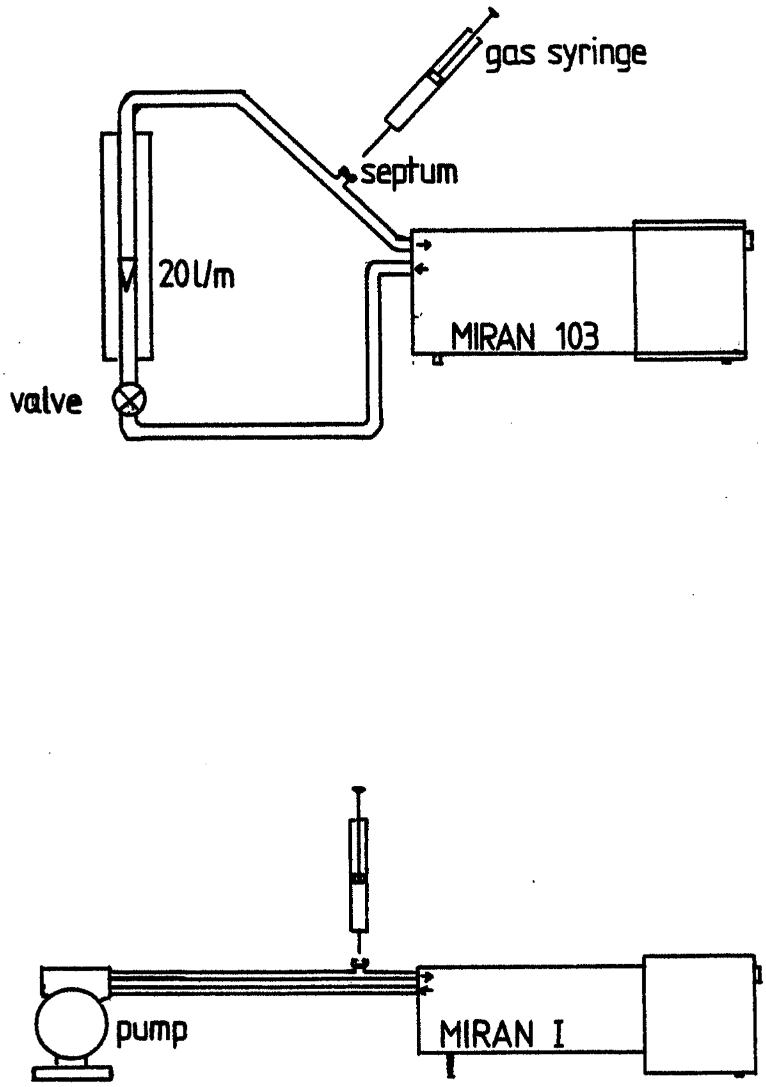


Figure 4. Calibration of gas analysers

