# Studies of the performance of weatherstrips for windows and doors

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This document refers to research grant 770904-6 from the Swedish Council for Building Research to the Department of Building Technology at the Royal Institute of Technology, Stockholm, Sweden.

# 1 Introduction

The aim of Swedish energy policy is to reduce energy consumption in the building sector for heating, ventilation, the provision of hot water and household electricity. The target for the ten-year period 1978–1988 is that net energy consumption in 1988 must be 32–39 TWh per year lower than it is today. This is equivalent to 25–30% of total energy consumption in the present housing stock.

Expert Group C of the Energy Commission (EKC) has examined different ways in which energy can be saved in the building sector.

In the existing housing stock, for instance, very large savings of energy can be made by improved weatherproofing. The EKC estimates that, by 1990, between 7 and 10 TWh per year can be saved. Of this figure, not less than 80% is attributable to the weatherproofing of doors and windows.

The investigation also shows that the weatherproofing of doors and windows is a profitable measure (see FIG. 1). Another consequence of weatherproofing is that there is an appreciable improvement in the indoor climate. Ventilation is less dependent on wind direction, and direct draughts from

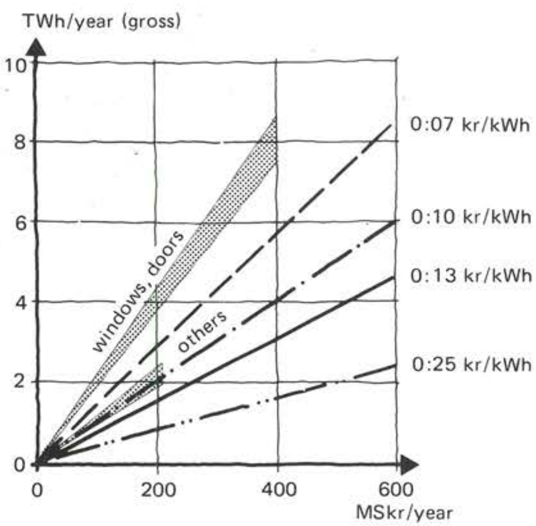



*FIG. 1. Diagram showing profitability lines for gross savings in 1990 obtained by weatherproofing windows, doors and »others» (walls, roofs and junctions), and annual costs of this in the existing housing stock. The effect due to weatherproofing of windows and doors (max. 7.5–8.5 TWh/year) is considerably greater than that due to other weatherproofing. Weatherproofing of windows and doors is a profitable measure even at an energy price as low as ca. Skr. 0.05/kWh. Other weatherproofing is profitable when price of energy exceeds Skr. 0.10/kWh. (Höglund & Stillesjö, 1978.)*

doors and windows are eliminated. There is, consequently, greater freedom in furnishing the dwelling, and it can be better utilised.

If recovery of heat is to be made use of, then good results cannot be achieved unless the building is airtight.

## 1.1 AIRTIGHTNESS REQUIREMENTS

Swedish Building Regulations 1975, Supplement No. 1 »Economical management of energy etc.» which was published in 1976, laid down, for the first time, specific requirements concerning the airtightness of doors and windows.

The object of these requirements, which apply to new buildings, is to reduce the losses of heat which occur through leakage of air or, in other words, unintentional ventilation.

In TAB. 1, Swedish regulations concerning the maximum acceptable leakage of air through doors and windows, for specified differential pressures under laboratory conditions, are set out.

The requirement curve for doors and windows opening into the external air conforms to the power law

$$q \sim 0.125 \cdot \Delta p^{2/3}$$

where

$q$ = air leakage, $m^3/m^2$ h

$\Delta p$ = difference in air pressure, Pa

When the airtightness requirements in Swedish Building Regulations 1975 were published, many thought that compliance with these by doors and windows would be very difficult. It was supposed that either a reduction in the gap, or an increase in the size of the weatherstrips, would be necessary. The result of this would be that doors and windows would become considerably more difficult to close. The organisations for the handicapped called attention to the problems which this would cause for the handicapped, some of whom may in the future perhaps be unable to open and close ordinary external doors

| Building element | Pressure difference, Pa | Maximum acceptable air leakage, $m^3/m^2$ h, in buildings with the following number of storeys 1–2 | 3–8 | 8 |
|---|---|---|---|---|
| Windows and doors opening into the external air (relates to the airtightness of the gap between frame and casement or between frame and door leaf) | 50 | 1.7 | 1.7 | 1.7 |
| | 300 | 5.6 | 5.6 | 5.6 |
| | 500 | – | – | 7.9 |

*TAB. 1. Maximum acceptable air leakage.*

in dwelling houses. In this work it was therefore considered important that attention should be paid not only to the sealing capacity of the different weatherstrips, but also to the magnitude of the closing force required for doors fitted with different types of weatherstrips.

## 1.2 LEAKAGE OF AIR, PRESSURE DIFFERENCES AND AIR CHANGE

Leakage of air through the construction enclosing a building occurs when there is a difference in pressure indoors and outdoors and the construction is not airtight. Gaps, cracks, joints, junctions, points of entry for pipes etc. give rise to an uncontrolled movement of air which causes large losses of energy and, in addition, often has a negative effect on the indoor climate.

In practice, a difference in pressure is due to the combined effect of wind, temperature (»chimney effect») and the ventilation system (extract and supply terminals).

The effect of wind on the air pressure indoors is a function of wind pressure, wind direction, the air resistance of gaps and openings, and the positions of the latter in relation to the direction of the wind. On facades, wind usually gives rise to positive pressure on the windward side and negative pressure on the leeward side.

