VENTILATION AND THE DRAUGHT-PROOFING OF WINDOWS IN OLD BLOCKS OF FLATS.

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At the Department of Building Science, the Lund Institute of Technology, a research project is in progress entitled "The saving of energy in existing blocks of flats by means of building technology measures". The project is sponsored by the National Swedish Council for Building Research and covers the period from 1975.07-01 to 1977-12.31.

The project concerns blocks of flats built during the period between 1860 and until approx. 1960. Surveys have been concentrated on three different towns in Sweden - Malmö (large city), Eksjö (a town of timber houses) and Gävle (a town in the northern half of Sweden).

A part of the project includes the measurement of ventilation or air change in flats as well as the measurement of the amount of freedom from draughts of windows. The results of these measurements rae presented below. In addition a brief description is given of the draught-proofing of windows.

Measurements of air change - ventilation in flats

The air change of a flat describes the number of times the indoor volume of air is replaced by air from outside per unit of time.

Air change is measured according to the trace gas method. This entails the introduction into the air in the rooms of a certain measurable quantity of a known gas. After the gas has become well-mixed with the volume of air in a room the associated values of the concentration of gas and the time period involved are then measured. The greater the air change, the more rapid is the reduction in the concentration of the gas.

Air change can be calculated according to balance of mass transfer which states that alterations to the volume of trace gas in a room is equal to that volume of gas which is removed in the air that is extracted.

If the concentration of trace gas is c at time t and c-dc at time t+dt, then the following pertains on the assumption that trace gas is not normally present in the air

$$- V \cdot dc = n \cdot V \cdot c \, dt$$

where V = the volume of the room
n = the air change

This results in

$$n \cdot dt = - \frac{dc}{c}$$

Boundary conditions $c = c_o$ where t=0 gives after integration

$$n = \frac{1}{t} \ln \frac{c_o}{c}$$

At points in time t_1 and t_2 measurements are made, and the concentrations of gas are c_1 and c_2 respectively. The above equation then gives

$$n = \frac{1}{t_1} \ln \frac{c_o}{c_1} \quad \text{and} \quad n = \frac{1}{t_2} \ln \frac{c_o}{c_2} \quad \text{respectively.}$$

This can be simplified as

$$n = \frac{\ln \frac{c_1}{c_2}}{t_2 - t_1}$$

A gas analyser of the URAS 7N type was used for the measurements. This measures the concentration of a gas according to the principle of the absorption of infrared radiation by the gas. Plastic hoses are evenly distributed in the flat and these are connected to the inlet valve of the gas analyser. In this way the mean value of the concentration of gas in the flat can be obtained. When measurements were carried out in Malmö the gas analyser was connected to a digital voltmeter which recorded the output signals of the analyser in digital form. For the measurements in Eksjö and Gävle, the analyser was linked to an XY-writer giving a continuous record of the output signals.

Laughing gas (N_2O) was used as the trace gas for measurements. Since the air change has been studied for a number of different cases, the total length of time during which measurements were carried out was considerable. This has resulted in the volume of laughing gas that was released in the flat having a percentage of 0.2 - 0.3 by volume.

The differences between indoor and outdoor temperatures, together with wind speed, are of significance for the amount of ventilation obtained. Air change measurements were therefore carried out during the winter period. In addition, days during which there was no wind were avoided. Wind speed as well as indoor and outdoor temperatures were recorded on all occasions when measurements were carried out.

As has been mentioned previously, air change has been studied in different cases from involuntary ventilation to an assumed case of normal ventilation. This has been obtained by first draught-proofing all vents and outer doors. By this means the amount of the leakage of air through non-draught-proof gaps in walls and windows was obtained. Afterwards the draught-proofing material was removed from the outer doors, as a result of which the amount of involuntary ventilation or infiltration could be obtained. The next stage involved the removal of draught-proofing from all the vents. At this stage the vents in the larders and bathrooms were opened, so that the assumed normal case was obtained. Finally, the effect of the vent above the stove on ventilation was studied. This was opened and in this way a situation corresponding to a normal situation when cooking was obtained.

In reality it is only the studies of involuntary ventilation that have been carried out in the same way for all the flats. The other cases have varied to some extent due to the varying design of the ventilation systems in the different flats.

The measurements of air change that were carried out show that the outer door has very little effect on ventilation, whereas the opening or closing of vents is of importance for ventilation. FIG.1 shows the results for different situations and where natural ventilation prevailed. The figures illustrate the assumed normal case as well as the involuntary ventilation or infiltration. In cases where the vent above the stove was open, this increased ventilation by an average of 0.22 air changes per hour, these values varying between 0.02 and 0.46 air changes per hour.

No general conclusions can be drawn from the figure. The air chagne varies considerably for the different buildings that were studied, and the age of buildings does not appear to have any direct influence on the air change. For all flats, infiltration corresponded to an average of 0.28 air changes per hour and normal ventilation to an average of 0.54 air changes per hour. This is somewhat lower than that accepted generally.

The condition of windows and their ability to prevent draughts are of considerable importance to infiltration. However, it is important to remember that this does not always mean that flats built only more recently have low infiltration. The figure shows that many of the older flats have low infiltration values. For the flats built in 1887, 1922 and 1923 respectively, the low values may possibly be due to the fact that the windows were provided with quite modern draught excluders.

For two of the flats in Malmö the windows were provided with new draught excluders. Measurements were carried out both before and after these draught excluders were put in. More measurements of this sort will be made during the coming Autumn, in order to obtain an idea of the way in which these draught excluders affect ventilation.

In the first flat, which was built in 1894, there were no draught excluders in the windows. Before these were inserted, normal ventilation of 0.70 air changes per hour and infiltration of 0.45 air changes per hour were recorded. After their insertion the corresponding values were 0.31 and 0.1 air changes per hour. In this case, providing the windows with draught excluders reduced ventilation considerably, which is probably due to the flat originally lacking these draught excluders.

In the other flat, built in 1919, the windows were provided with cloth draught excluders, which were old an had been painted over in some places. Before replacement of the draught excluders, normal ventilation of 0.40 air changes per hour and infiltration of 0.15 air changes per hour were recorded. After their renewal the corresponding values of 0.70 and 0.19 air changes per hour were recorded. In this case infiltration was approximately similar both before and after, whereas normal ventilation was higher after the renewal of the old draught excluders. This is somewhat curious, but is probably due to adjustments not being carried out to the casements and the window fasteners. Ensuring that a window is made less draughty does not only entail the replacement of the old draught excluders with new ones, but also the precise adjustment of casements and window fasteners.

Measuring the draught-proofing of windows

Experiments have been carried out with a measuring "tent" in order to measure the draught-proofing of windows. This tent is constructed according to the following principles (see also FIG.2). A plastic tent is fastened to the indoor side of the window. This must be carried out very carefully ensuring that the area is completely sealed-off. A protective tent is then arranged around the first one.

With the aid of fans, an over or underpressure is created in both tents in relation to the exterior of the window. The pressure is regulated in such a way that it is equal in both tents and that no air currents pass from one tent to the other. As a result of the difference in pressure between the two sides of the window, air will flow inwards or outwards through cracks in the window. The volume of air flowing inwards or outwards is recorded by a gas meter attached to the air pipe leading to the inner tent.

In this way the amount of air leackage through the window, created by various pressure differences, can be determined. The volume of this air leackage is obtained as a function of the pressure difference between the inner tent and the outdoor side of the window.

Both tents are made from transparent plastic sheeting. This allows the observation of the way in which the window and the tent react during the experiment. First, the tent is attached to a tube through which all pipes are led. The tent is then fastened to the reveal, if this is sufficiently large, or to the wall around the window. Certain problems can arise when attaching the tent in this way if there is a niche under the window for a hot water radiator. No general solution can be provided for this problem which must be solved from case to case.

The pressure difference is measured with the aid of a spirit manometer. The flow of air from the fan to the tent is regulated by the number of revolutions of the fan. Measurements are carried out when the pressure in both tents is equal and when the air flows are constant.

For well draught-proofed windows, measurements have been carried out while the difference in pressure between one side of the window and the other has been gradually increased from 0 to approx. 30 mm vp. The latter value corresponds to a wind speed of approx. 22 m/s, and this has been regarded as a reasonable limit since there are few days when it blows as hard as this or more violently. For windows that are not well draught-proofed it is, however, difficult to obtain such wide differences in pressure. In this case the difference in pressure between the inside and the outside of the window has been gradually increased from 0 up to the value that corresponds to an air leakage of approx. 30 m^3 per hour.

When one or other of these higher values has been obtained, the pressure difference is then gradually reduced to 0, and then increased again to the higher value. This means that three consecutive series of measurements are obtained for each window. See FIG.3. It can be noted for all windows studied that these series of measurements are well-grouped.

The results of these investigations of windows are illustrated in FIG. 4a-4b. FIG.4a illustrates the air leakage from one side of the window to the other when there is overpressure on the inside of the window, and FIG.4b illustrates the air leakage when there is underpressure on the inside of the windows. The figure shows that the majority of the windows are not well draught-proofed. Only windows 18, 19 and 20 are draught-proofed to an acceptable level. It should be pointed out that windows 19 and 20 are very old and draught-proofed in the old-fashioned manner using adhesive tape to cover the inside gap between the casement and the window frame.

According to new standards (Swedish Building Code, 1975, SBN-75, Supplement 1, "The conservation of energy, etc..") the leakage of air through windows should not exceed 1.7 m^3/m^2 per hour with a pressure difference of 50 Pa (5 mm vp). Among the windows examined, nos.19 and 20 meet this requirement. The other windows are well above this level.

Comparing the curves for air leakage for different types of window, when over- or underpressure occurs, has shown the following. For inward-opening linked casements, the leakage of air increases by about 12% when underpressure occurs on the inside of the window, the values varying between 3% and 25%. For outward-opening linked casements the leakage of air is reduced by about 13% when underpressure occurs on the inside of the windows, the values varying between 0% to 30%.