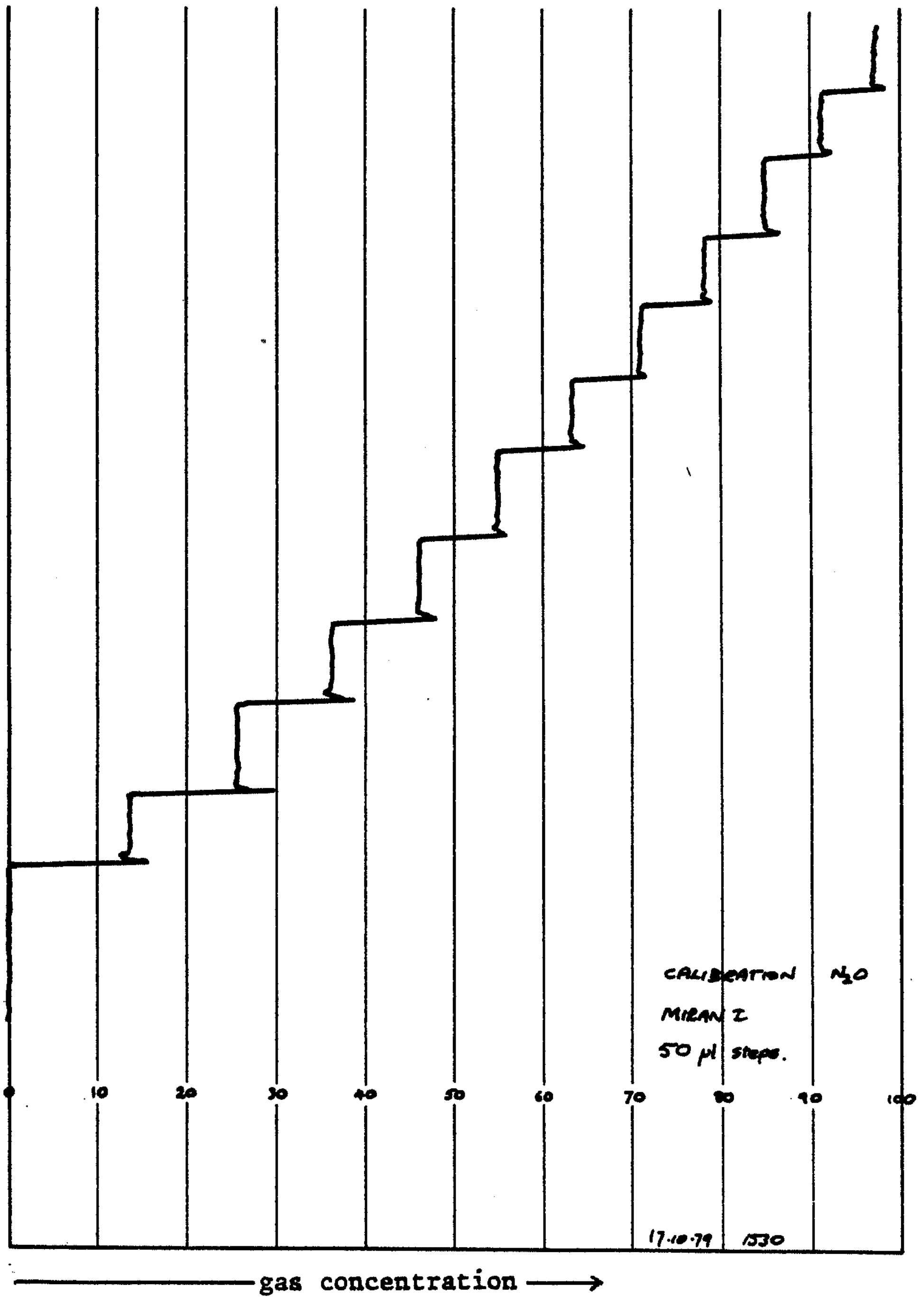


Figure 5. Calibration trace for gas analyser

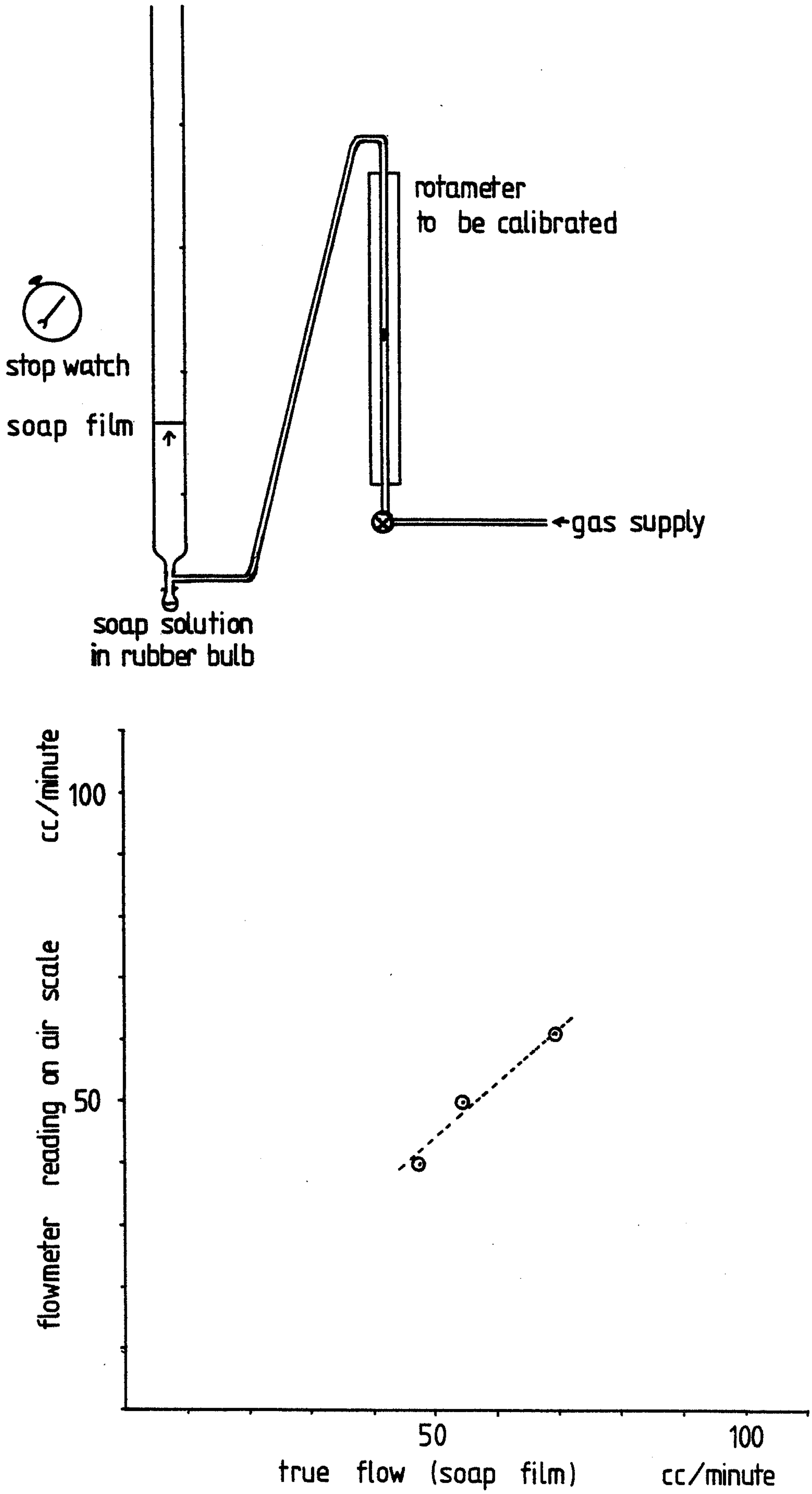