The effect of temperature is particularly noticeable in winter in tall buildings. When the temperature indoors is higher than that outdoors, a reduction in pressure occurs at lower levels, and air is forced in. Higher up, there is an increase in pressure, so that air is forced outwards. This is due to differences in the density of air at different temperatures, and the difference in

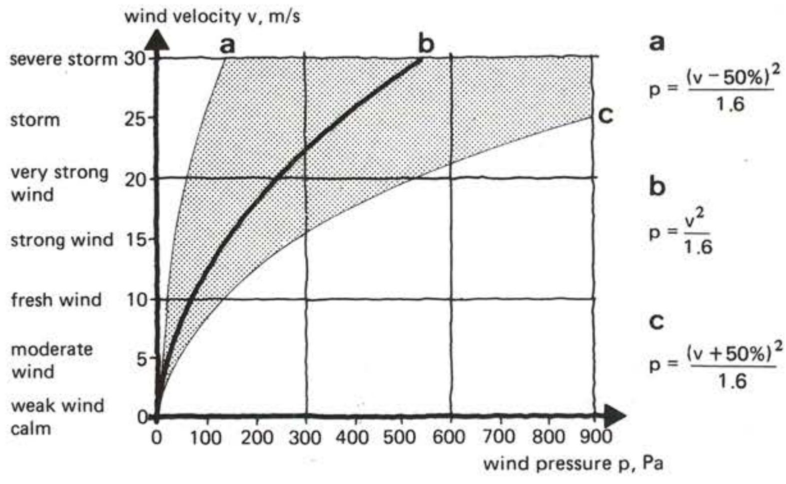



*FIG. 2. Relationship between wind velocity and wind pressure. For gusty and not excessively strong wind the velocity may vary by ±50% from the 10 minute mean. The nature of the country and building development has a great effect on the local wind velocity.*

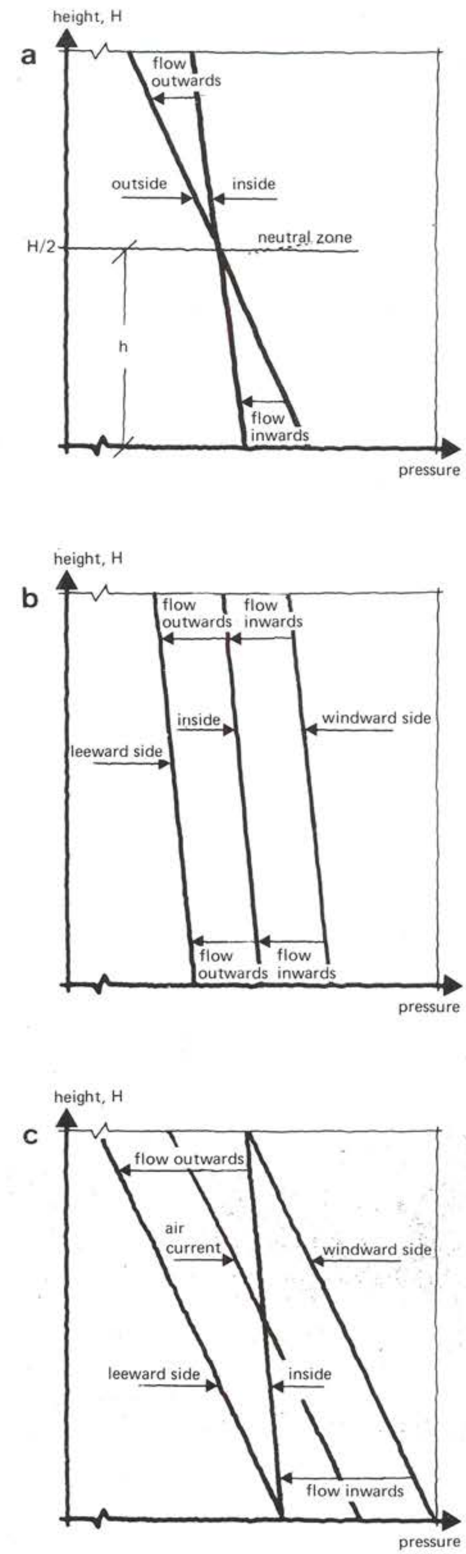



*FIG. 3. Vertical distribution of air pressure on the inside and outside of a building.*

*Diagram a shows only the chimney effect, the neutral zone being assumed to be at the mid-height of the building.*

*Diagram b shows only the effect of the wind which, in principle, gives rise to the same pressure at all levels.*

*Diagram c shows the pressures due to simultaneous chimney effect and wind pressure. In this case the effect of the wind is so great that it counterbalances the chimney effect at the top of the building, i.e. the differential pressure between the inside and outside is equal to zero on the windward side.*

pressure between low and high levels has in many cases been found to be as much as 50–60 Pa.

Points of leakage in the climatic envelope thus increase the air change rate in an uncontrolled manner. This is usually referred to as uncontrolled ventilation, i.e. air change through points of leakage.

Energy losses can be limited by increasing the airtightness of buildings. Air must be admitted through ventilation openings, so that the rate of ventilation can be suited to the requirements of the occupants. *However, ventilation in buildings must be at least so large that the hygienic requirements (regarding humidity, odours and possibly the incidence of radon) are safeguarded. The extent to which ventilation can be cut is open to debate, but an air change rate of 0.5 per hour is normally required in a residential building. When existing residential buildings are weatherproofed, it may in certain cases be necessary to modify the ventilation system in conjunction with weatherproofing.*

## 1.3 CASE STUDY

On the basis of the results of this investigation, studies of the performance of weatherstrips were made at the same time under practical conditions in a building provided with natural ventilation. This building is part of the Ulvsunda project (Höglund & Johnsson, 1976).

In order that the effect due to weatherproofing windows and doors may be determined, the old and ineffective weatherstrips in the windows were replaced by tubular strips, FIG. 4. Doors opening onto staircases were weatherproofed using straight strips[1], FIG. 5 (which work in the same way as angle strips).

The air change rate in the building was measured by two different methods both before and after installation of the weatherstrips. Natural ventilation in nine dwellings was determined by the tracer gas method (see e.g. Elmroth & Höglund, 1973). Four dwellings were pressure tested at 50 Pa (see e.g.

[1] Laboratory investigations showed (see later) that tubular strips were best with regard to airtightness. In doors, however, the closing forces measured for tubular strips were higher than for angle strips.

In the case of doors, it was therefore decided to allow a somewhat higher air leakage in exchange for greater ease of closing by the handicapped, the elderly and small children.