The relationship between the degree of freedom from draughts of the windows and the ventilation of the flats is to be studied for all the cases investigated so far.

Field measurements have been carried out on two windows before and after the renewal of the draught excluders between the window frame and the casement. The first window (1922) had inward-opening linked casement and had the earlier type of draught excluder made from cloth. This was removed and replaced with a 4 mm thick rubber draught excluder and the casements were adjusted. Measurements were then made of the freedom from draughts and the results are illustrated in FIG.5a-b. These figures enable the comparison to be made of the effect of the draught excluder after it was put up and the earlier draughty condition of the window. From FIG.5a it can be noted that when there is overpressure on the inside of the window, the leakage of air is 6% less after the addition of the rubber draught excluder. The corresponding figure, for the situation with underpressure on the inside of the window, is 20%, see FIG.5b. That this figure is so high, is due to the fact that a rubber draught excluder is more easily adaptable to movements of the casement compared to other types of draught excluders. Because the casements were adjusted, and the rubber draught excluders were inserted, the window was much less draughty. This situation could have been further improved if the casements had been adjusted again.

The other window (1946) also had inward-opening linked casements. Previous draught-proofing had been carried out with draught excluders from rubber foam. A rubber draught excluder 4 mm thick was fastened all the way round the casement, and the window fasteners were very carefully adjusted. Measurements were made of the degree of freedom from draughts and the results are presented in FIG.6. A comparison is made in the figure of the situation before and after the rubber draught excluder was fitted. The figure shows that the freedom from draughts has been improved by over 90%. The window, with its new rubber draught excluder, fully meets the draught prevention requirements that SBN (Swedish Building Code) demands of new windows.

In the laboratory, measurements have been carried out on two windows consisting of two single casements. The outer casements open outwards and the inner casements open inwards. The casements and window fasteners of both windows were adjusted and the inner casements were provided with draught excluders. For one of the windows (from the 1890´s), the inside casement was provided with a rubber draught excluder (4 mm) and the resultant reduction in draughtiness was measured. This was followed by the outer casement being provided with the same type of rubber excluder, and the results were measured again. The resulting measurements are presented in FIG.7a-b. The window has become 55% less draughty.

For the other window (from the 1920´s), the inner casements were provided partly with cloth draught excluders with a foam rubber core, and partly with O-section, plastic draught excluders. Measurements were then made of the degree of freedom from draughts. This was then followed by the outer casements being provided with a rubber draught excluder (4 mm). Measurements were carried out again. From FIG.8a-b it can be noted that the window has become 50% less draughty in the latter case.

From the experiments above, it appears that old windows can be made relatively draught-free, and prove fully acceptable in terms of draught prevention. This means that energy can be saved by just checking the condition of windows. In addition the measures which are necessary are not particularly expensive or time-consuming. Improvement of the draught-proofing of windows often has a double energysaving effect. It is not only the leakage of heat that is prevented, but also the draught from windows disappears. This results in the indoor climate being more comfortable, with the result that the indoor temperature can often be lowered a few degrees.

The prevention of draughts from windows

Draught excluders between the casement and the window frame

When fitting draught excluders between the window frame and the casement, these should be placed furthest in towards the room. In this way the best protection from the elements is provided and condensation on the outer panes is counteracted (see FIG.9). For inward-opening casements, the draught excluder is fitted to the casement and for outward-opening casements the excluder is fitted to the window frame.

There is on the market today a wide variety of draught excluders made from different materials such as rubber foam, plastic, cloth, rubber, etc.. Of course, it can be difficult to know which material is best, but one made from rubber is preferable. This material is highly elastic, has good ageing properties, has the ability to absorb irregularities between the casement and the window frame, as well as the ability to adapt to the opening and closing of the casement.

Rubber draught excluders are available with different sections. There are sealing strips, O- or P-section strips, V strips and serrated strips (see FIG.10). The O- and V-section strips are attached to the casement with the help of a stapler, while the sealing strips and the serrated strips are self-adhesive. It should be noted that the V-section strip is difficult to fit correctly.

When fitting draught excluders to doors and windows, in order to prevent draughts, the following points should be observed when carrying out the work so that good results may be obtained.

1. Inspection of windows and doors.
2. Adjustment of casement/door and respective frame to check that casement/door opens and shuts easily.

3. Check that all fasteners and hinges work properly and carry out any adjustments or oiling that may be necessary.

4. Check that the air slit that is to be found on all linked casements and doors has not been painted over and therefore non-functional. Where necessary, fit a sealing strip 9x3, L=20-30 mm to two places between the bottom rails of the sashes.

5. Always paint all surfaces that are exposed bare wood (including areas not treated with wood stainer or other surface finish) before fitting the draught excluders.

6. Check carefully that there is room for the rubber excluder. For example, try different dimensions (the O-section strip 9x5 is very good and fits 80-90% of all windows). See further the table below.

7. The following rubber sealing strips, intended for the draught-proofing of doors and windows, are available on the market.

Sealing strip	9x3	max.gap 2.5 mm
O-section strip	9x5	" " 5.0 mm
V-section strip		" " 7.0 mm
Serrated strips	10x5 8x4 15x8	can be compressed to max. 15-20% of original thickness

Other rubber draught excluders are available e.g. for doors, but may be difficult to obtain from normal retail outlets.

8. When fitting draught excluders, use the rubber strips that provide the correct pressure when the window is closed. It is extremely important that the correct rubber draught excluder is used to obtain satisfactory draught prevention. It is equally important that the rubber draught excluder is fitted to the correct part of the casement/window frame, see FIG.10.

   (Note. Experience shows that e.g. six out of ten houses have incorrectly fitted draught excluders. For flats, the figure is even higher. A very common mistake is that a foam rubber sealing strip has been fitted in the drip, see FIG.9, with relatively extensive damage as a result).

Caulking between the window frame and the wall

The joint between the window frame and the wall should function in the same manner as the wall itself, and should therefore be constructed according to the same basic principles. These principles should be based on a two-stage method of insulation, i.e. that there are separate layers to provide proofing against wind and rain. In addition the joint must provide heat insulation in order to reduce heat losses and also to provide protection against condensation.

FIG.11 illustrates different methods of insulating the joint between the window frame and the wall. When insulating the joint with caulking it is important that the latter is stuffed in properly so that the required protection is obtained. The results of caulking are directly related to the way in which it is carried out. The most common material for caulking is mineral wool. For this purpose, approx. 5 cm wide strips are stuffed into the joint. There are also plastic coated mineral wool strips that can be used in the inner section of the joint. The joints can also be sealed with elastic strips of artificial rubber. These strips are manufactured from porous material or as hollow cylindrical strips. On the outside the joint is sealed with an elastic sealing compound and on the inside is placed the inner reveal.

The draught-proofing of all windows is being carried out at the moment in a large block of flats in Malmö. Draught excluders are being fitted between the casements and the window frame and caulking is being carried out between the window frames and the walls. Caulking is carried out from the inside. The joints are being insulated according to c in FIG.11.

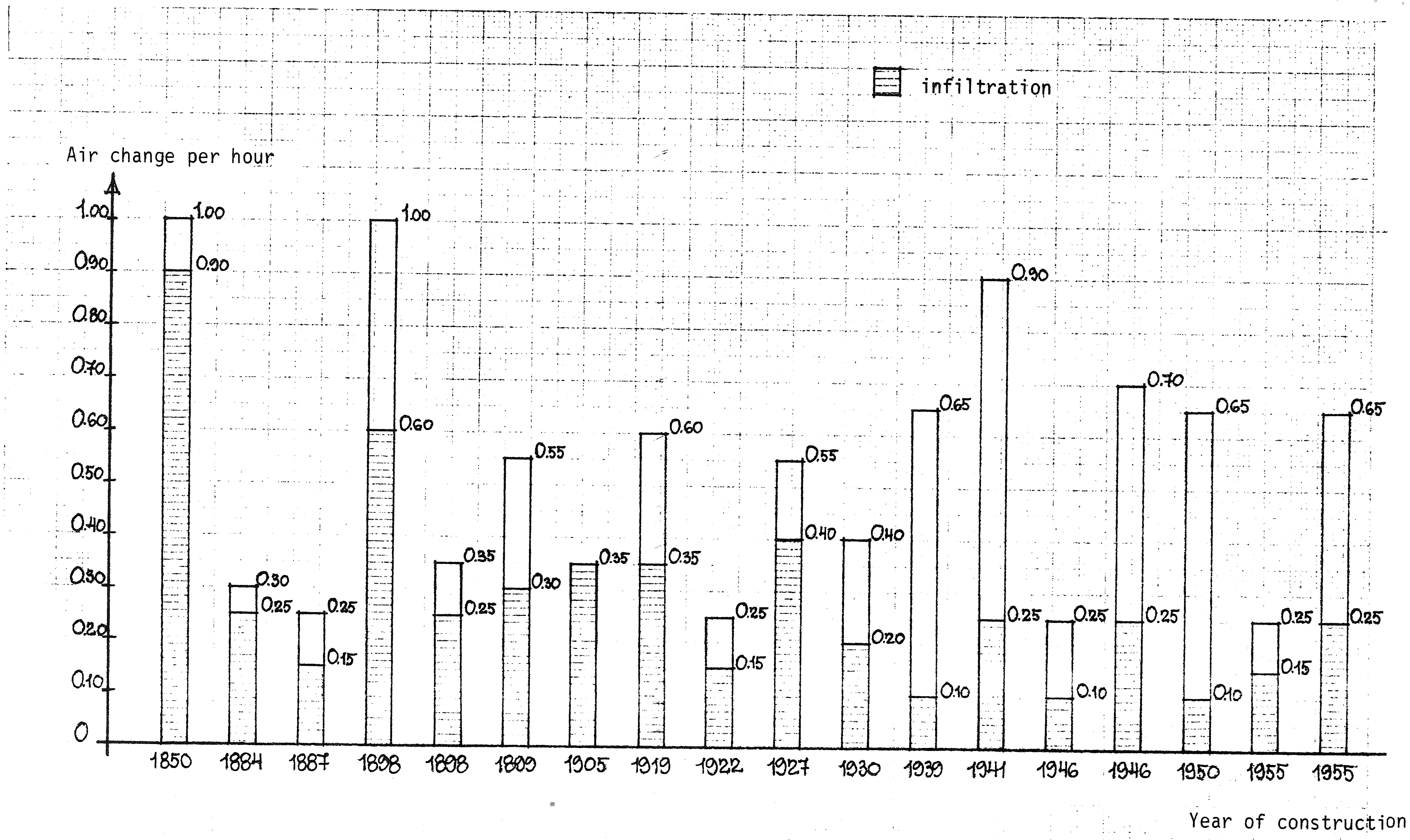


FIG.1 Normal ventilation in the flats investigated.