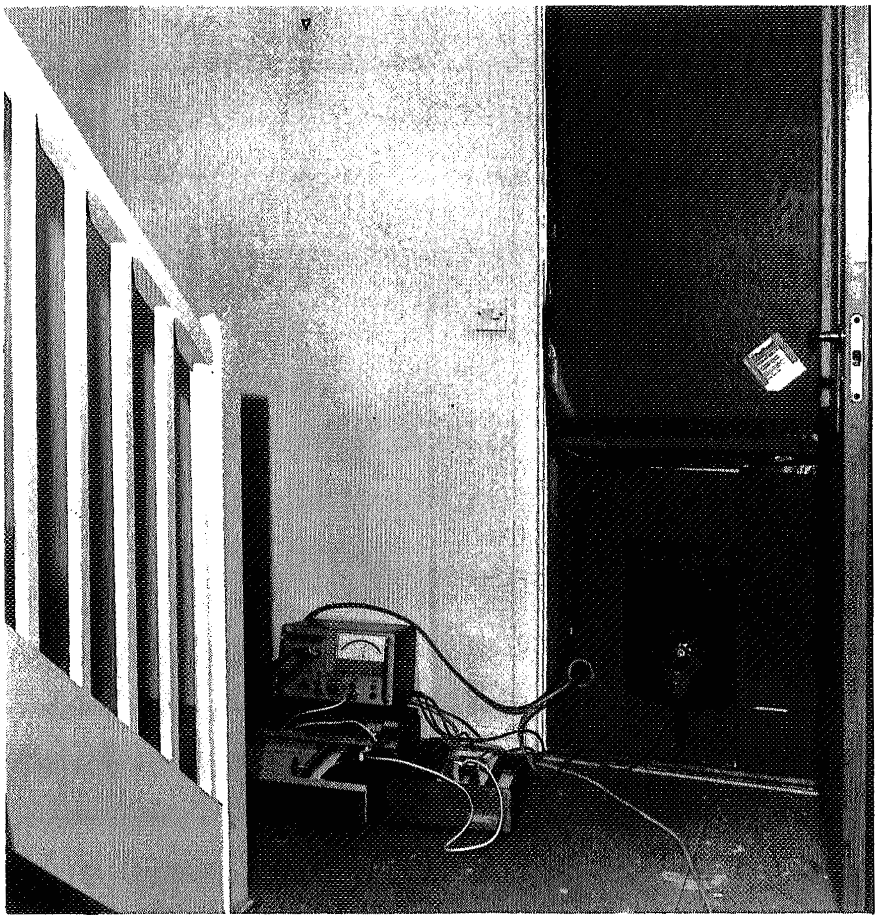
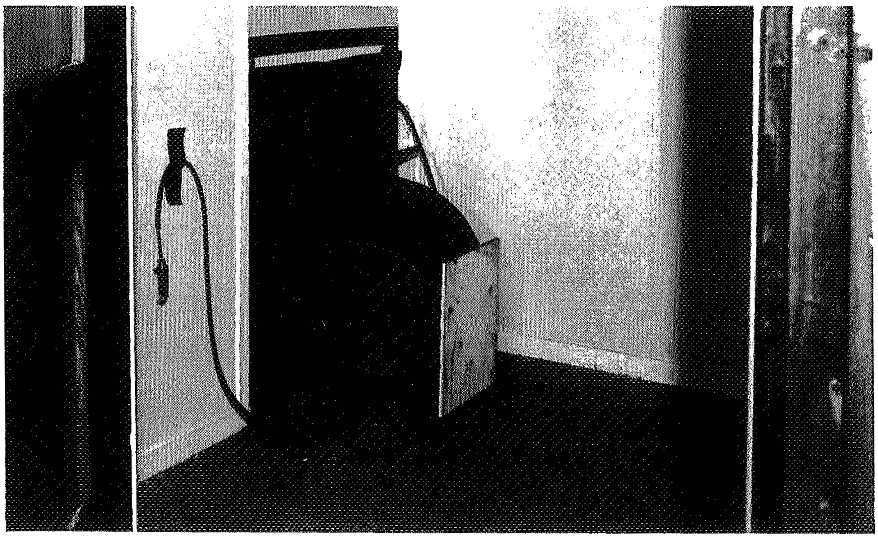