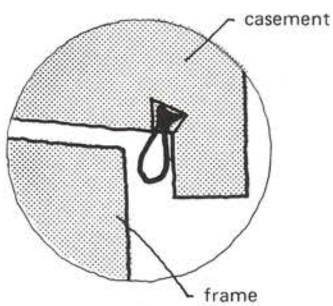



*FIG. 4. (left) Newly installed window strip.*

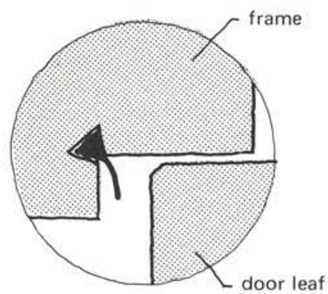



*FIG. 5. (right) Newly installed door strip.*

Blomsterberg, 1977). The results are set out in FIG. 6 and 7.

The tracer gas measurements indicate that, in absolute terms, the greatest reduction occurs in dwellings in which the air change rate before weatherproofing had been large. After weatherproofing, the air change rates in the different dwellings are in relatively good agreement, i.e. the scatter is small.

Pressure testing showed that points of leakage mainly occurred near the windows. Owing to the new weatherstrips, the airtightness of the building increased by about 40%.

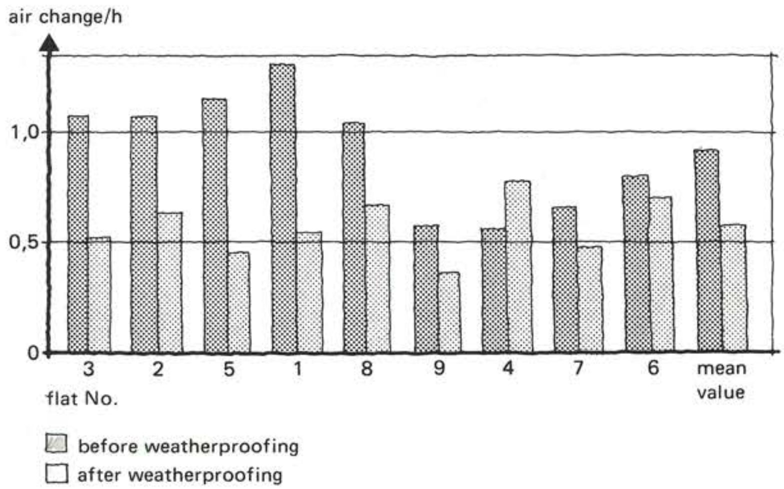



*FIG. 6. Result of air change rate determinations before and after mounting of weatherstrips in a test building at Ulvsunda. On average, the air change rate was reduced from 0.90 to 0.53 change/h. (Malmros & Sahlin, 1977.)*

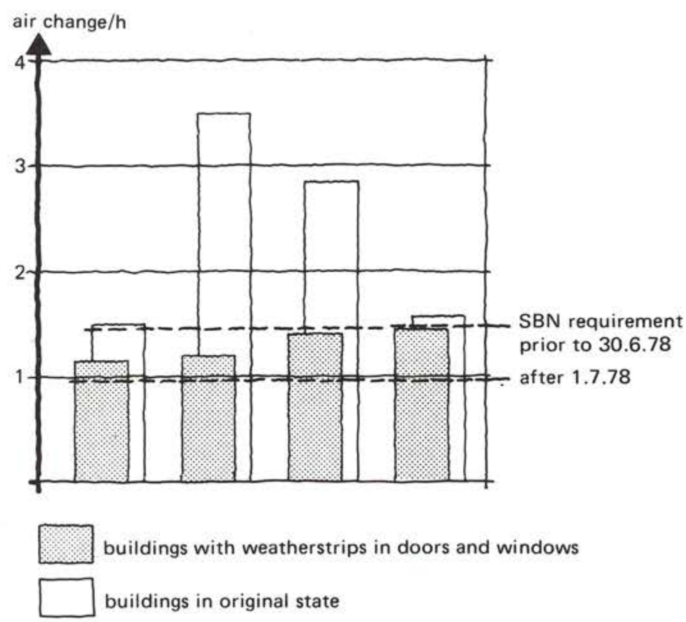



*FIG. 7. Air changes/h determined at an outdoor-indoor pressure difference of 50 Pa for four flats before and after installation of new weatherstrips in windows and doors.*

*On average, air leakage was cut from 2.3 to 1.3 air change/h (note that these air change rates are not directly comparable with those determined by the tracer gas method).*

These results may also be compared with the Commentary to Swedish Building Regulations, 1977:3. This sets out reasonable values for new residential buildings pressure tested at 50 Pa.

| | |
|---|---|
| Detached houses and linked houses | 3.0 air changes/hour |
| Other residential buildings (not exceeding 2 storeys) | 2.0 air changes/hour |
| Other residential buildings (three or more storeys) | 1.0 air change/hour |

It is evident that the Ulvsunda buildings now have an airtightness of the same order as that specified for new buildings. An oil saving of 4.6 litres/m$^2$ floor area was possible.

It may be mentioned as an example of the economic result that the internal rate of return was 25% (assumed service life of 10 years) and the break-even period 5 years (at a discount rate of 10%). The profitability of the measure is thus satisfactory.

## 1.4 RESEARCH NEED

Only a few investigations of the weatherproofing properties of door and window strips have been made previously in Sweden and abroad. There were thus good reasons for the setting up of a special research project to elucidate this problem area.