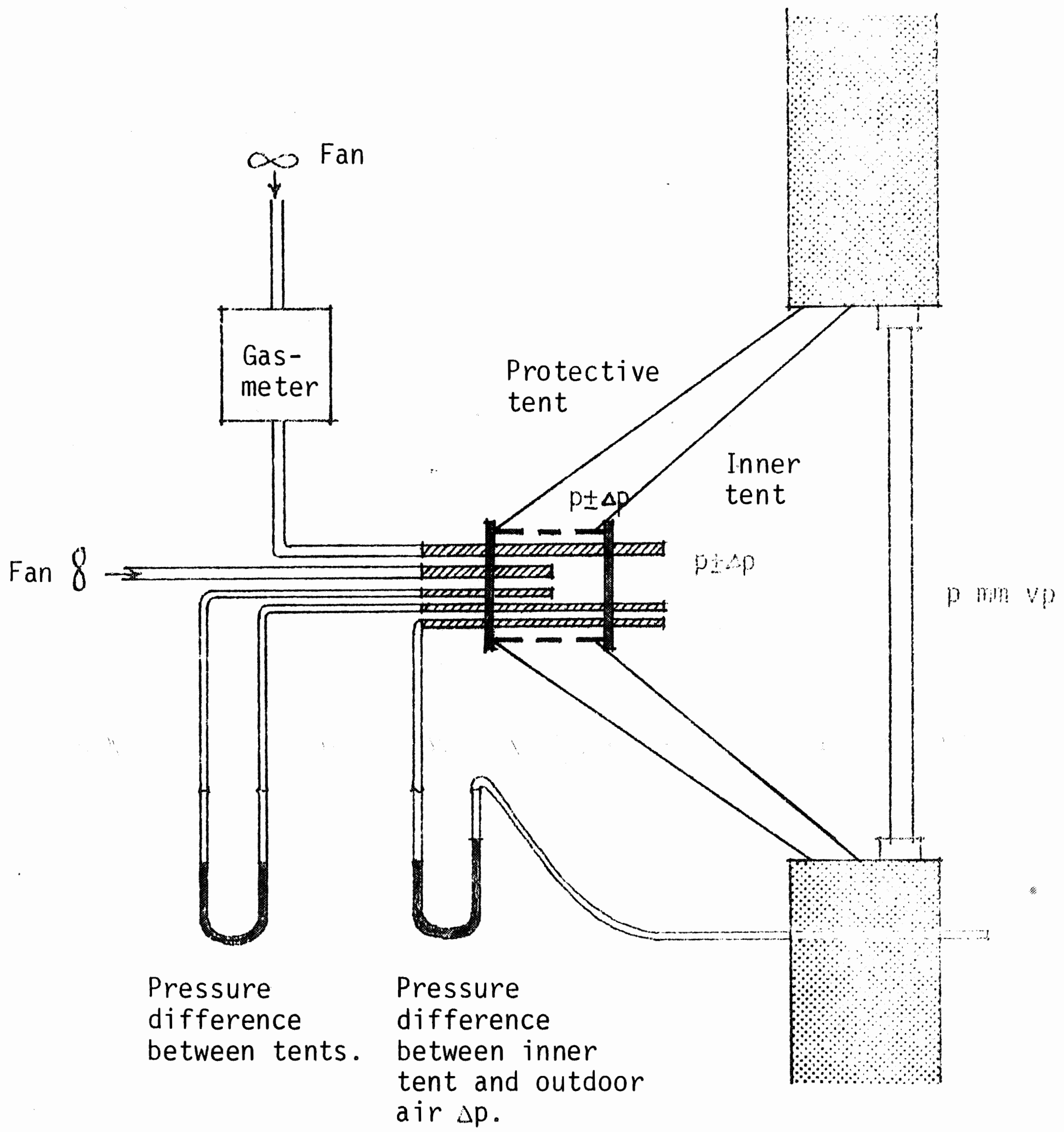


FIG.2 Sketch of principle of measuring the degree of the air tightness of windows.

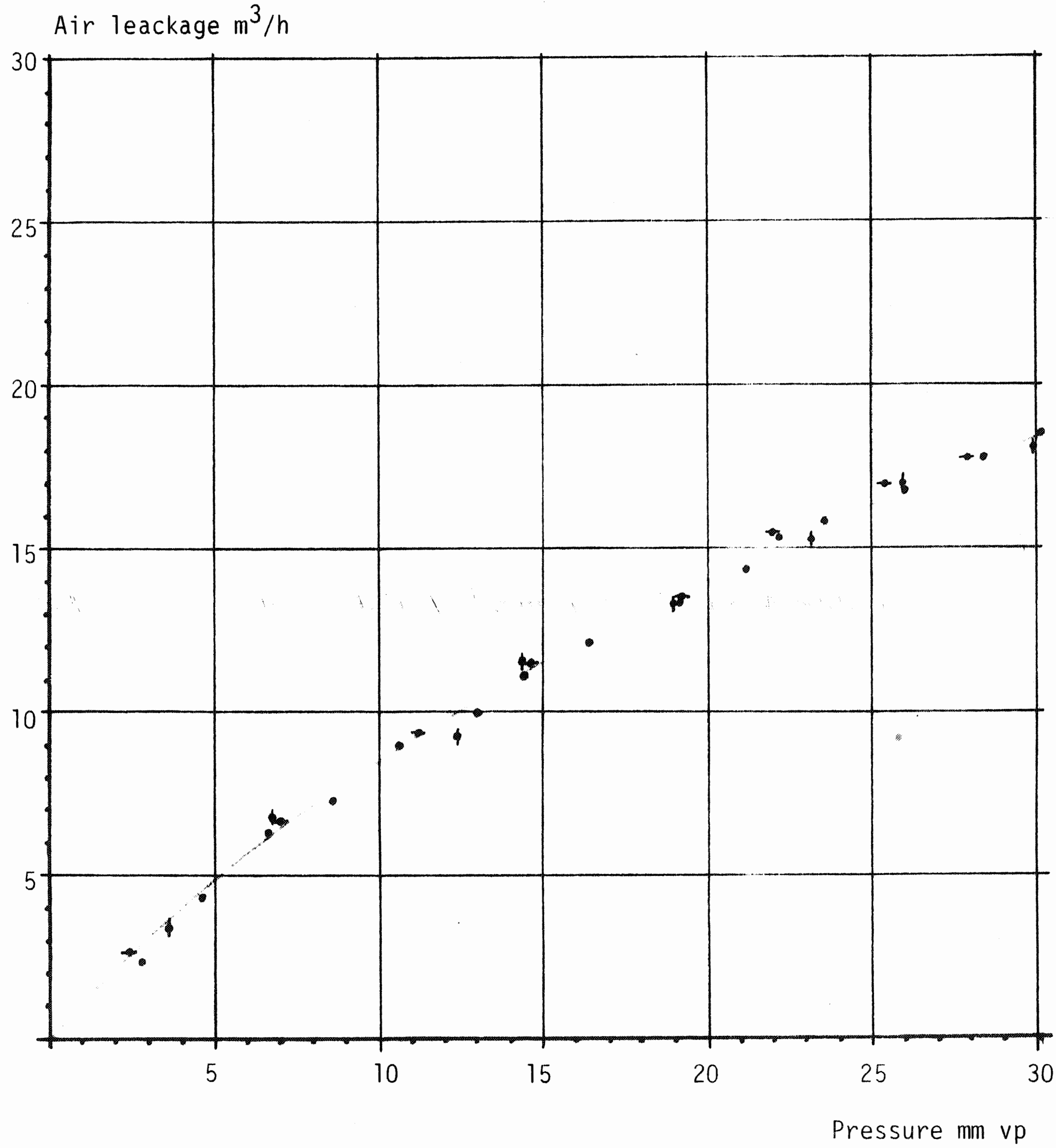


FIG.3 Example of series of measurements.