Figure 6. Rotameter calibration



Pressurisation panel viewed from inside



Fan unit viewed from outside

Figure 7. House leakage apparatus

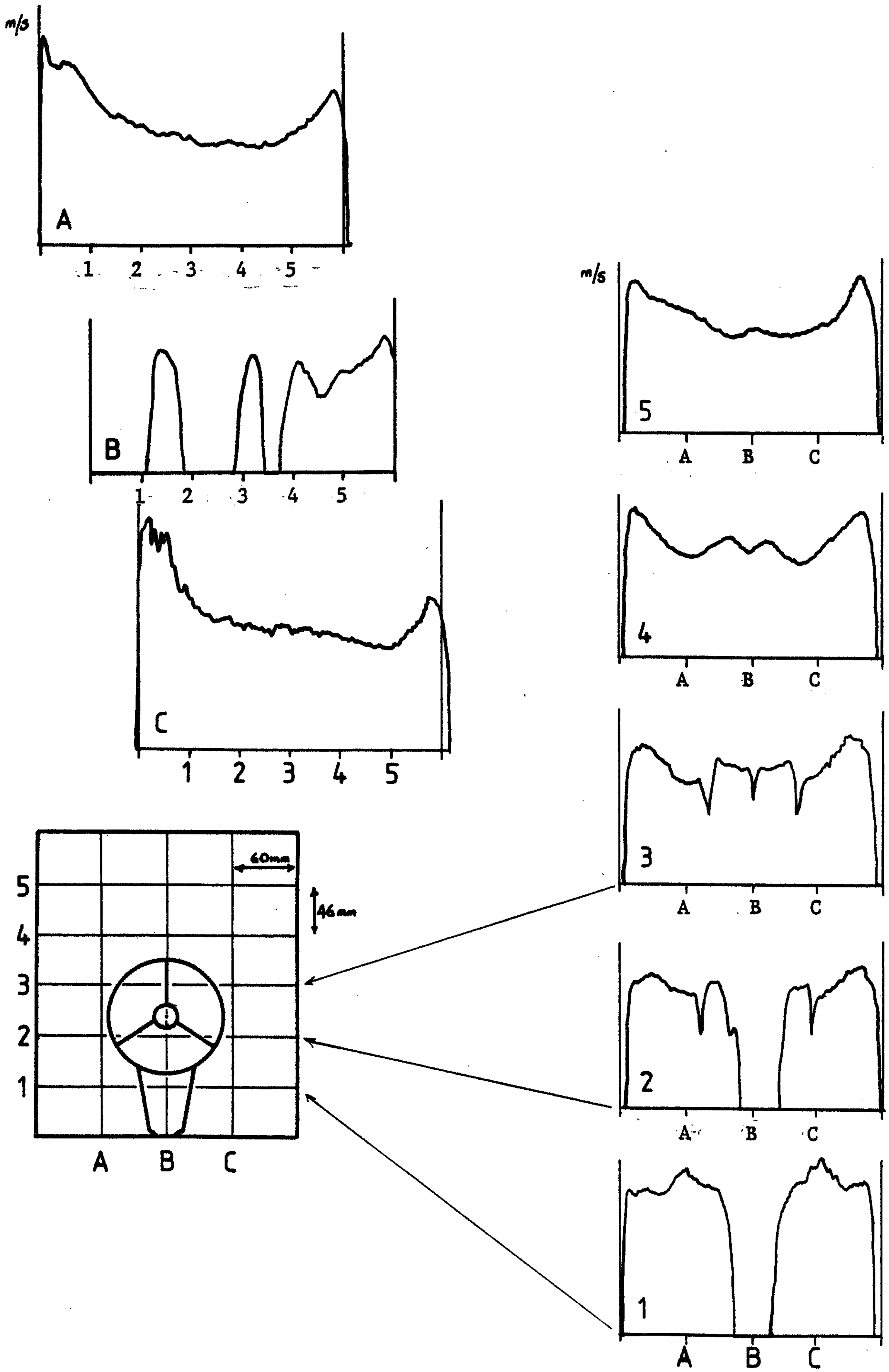


Figure 8. Flow calibration of house