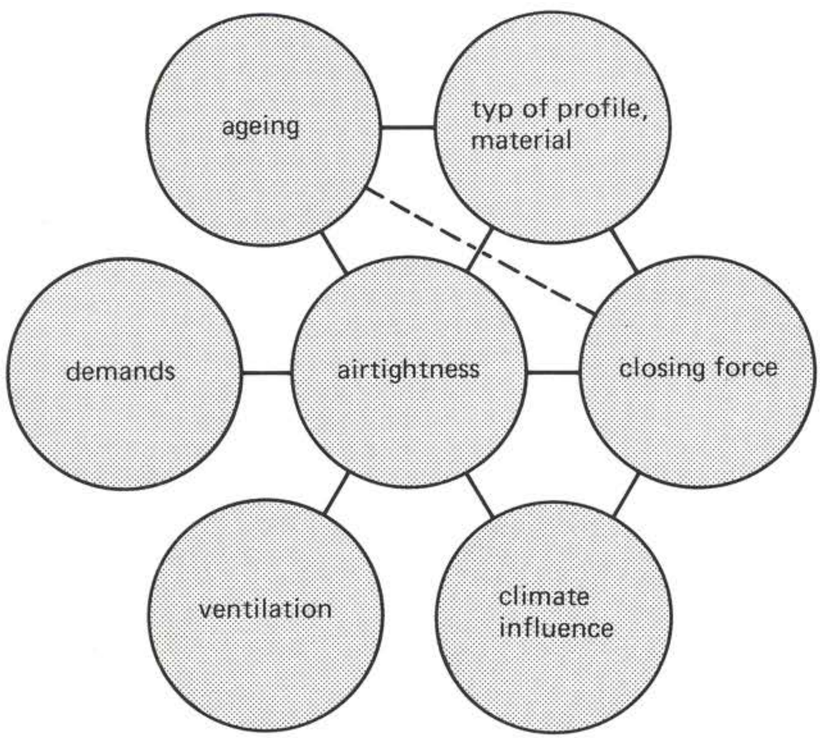
A project of this nature was therefore started in 1976 at the Department of Building Technology, Royal Institute of Technology, Stockholm, with some economic assistance from the National Swedish Council for Building Research.

We hope that this publication, the research work is still going on, will be instrumental in raising the level of knowledge in this hitherto neglected area, and will provide assistance and guidance to all who have to tackle the problem of weatherproofing doors and windows.

# 2 The scope of the investigations

This publication gives details of studies of the performance of weatherstrips for doors and inward-opening windows. It deals only with the seal between casement and frame, and disregards leakage of air between the frame and the wall construction. All investigations were made on new windows and doors, and the results are therefore mainly applicable to newly produced doors and windows.

The effect due to weatherstrips for doors and windows was assessed with regard to their sealing capacity and, in the case of doors, also with regard to the requisite closing force. Tests concerning airtightness and closing force were made at full

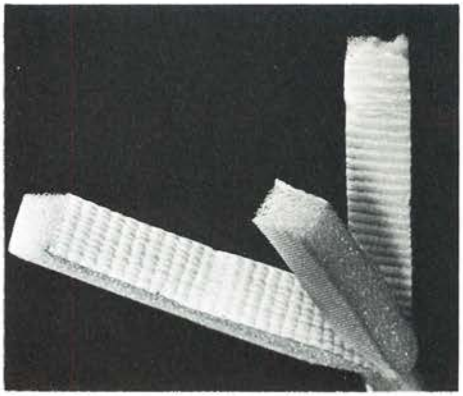


scale. For purposes of comparison, the closing pressure according to Proposal No. 600/13 (»Weatherstrips for doors and windows — Testing», Swedish Standard SIS 36 71 10) of the Building Standards Institution was also determined for weatherstrips for doors. The ageing properties of the strips were determined by subjecting them to heat when they were compressed or extended.

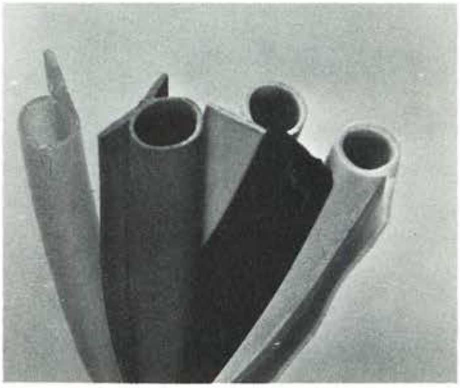
Investigations of door strips were made on strips designed for mounting in a groove provided in the frame, which is the most common method of mounting in conjunction with new production. Leakage of air and closing force were determined for strips of different types and material thicknesses, for gaps varying between about 4 and 8 mm.

The window strips were subjected to airtightness tests in a new inward-opening triple-glazed window of the dimensions 100 x 120 mm, made to conform to Swedish Standard SIS 81 81 14. The gap width in the window was about 3 mm. The strips were of different types and had different material thicknesses.

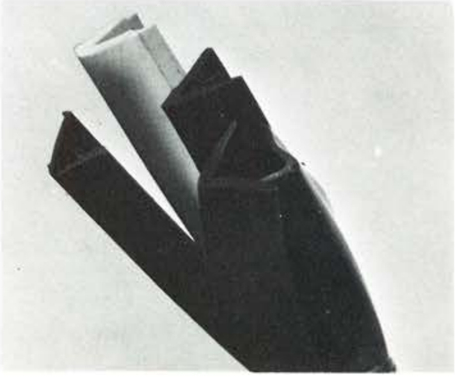
*Spun fibre strips with core of foamed plastic and porous rubber.*



*Self-adhesive strips of foamed plastic*



*Tubular strips of synthetic rubber and plasticised PVC.*



*Angle strips of synthetic rubber and plasticised PVC.*

# 3 Weatherstrips on the building market

## 3.1 DEVELOPMENT

Weatherstrips in the modern sense of the term have a relatively short history in building technology. The strips which were first made and which are still in use were spun fibre strips of wool or cotton. They bear a close resemblance to a soft string, and often have a diameter of 8 mm. Nowadays these are also made of synthetic fibres and may have a core of foamed plastics or porous rubber. Self-adhesive weatherstrips of foamed plastics, foam strips, were also used in the early days.

Naturally, these types of strips caused an appreciable improvement in airtightness at the time. However, it is a common characteristic of both fibre strips and foam strips that they are permeable to air and must therefore be extensively compressed in order that they should perform as intended. Foam strips are nowadays mainly sold as dust excluders and are placed between the casements in dual windows, i.e. not between the casement and the frame.

The modern types of strips are made of impermeable materials and have a profile of such design that they can be deformed relatively easily so that the door or window may be easy to close, but nevertheless provide a satisfactory seal. The strips must at all times endeavour to regain their original shapes (i.e. they must be resilient). Strips of this type often have a tubular or angular profile.

### Tubular

Tubular strips are made in profile heights of about 5 mm upwards, and angle strips about 7 mm upwards. The materials most commonly used are synthetic rubber (EPDM and chloroprene) and plasticised PVC. EPDM probably has the greatest share of the market. Silicone rubber is also used, but this material is considerably more expensive than those mentioned above and is therefore used to a lesser extent.