Types of windows in the air-tightness diagrams

1.	Outward-opening linked casements	1850 Eksjö
	Double, non-linked casements	1905 Eksjö
2.	Outward-opening linked casements	1898 Eksjö
3.	Double, non-linked casements, both inward-opening	1898 Malmö
4.	Double, non-linked casements	1922 Malmö
5.	Inward-opening linked casements	1946 Gävle
6.	Inward-opening linked casements	1927 Gävle
7.	Double, non-linked casements	1922 Malmö
8.	Outward-opening linked casements	1919 Malmö
9.	Perspective windows	1955 Malmö
10.	Inward-opening linked casements	1939 Gävle
11.	Inward-opening linked casements	1922 Malmö
12.	Inward-opening linked casements	1922 Malmö
13.	Outward-opening linked casements	1884 Eksjö
14.	Outward-opening linked casements	1950 Eksjö
15.	Double, non-linked casements - inward-opening linked casements	1922 Malmö
16.	Inward-opening linked casements	1941 Malmö
17.	Double non-linked casements with inner casements sealed with adhesive tape	1850 Eksjö
18.	Inward-opening linked casements	1955 Malmö
19.	Double non-linked casements with inner casements sealed with adhesive tape	1887 Gävle
20.	Double non-linked casements with inner casements sealed with adhesive tape	1899 Gävle

The modern window is triple-glazed, linked casement, inward-opening

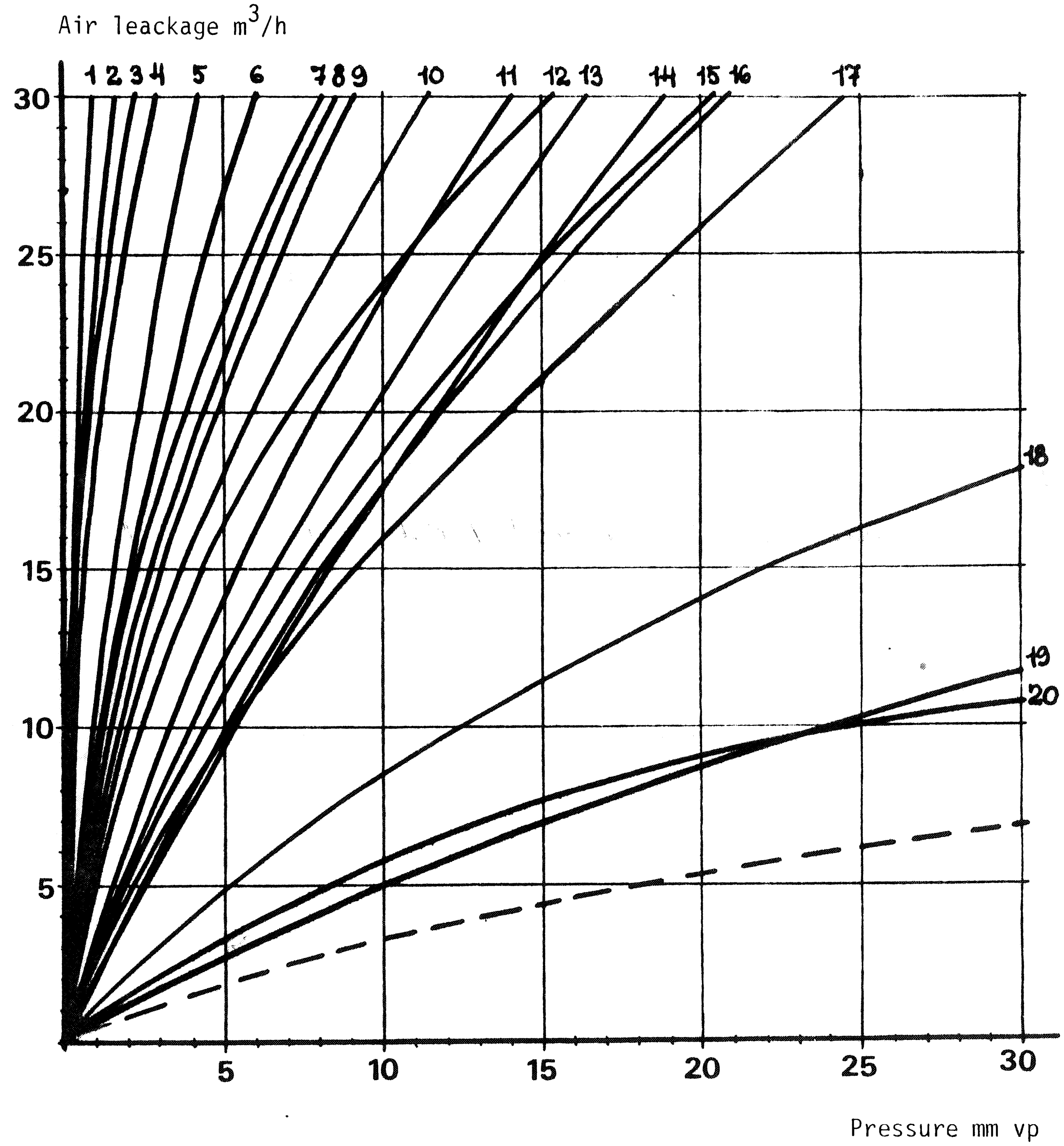


FIG.4a The air tightness of the windows studied when overpressure occurs on the inside of the windows. (See page following FIG.4b for figures).

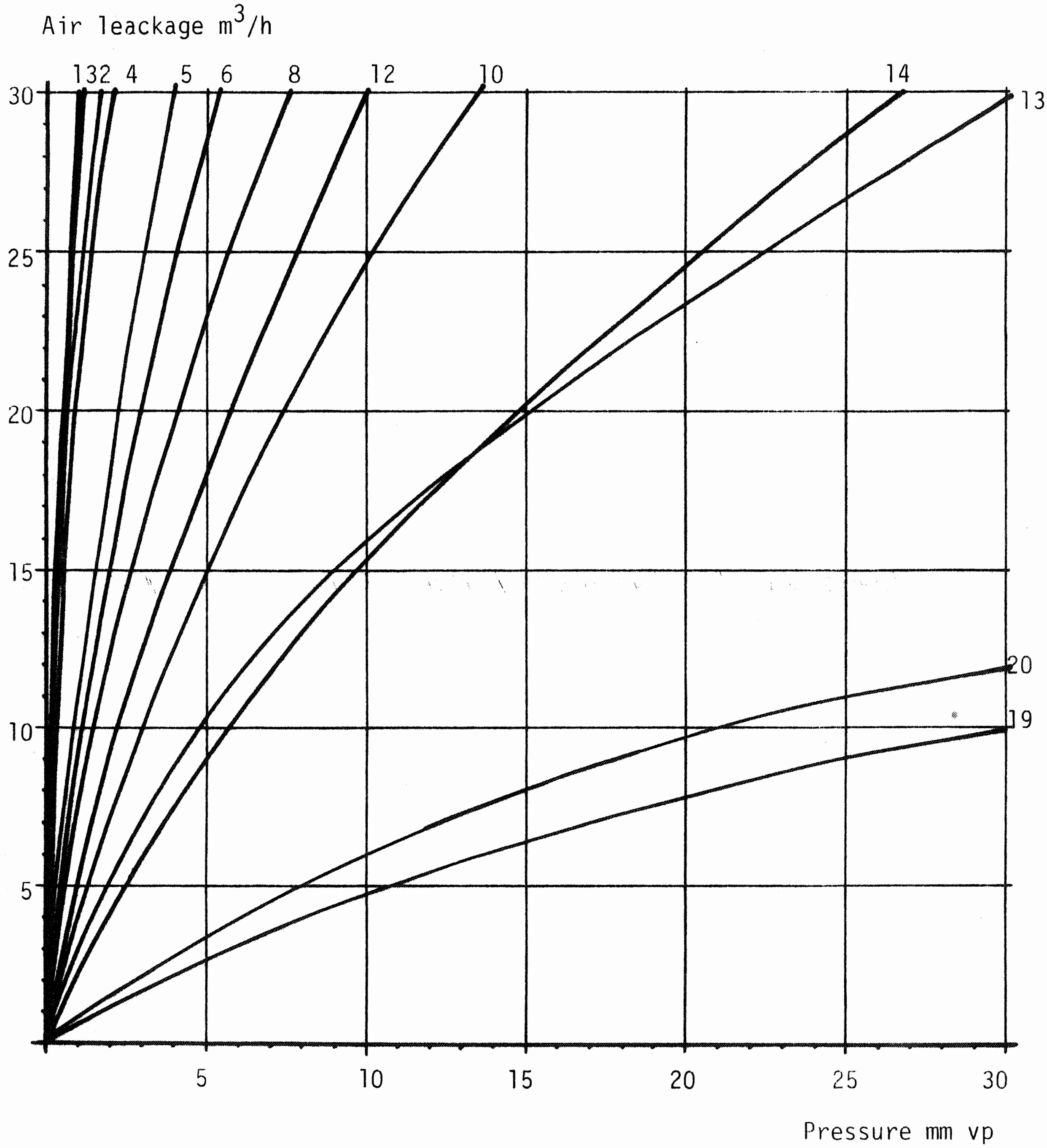


FIG.4b Air tightness of the windows studied when underpressure occurs on the inside of the windows (see following page for figures).