leakage apparatus

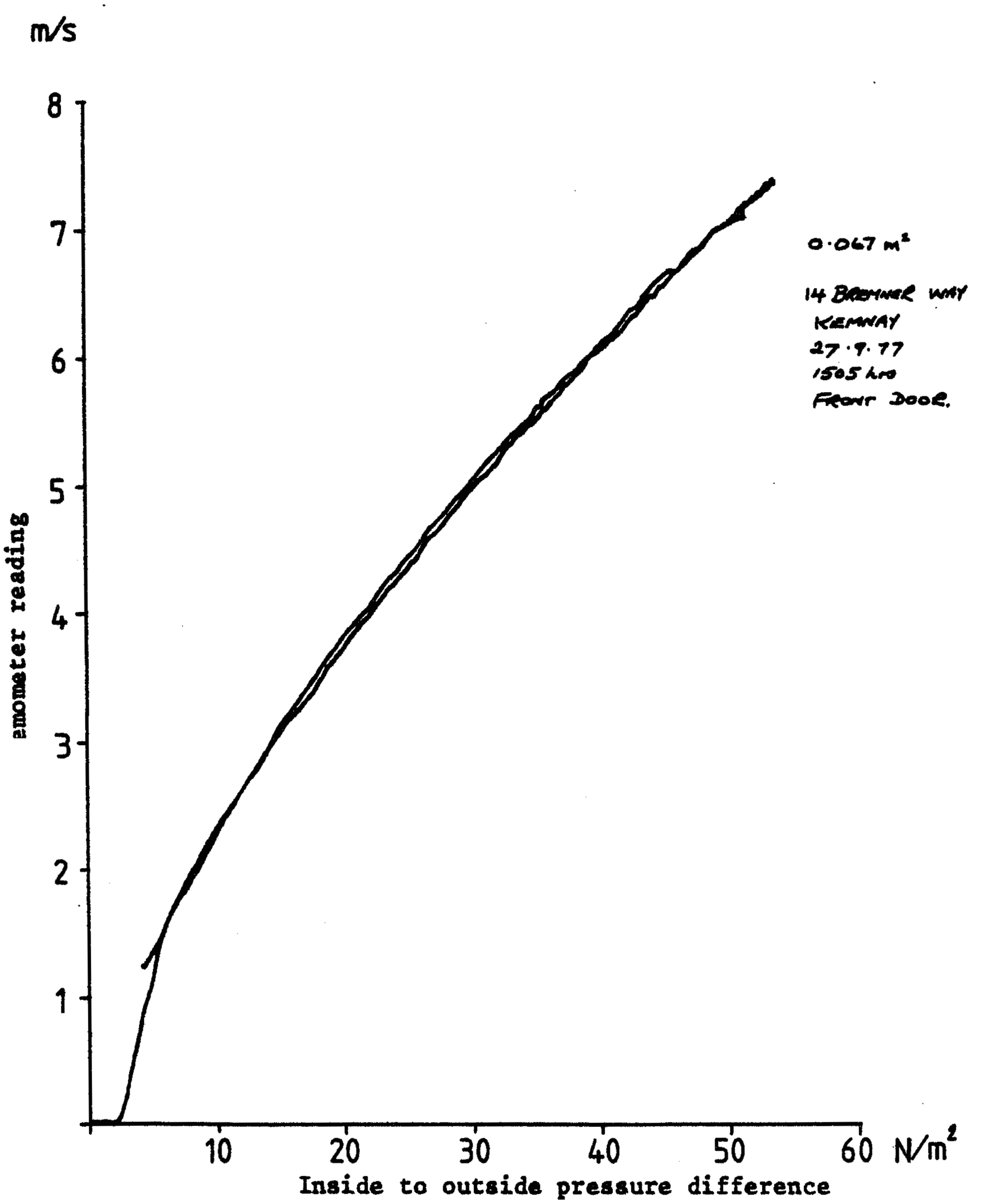


Figure 9. House leakage curve

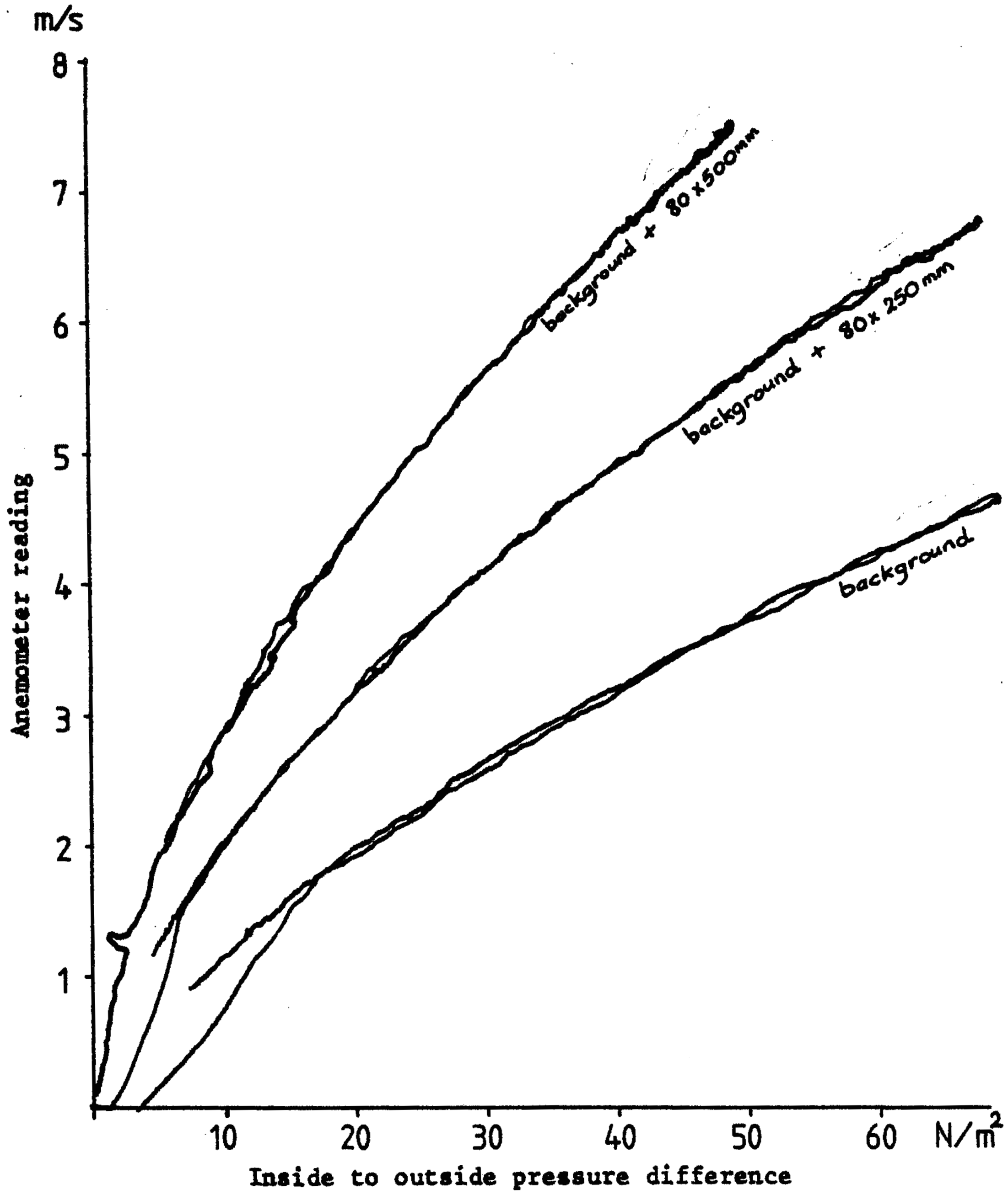