Expanded strips, i.e. porous rubber strips with closed pores, are also relatively new on the market. These strips must not be compressed more than 30%, or the pores may rupture. They are made in heights ranging from 3 mm upwards.

## 3.2 TYPES AND SYMBOLS

Types

Tubular strip (O strip) with toe for mounting in a groove. It is pressed into the groove.

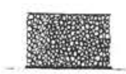
Tubular strip (O strip) for mounting on a flat surface. Self-adhesive, or mounted by stapling, nailing or gluing.

Angle strip (V strip) with toe for mounting in a groove. It is pressed into the groove.

Angle strip (V strip) for mounting on a flat surface. Mounted by stapling, nailing or gluing.

Tubular strip (D strip) with toe for mounting in a groove. It is pressed into the groove.

Expanded strip for mounting on a flat surface. Self-adhesive.



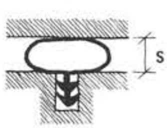
Foam strip for mounting on a flat surface. Self-adhesive.

Fibre strip for mounting on a flat surface. Mounted by nailing or stapling.

Symbols


t Wall thickness of strip. Does not refer to toe.


h Height of the unloaded strip. Toe is not included.




s Width of gap between closed door leaf or window casement and frame. A groove provided for mounting is not included. In the section on deformation tests, s denotes the height to which the investigated strip has been compressed.

Performance range of strip

That range, bounded by two values of s, within which a strip meets the requirements specified with regard to air-tightness and closing force.

The upper bound of the performance range is the maximum permissible air leakage, and the lower bound is the maximum acceptable closing force.

The terms positive and negative pressure, used in this publication, are defined as follows in accordance with Swedish Standards.

| | |
|---|---|
| Positive pressure | a pressure greater than the atmospheric pressure on the outside of the door/window. |
| Negative pressure | a pressure smaller than the atmospheric pressure on the outside of the door/window. |

## 3.3 MATERIALS AND PROPERTIES

The sealing performance of a weatherstrip is gradually affected as its properties change.

The property of primary importance is the resilience which is affected by the following factors which also determine the life of the strip:

- □ temperatures over the range -25°C – +75°C
- □ variation in moisture or evaporation of plasticiser which gives rise to swelling or shrinkage movements
- □ chemical action by solvents and detergents
- □ the action of sunlight and substances contained in the air.

The design of the strip should be such that it can be easily replaced when its performance deteriorates. Furthermore, the closing force shall not change during its service life. The strip should also have good resistance to mechanical action.

Weatherstrips are made of many materials. Some of the most common are rubber, PVC, polyethylene, wool, synthetic fibres and stainless steel sheeting. This investigation is concerned primarily with synthetic rubbers and PVC.

Most rubbers and plastics are sensitive to the action of oils and petrol, and also often to that of weak acids and bases. All are resistant to soap-based detergents.

Ozone attacks all rubbers which have double bonds in the main chain. This gas is formed in the higher air strata and also as a result of electrical discharges. It is therefore very unsuitable to store weatherstrips in rooms where electric motors are in operation. The action of ozone can be counteracted by the addition of anti-ozonants, i.e. substances which counteract cracking due to ozone.

Ultraviolet light mainly affects light or coloured materials. Black rubber contains carbon black (soot) which, apart from its reinforcing effect, also acts as an effective protection against ultraviolet radiation.

Heat affects most rubbers and plastics. Temperatures of over 100°C for rubbers and over 60°C for plastics are in most cases very unsuitable. Even at lower temperatures, temperature has a great effect on the life of the materials. As a rough guide, a 10°C rise in temperature doubles the ageing effect.

### 3.3.1 Plastics

The plastics which are mainly used for weatherstrips are different types of polyvinylchloride (PVC). PVC is a thermoplastic material which is extruded in the molten state through a nozzle which gives the strip its shape. In order that it should be resilient, a high proportion of plasticiser must be added. If poor-quality plasticisers are used, these evaporate after a time, and the strip may become tacky (dirt is accumulated) and also too hard. There is then a great risk that it will shrink. Shrinkage also occurs due to the release of internal stresses set up during manufacture.

### 3.3.2 Rubbers

The rubbers used in weatherstrips are synthetic. The raw material is oil. Synthetic rubbers such as EPDM, chloroprene and silicone rubber are suitable for outdoor use. The rubber is mixed with filler and plasticiser, extruded through a nozzle and then vulcanised. In this case also, plasticisers of low volatility should be used. If the rubber strip is under- or over-vulcanised, it will age more rapidly than normal.

*Chloroprene rubber (CR)* has good resistance to ozone, heat and oils. However, its resistance to oils is not sufficient for extended contact with petrol or oil. The material has excellent resistance to weak acids and bases.

*EPDM* denotes Ethylene Propylene Terpolymer. It is a characteristic of EPDM that it is wholly resistant to ozone. This is due to the fact that the double bonds necessary for vulcanisation are placed in side groups and not in the main molecular chain. EPDM also has good resistance to oxidation and the action of heat, but it is not resistant to oils. It has excellent resistance to weak acids and bases.

*Silicone rubber (Q)* is primarily characterised by the fact that it can be used at both very high and low temperatures. It has excellent resistance to ozone and to the action of the weather, but has limited resistance to oils. On the other hand, the material appears to be sensitive to wear and is affected by weak acids and bases to a greater extent than the above materials. The price of the raw material is considerably higher than that for EPDM, chloroprene and PVC.

Note that one and the same material may be manufactured by different makers, and that therefore the quality is not always the same.

It may be difficult to determine which material a strip is made of. An easy way to find out is to ignite a small piece of the strip. Characteristic reactions for the materials discussed above are given below.