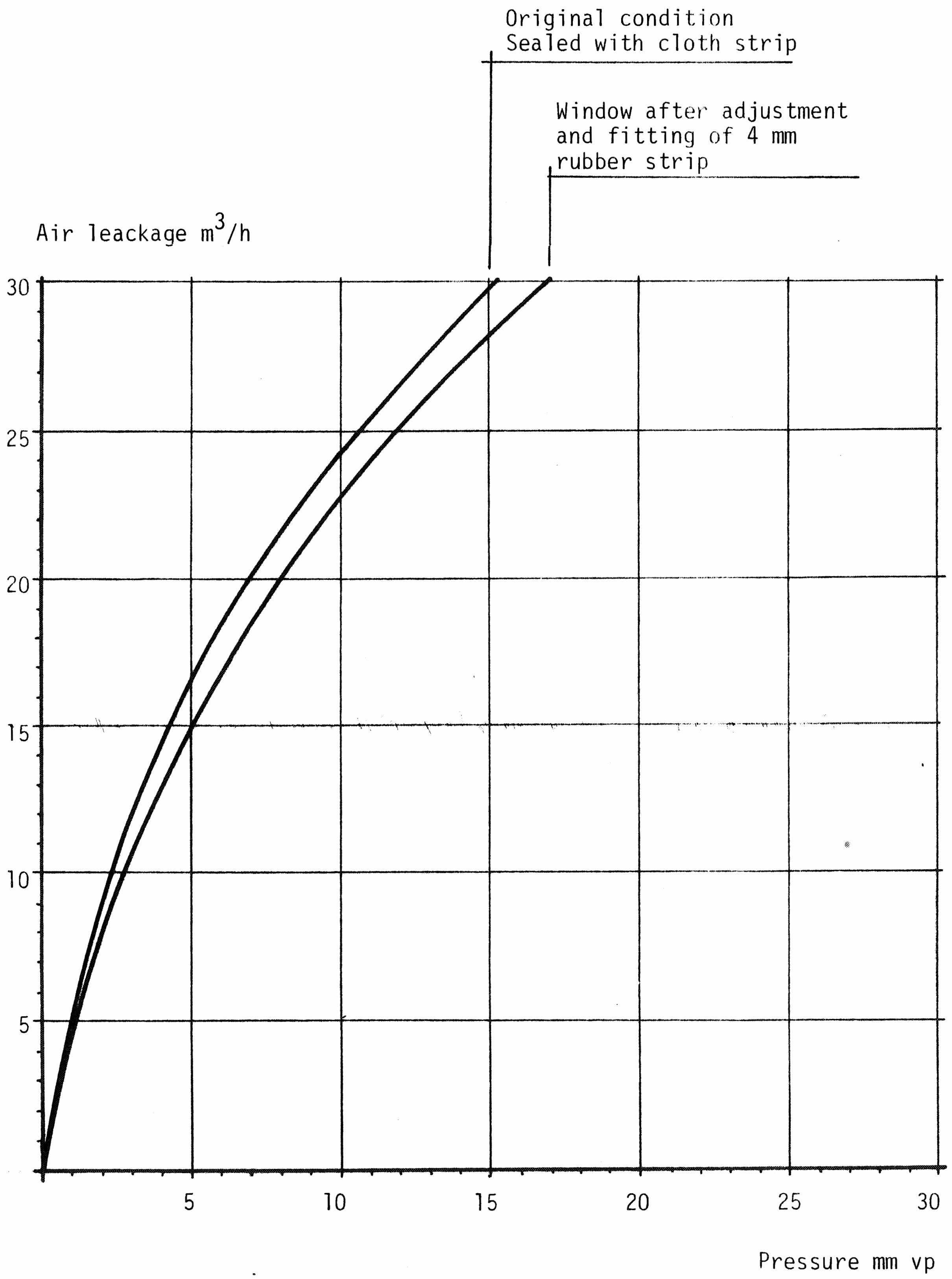


FIG.5a Comparison of air-tightness before and after renewal of draught excluder. Linked, inward-opening casements. Overpressure on inside of window.

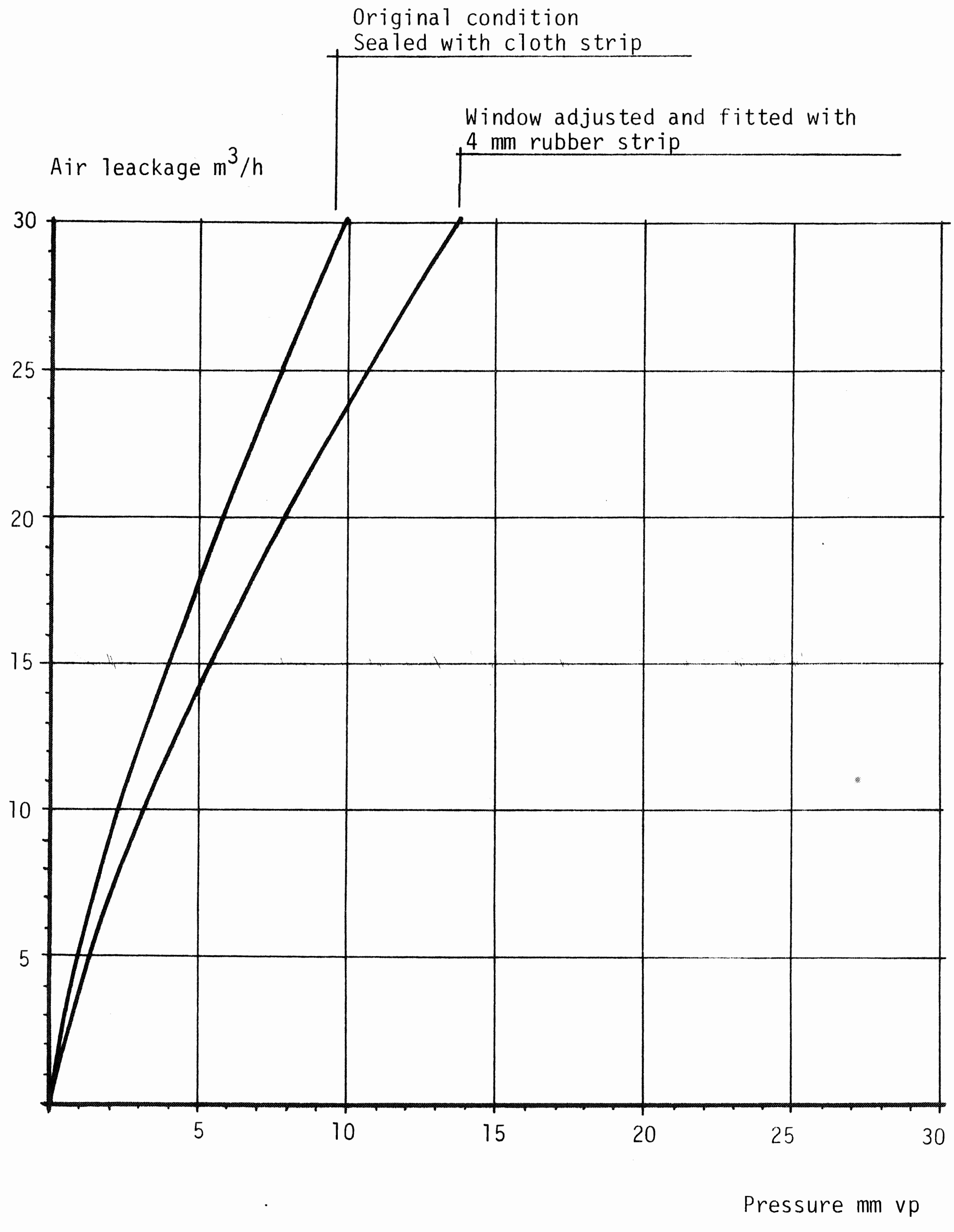


FIG.5b Comparison of air-tightness before and after renewal of draught excluder. Linked, inward-opening casements. Underpressure on inside of window.

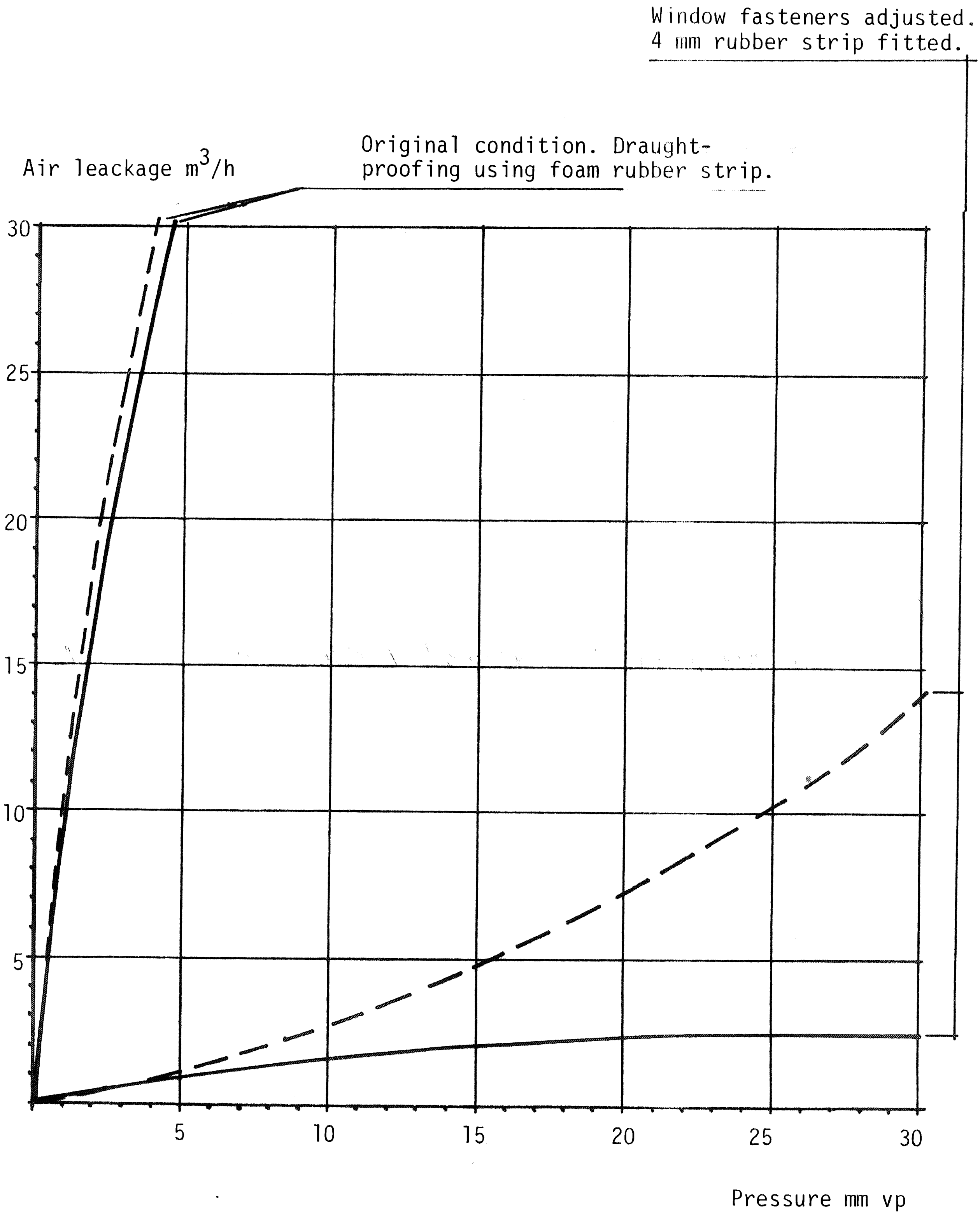


FIG.6 Comparison of air-tightness before and after renewal of draught excluders. Linked inward-opening casements. The full curve indicates the air-tightness when there is overpressure on the inside of the window. The dashed curve indicates the air-tightness when there is underpressure on the inside of the window.