Figure 10. Flow versus pressure for calibrated leaks

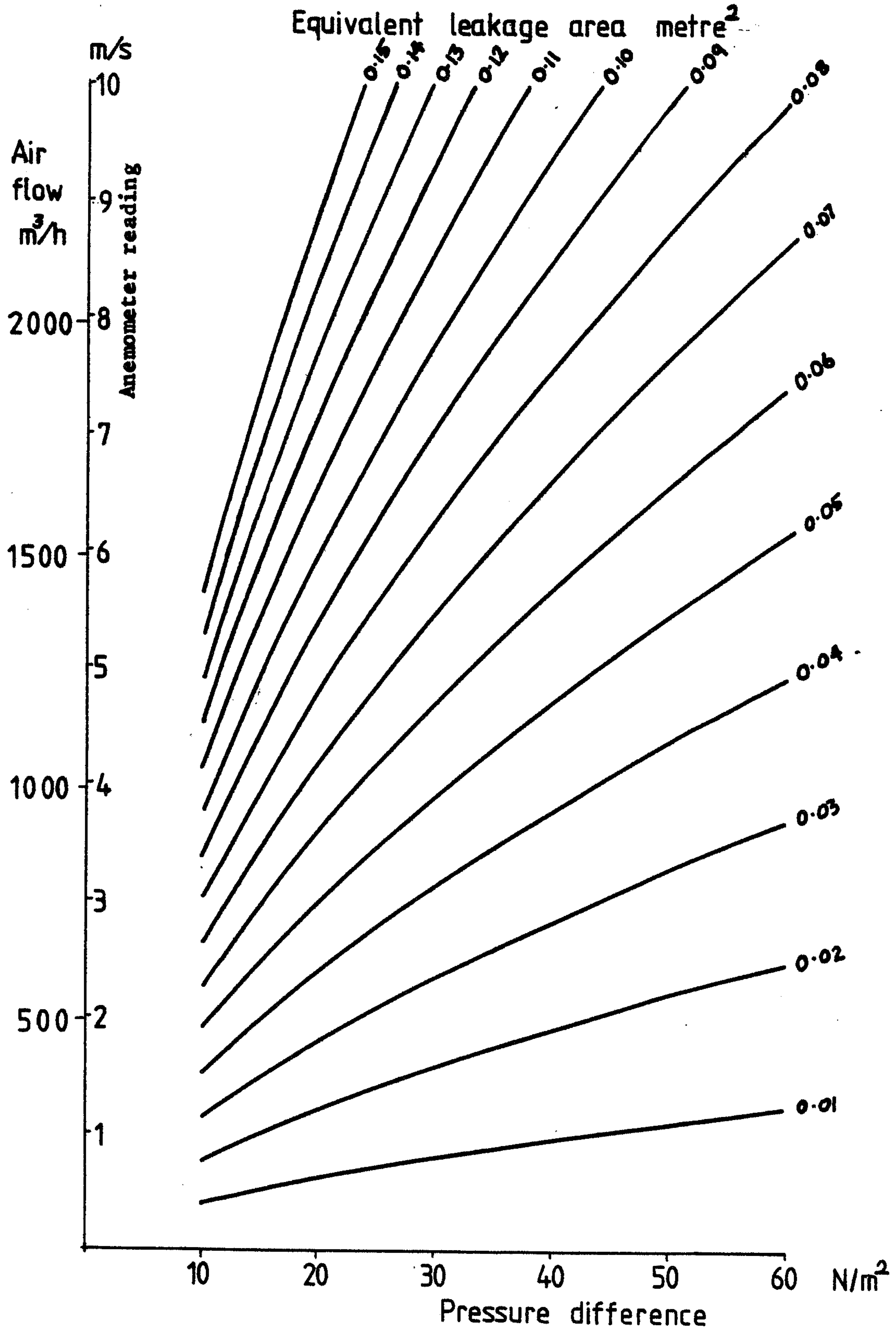