*TAB. 2 Characteristic properties on ignition of some materials used for weatherstrips (from Plastics in building technology).*

| Material | Combustion properties | Flame | Smell |
|---|---|---|---|
| PVC | Burns but goes out | Yellow with green base | Pungent |
| Chloroprene rubber | Burns but goes out | Yellow-green, smoky | Pungent, burnt rubber |
| Silicone rubber | Burns and continues to burn | Light yellow-white, white smoke | No smell, white ash |
| EPDM | Burns and continues to burn | Yellow flame with blue base | Like the smell of a burning wax candle |

# 4 Performance studies

## 4.1 AGEING – WEATHERSTRIPS[1)]

Investigations of the ageing properties of the materials EPDM, chloroprene rubber, silicone rubber and PVC were made, as mentioned before, in collaboration with tekn.dr. Bengt Stenberg of the Department of Polymer Technology, KTH. Ten different strips were studied. TAB. 3 shows the breakdown per material and profile.

[1)] The research work is still going on.

*TAB. 3. Breakdown of ageing tests per strip type and material.*

| Type | EPDM | Silicone rubber | Chloroprene rubber | PVC |
|---|---|---|---|---|
| Tubular strips | 3 | 1 | 1 | 1 |
| Angle strips | 1 | – | 2 | 1 |

### 4.1.1 Methods of investigation

*Extension test*

Four similar sets of strip samples of 100 mm length were weighed and mounted on sheets. One set was mounted in its original state while the other three were mounted after being extended by 5, 10 and 20% of their original lengths. The samples were then placed in a heating cabinet at a temperature of +60°C. Observations of cracking and other effects were made every day in the beginning, and later once a week, for 100 days.

*Deformation test*

The deformation properties were investigated by compressing four similar sets of strip samples. Tubular strips were compressed to s=4.5 mm, and the angle strips to s=6 mm. Two sets were stored in a heating cabinet at an air temperature of +60°C, and the other two at room temperature of +22°C. The tubular strips, which according to the manufacturer's information had a nominal height of 8 mm, were however found, after being mounted onto the test sheets and a short initial compression, to have heights varying between 6.2 and 9 mm.

The same applied in the case of the angle strips, for which the heights of 11–14 mm (according to the makers) were measured as 9.2–13.1 mm.

During the investigation, the strips were relieved of load once a week (over a period of 100 days) for 10 and 30 minutes. These times may be considered to be equivalent to the times a window or a door is kept open. At the end of the above times the heights of the strips were measured with a depth gauge. The difference between this height and the original height of the strip provided a measure of the deformation which remained after removal of the load.

### 4.1.2 Results

*Extension test*

All the chloroprene strips which had been extended by 20% of the original length cracked and broke during the first day.

After a few more days, a chloroprene strip which had been extended by 10% also broke. The other samples were still completely undamaged after 100 days, and no detrimental effect could be detected.

The investigation showed that EPDM, silicone rubber and PVC have a higher resistance to cracking while subjected to tensile stresses than chloroprene rubber. This property has great significance for weatherstrips of angular or tubular profile. When these strips are compressed between the mating surfaces of a door or window, the profile of the strip is deformed, and zones subjected to tensile stress are set up. In unfavourable cases this can give rise to longitudinal cracking.

*Deformation test*

The results of the deformation test are set out in the diagrams in FIG. 8.

The strips recovered rapidly when they were relieved of load. The difference in readings made 10 and 30 minutes respectively after removal of the load is therefore small, and is not shown separately.

Most of the permanent deformations occurred as early as after about 50 days, i.e. half the duration of the test.

The test results showed that silicone rubber strips had very small permanent deformations. EPDM and chloroprene rubber strips had somewhat larger deformations. In all the tests, PVC strips had the largest permanent deformations.

Weighing of the strip samples after 120 days at +60°C showed that all strips, with the exception of those made of silicone rubber, had lost weight. In some cases, the PVC strips