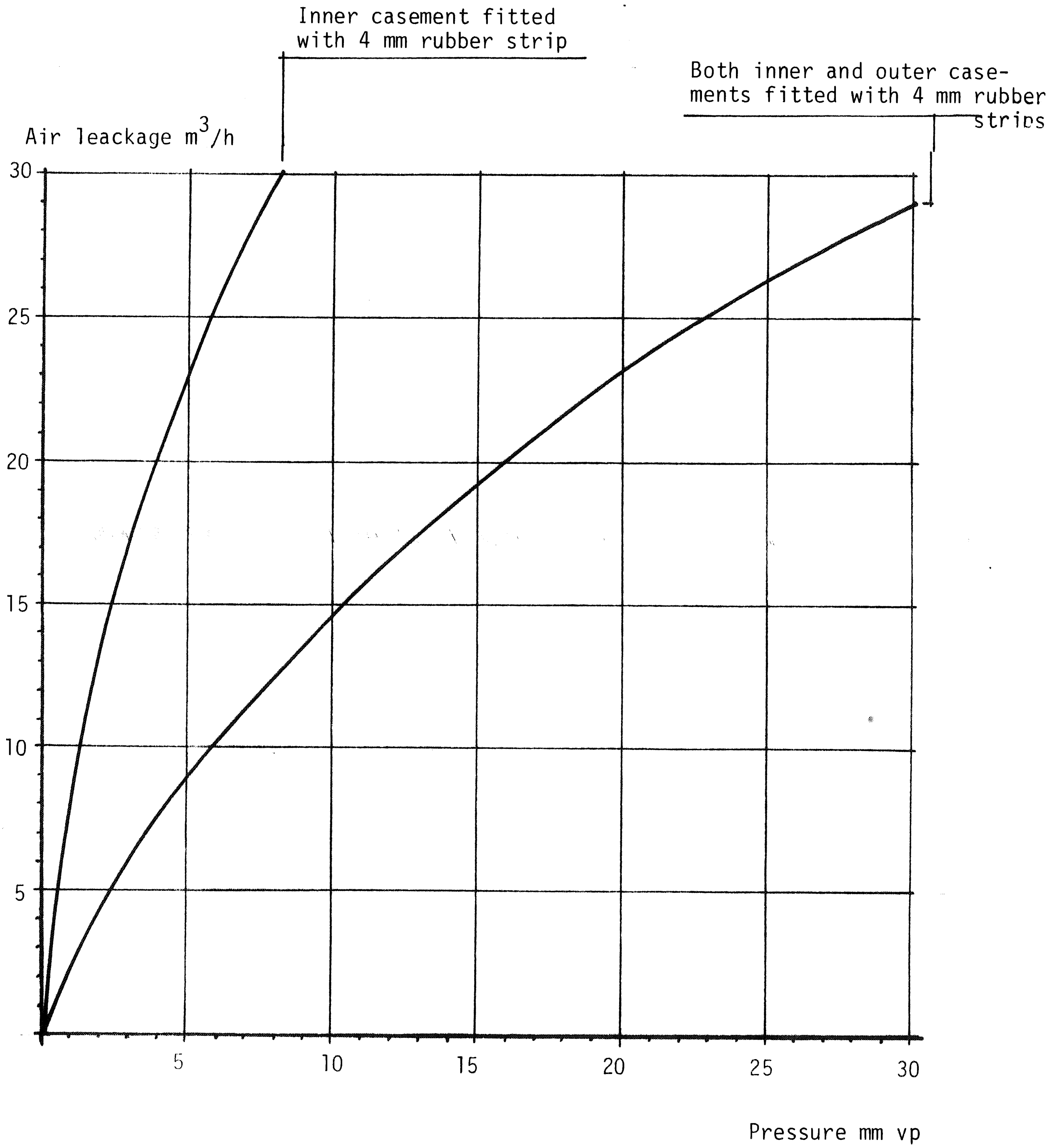


FIG.7a Comparison of air-tightness of different methods of draught prevention in windows with double, non-linked casements. Overpressure on the inside of the window.

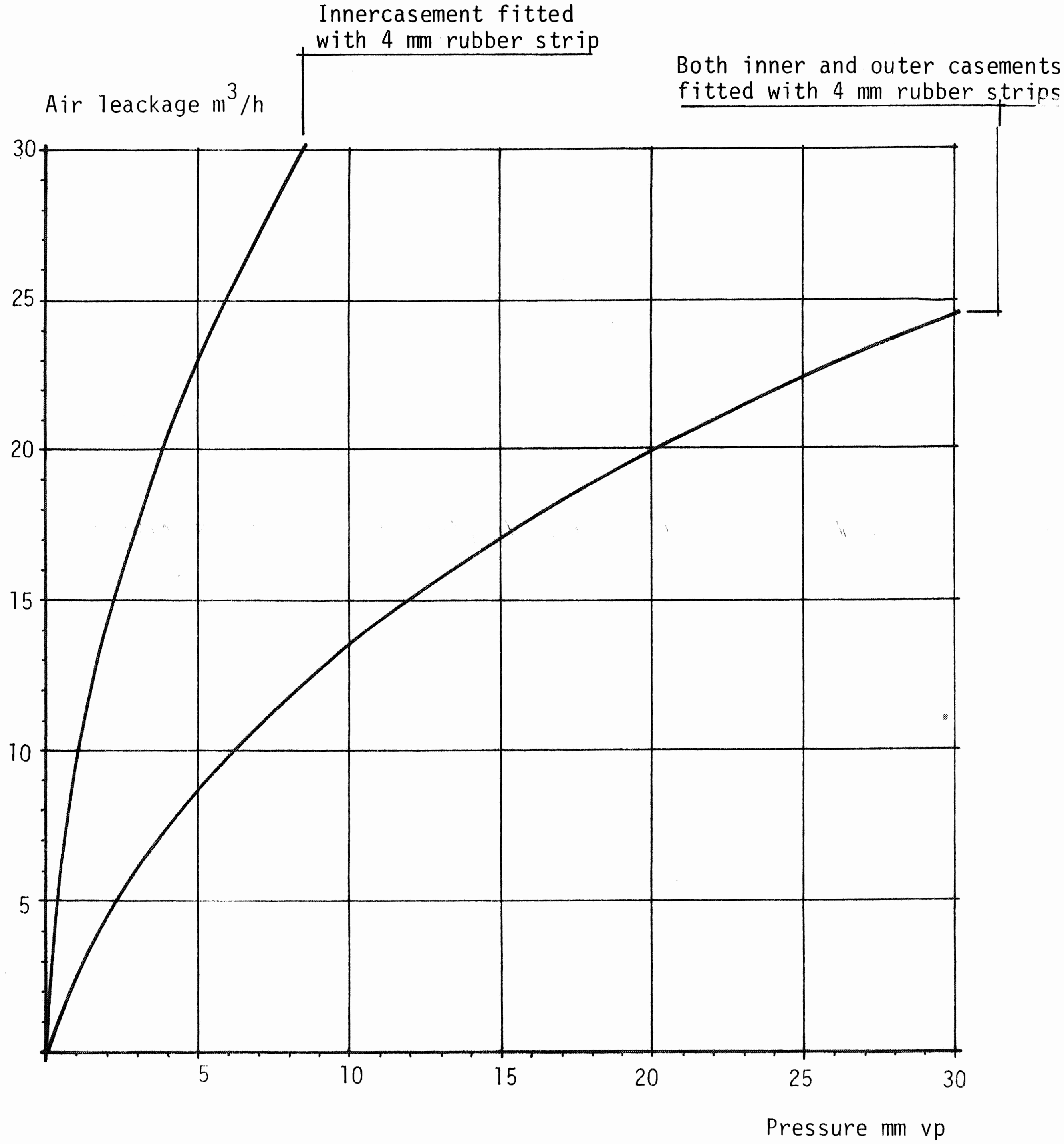


FIG.7b Comparison of air-tightness of different methods of draught prevention in windows with double, non-linked casements. Underpressure on the inside of the window.