Figure 11. Family of leakage curves

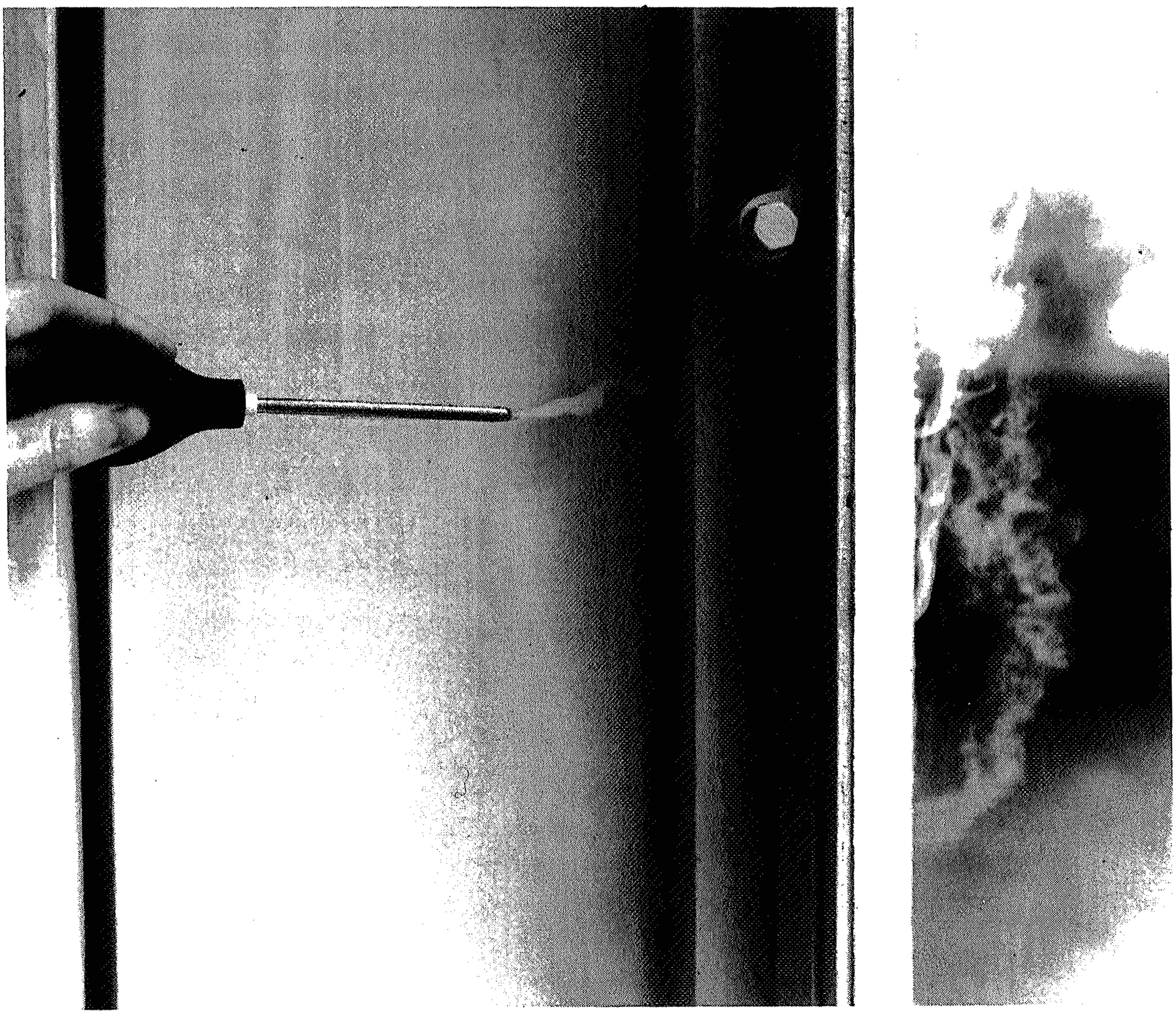


Figure 12.   Smoke puffer