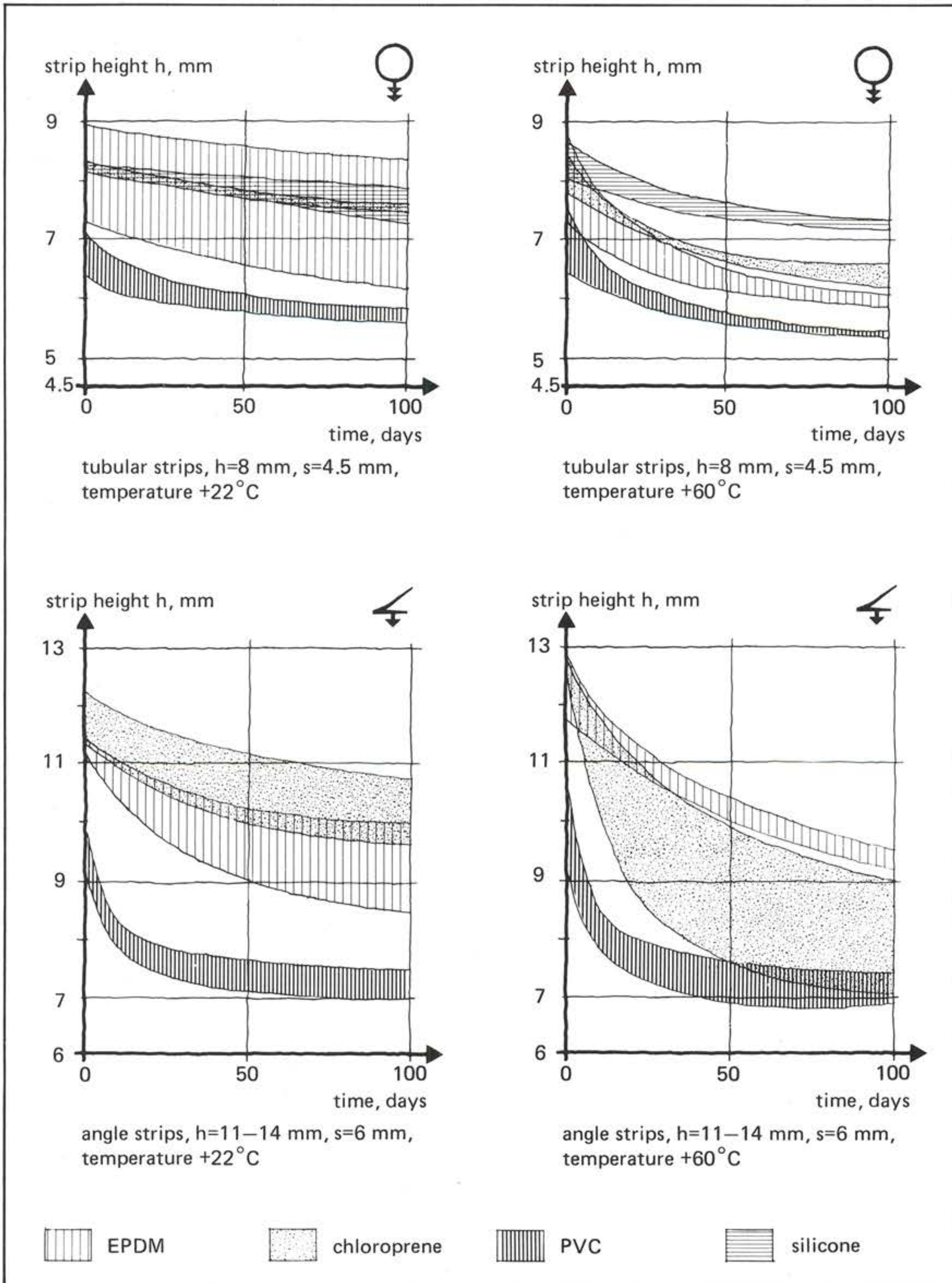



*FIG. 8. Summaries of permanent deformations measured for weatherstrips. Tubular strips had been compressed to s=4.5 mm and angle strips to s=6 mm. The vertical axes of the diagrams start at these values of s. The distance between the horizontal axis and the deformation curve is a measure of the recovery of the strip after removal of load.*

had lost 4% weight, and strips of chloroprene and EPDM about one half of this. One EPDM strip had lost more than 5% of its original weight. The reason for the loss in weight by the strips is evaporation of process oil, plasticiser and other additives in the rubber and PVC mixes. In the case of PVC, the result was that the strips had become more brittle and harder, with a reduced airtightness, since PVC itself is a hard material. EPDM, which is a soft material, was not affected so unfavourably by evaporation of the plasticiser.

### 4.1.3 Summary

Our investigations and experiences, which are also confirmed by the results gained by the Building Research Division of the National Association of Tenants' Saving and Building Societies (HSB) and the Norwegian Building Research Institute, thus indicate that special rubber mixes such as silicone rubber, EPDM and chloroprene rubber are preferable to PVC for weatherstrips for doors and windows. The probable life expectancy of these synthetic rubbers is about 10 years.

## 4.2 AIRTIGHTNESS – WINDOWS

In determining the leakage of air, the guarded pressure box method, a technique developed in the 60s at the Department of Building Technology, KTH, was used.

A measuring box (FIG. 9–10) was mounted with its open side towards the construction under investigation. The junction between the measuring box and the construction was

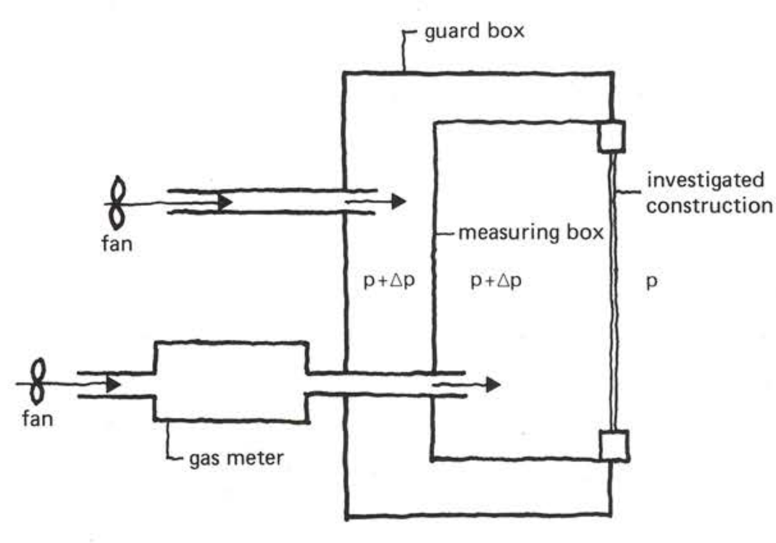



*FIG. 9. General layout of the guarded pressure box method, developed at the Department of Building Technology, Royal Institute of Technology, Stockholm.*