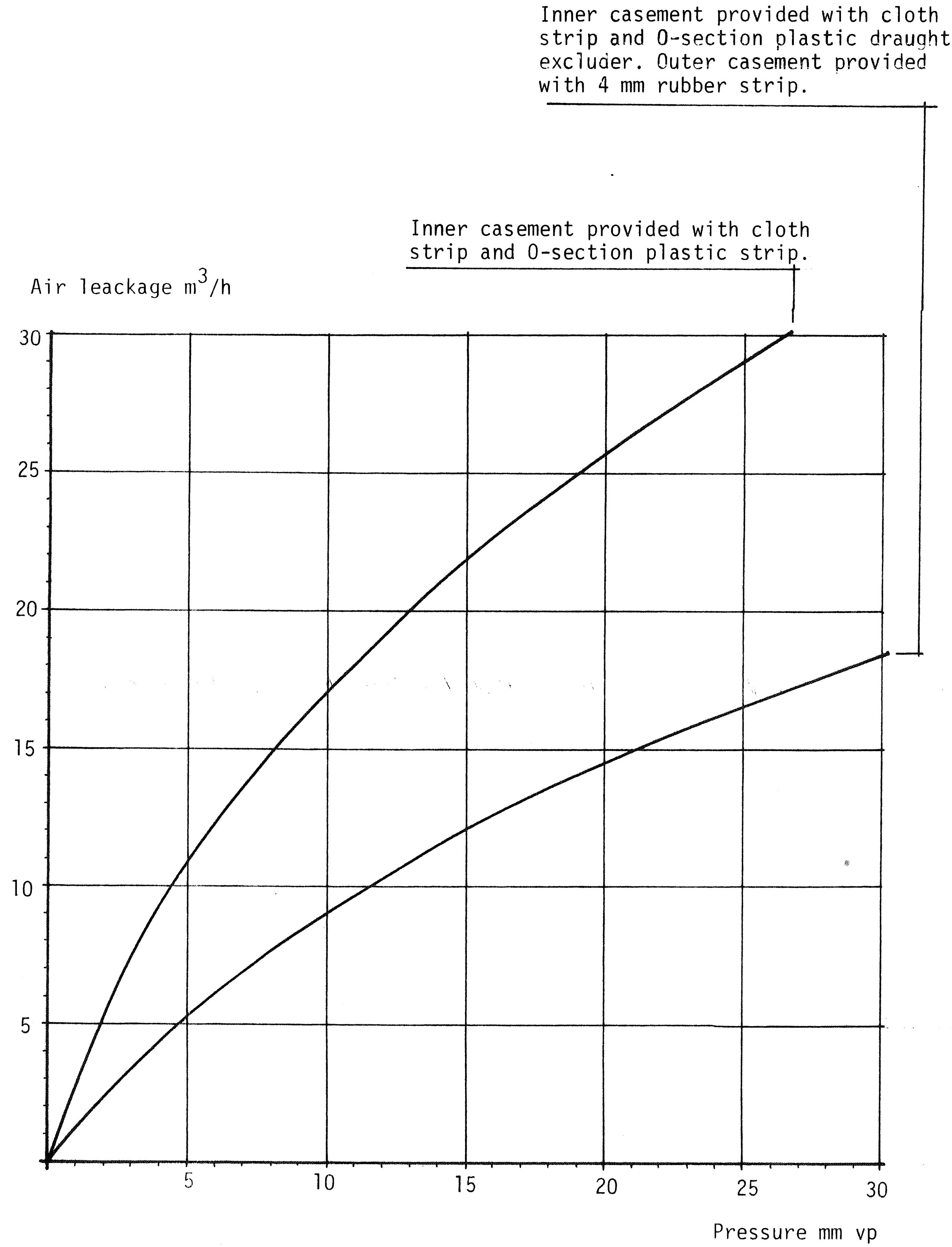


FIG.8a Comparison of air-tightness for different methods of draught prevention in windows with double, non-linked casements. Overpressure on inside of windows.

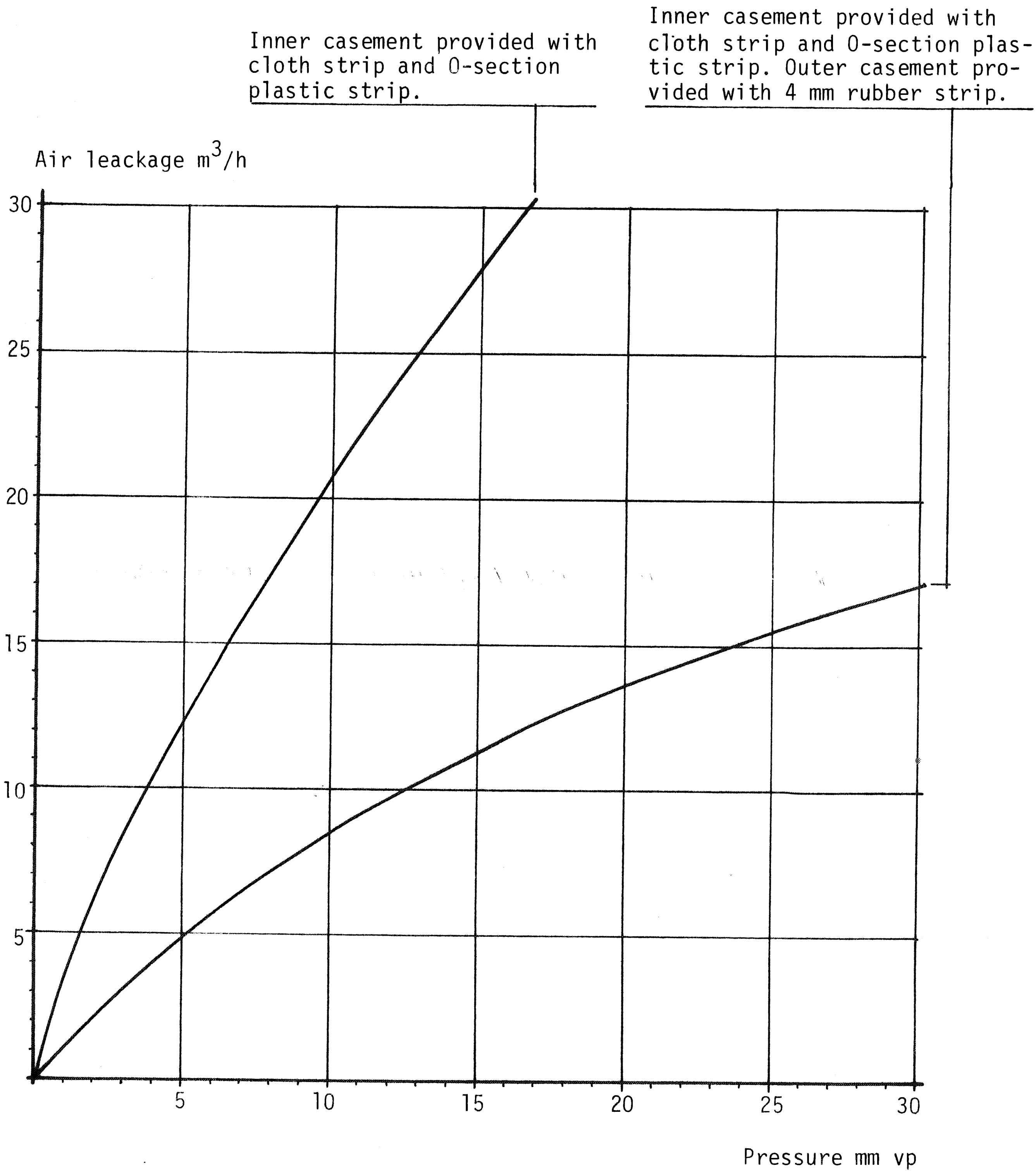
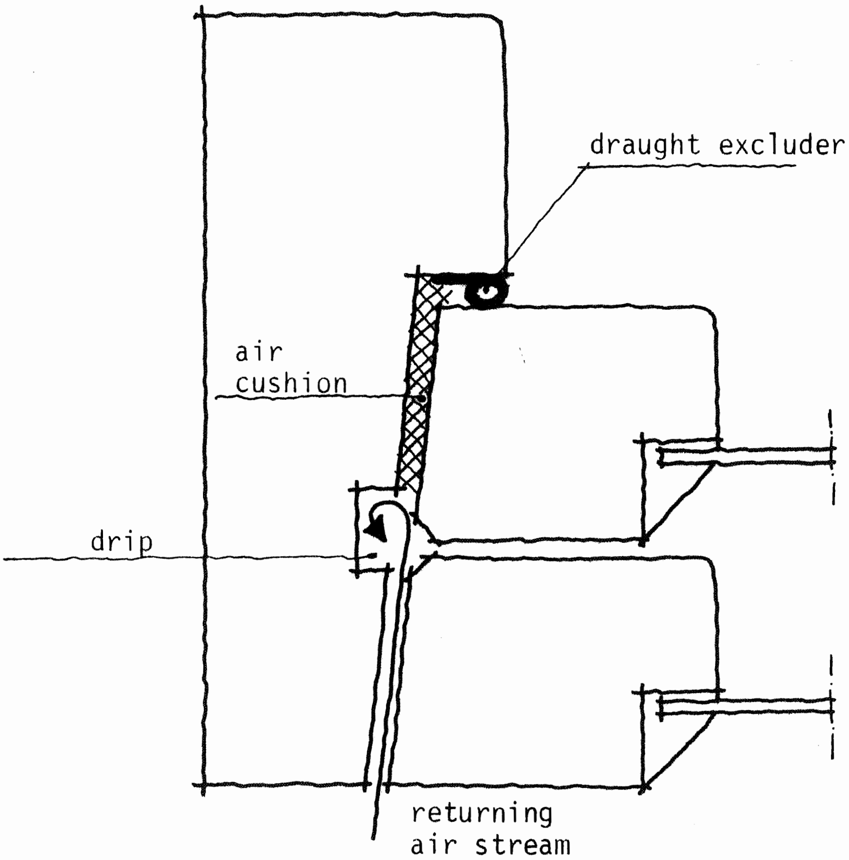
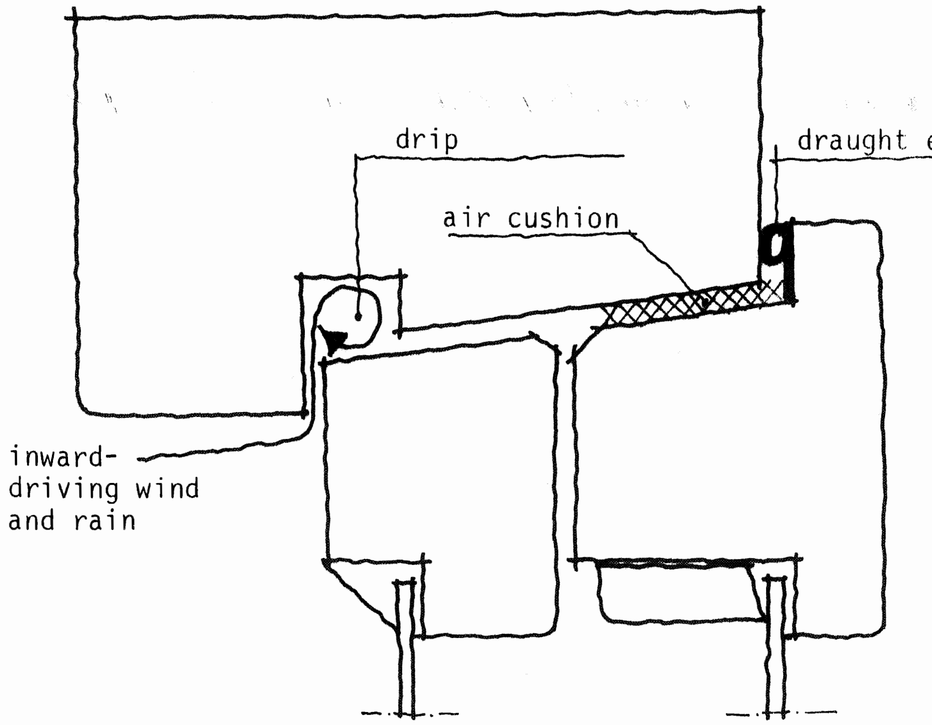


FIG.8b Comparison of air-tightness for different methods of draught prevention in windows with double, non-linked casements. Underpressure on the inside of the window.



Section through jamb and stile for outward-opening, linked casements. The arrow illustrat how wind and rain are prevente from entering.



Protection from inward-driving wind and rain for inward-opening, linked casements.

FIG.9 Basic principles of the protection of windows against driving rain and wind.

Type of section:	Sealing strip	O-section strip	V-section strip	Serrated strips		
Dimension mm:	9x3	9x5		8x4	10x5	15x8
Max.gap:	2.5	5	7 mm	Can be compressed to max 15-20% of original thickness		

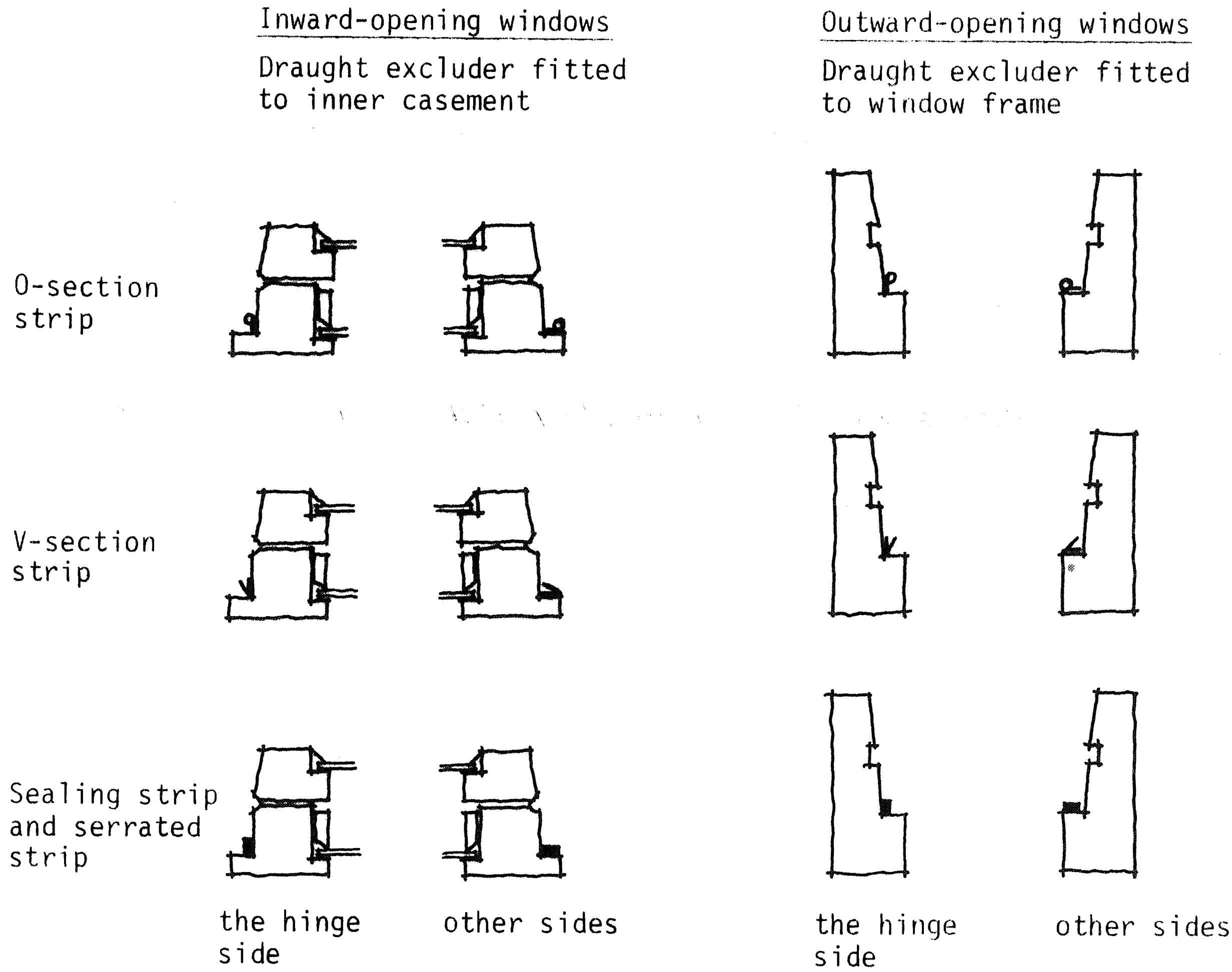


FIG.10 Different types of draught excluders and their fitting to casement or window frame repsectively.

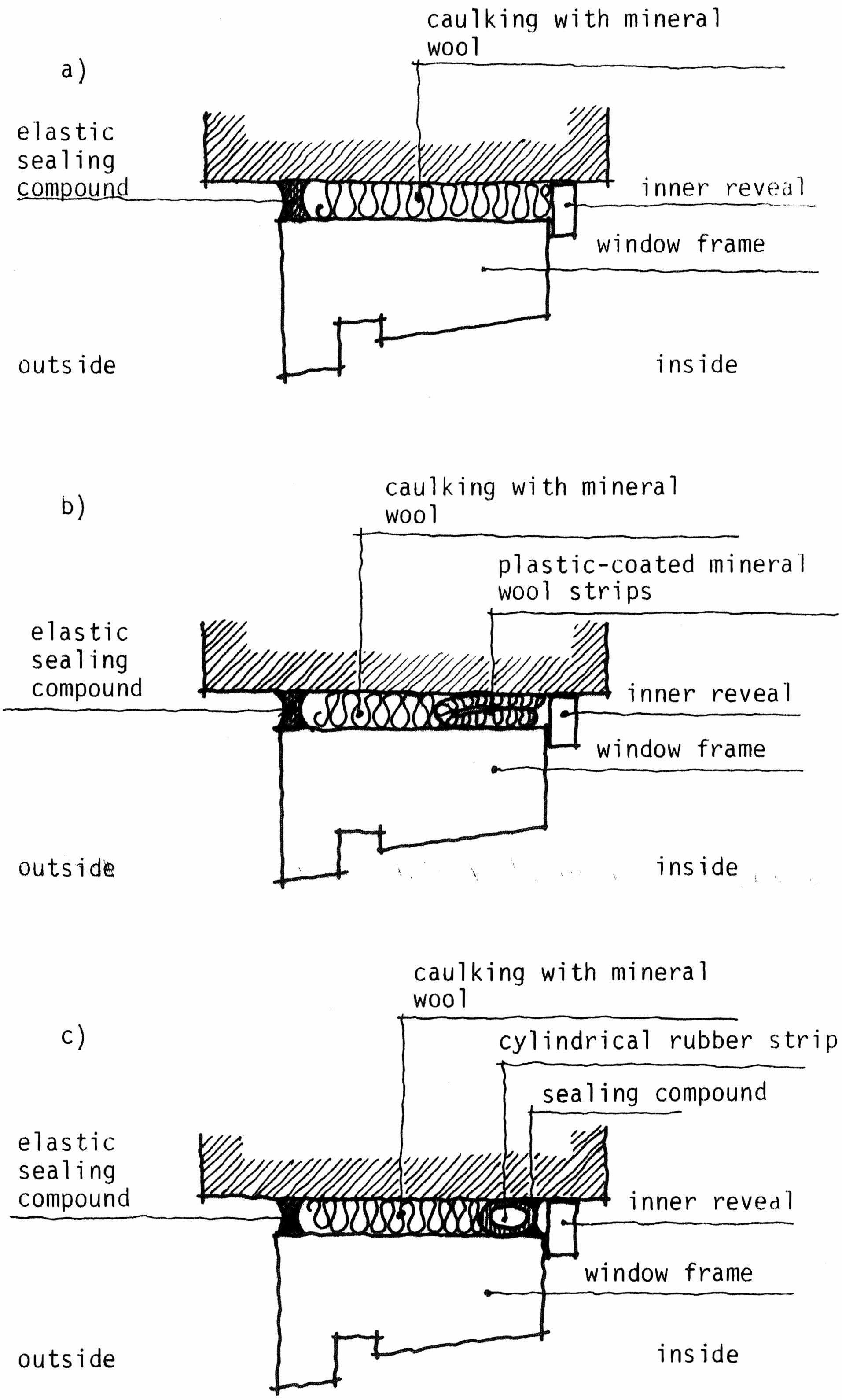


FIG.11 Different ways to caulk between window frame and wall.