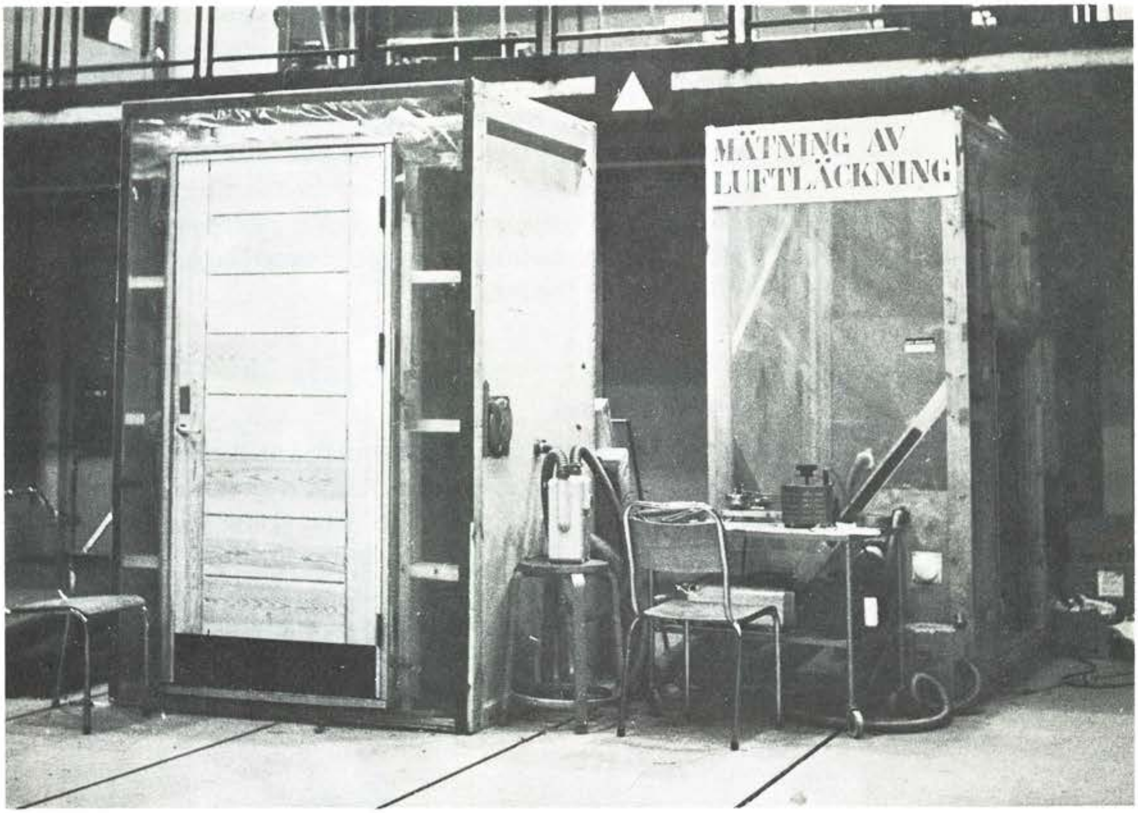


*FIG. 10. Test equipment. To the left, the guarded pressure box used in investigating the door strips, and to the right corresponding equipment used in testing the window strips. In the centre stands the measuring apparatus comprising gas meter, pressure gauge, control equipment and fans.*

sealed very thoroughly. Outside this measuring box there was placed a guard box. Fans were used to generate a negative or positive pressure of the same magnitude in both boxes, with the result that there was no difference in pressure between the measuring box and the guard box, and, theoretically, it was impossible for leakage of air to occur between the two boxes. In practice, flow of air between the boxes could be ignored if pressure was being regulated accurately. All the air which was forced into or drawn out of the measuring box (via a gas meter) leaked through improperly sealed joints in the construction under investigation. The guard box was thus used to prevent uncontrollable edge losses. Leakage of air was measured in this way at both positive and negative pressures. Pressures were varied in accordance with a predetermined plan which was different for doors and windows. Measurement of air leakage was made when the fans had been set in such a way that a steady state had occurred. Readings of the gas meter were made every minute for five minutes, and the mean value was calculated.

The air leakage figure set out below for the different strips is the highest reading, regardless of whether it had occurred at a positive or negative pressure.

### 4.2.1 Accuracy of the method

The guarded pressure box method provided very good accuracy during determinations of air leakage. When tests were repeated in the same test set-up, the maximum deviation was 5%. When tests were repeated, for instance when a door with its frame was removed and then mounted again on another occasion, there was a somewhat larger variation in results. This confirms the importance of accurate mounting. In order to obtain the best possible results, doors and windows were mounted vertically, at right angles and without bending or twisting.

Readings were made in units of l/min. This value was then converted into air flow per unit time and area (external frame dimension), the unit being $m^3/m^2$ h.

### 4.2.2 The quality of the test window

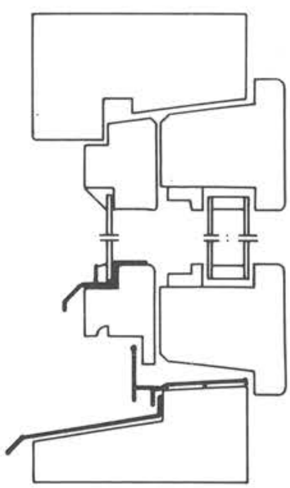


*FIG. 11. Section of triple-glazed window used in the investigations (in principal conformity with Swedish Standard SIS 81 81 14).*

Most wood windows made in Sweden today have a design in conformity with the appropriate Swedish Standard. For inward-opening windows this is SIS 81 81 14. The Standard applies to both double-glazed and triple-glazed windows.

The weatherstrip is placed where the casement abuts onto the frame, and the gap for the weatherstrip must be 3 mm in width. In practice, it is often found that the gap varies from about 2 mm to over 4 mm. This places great demands on the weatherstrip, which must have a performance range covering this variable gap. External weatherstrips attached by stapling, taping or gluing, are preferably used.

An inward-opening triple-glazed window[1], in principal conformity with Swedish Standard SIS 81 81 14 (FIG. 11), was used in the investigations. The window had the modular dimension 10 x 12 M (the dimension ~ 1000 x 1200 mm). The area, calculated over the external frame dimension, was 1.16 $m^2$.

### 4.2.3 Investigation samples

22 weatherstrips (TAB. 4 and 5) were investigated in the window.

[1] The research work is going on using other types of windows.

| Profile | Height h, mm | Wall thickness t, mm | Material and colour |
|---|---|---|---|
|  | 5 | 0.5 | EPDM, black |
|  | 5.5 | 0.5 | EPDM, grey |
|  | 5.5 | 0.6 | EPDM, black |
|  | 7 | 0.6 | PVC, white |
|  | 7 | 0.7 | Silicone, white |
|  | 8 | 0.6 | EPDM, grey |
|  | 6 | 1.0 | PVC, white |
|  | 9 | 1.0 | EPDM, black |
|  | 9 | 0.8 | PVC, black |
|  | 9 | 1.3 | Chloroprene, black |
|  | 7 | 0.8 | EPDM, black |
|  | 4 | 4.0 | Foam strip, white |
|  | 7 | 7.0 | Foamed polyethylene core surrounded by synthetic fibre, white |
|  | 7 | 1.3 | Expanded EPDM, black |
|  | 7 | 3 | Expanded EPDM, black |
|  | 4 | – | Expanded EPDM, white |
|  | 3 | – | Expanded EPDM, grey |
|  | 6 | 0.12 | Stainless steel on foamed plastics, shiny |
|  | 6 | – | Foamed polyethylene, white |
|  | 7 | – | Foamed polyethylene, white |
|  | 8 | – | Wool yarn, white |
|  | 8 | – | Expanded EPDM core surrounded by synthetic fibre |

*TAB. 4. Profiles and materials of the strips.*

| Strip type | Material EPDM | Chloro-prene | Sili-cone | Expanded EPDM | PVC or other plastics | Fibre with or without core | Stain-less steel | Total |
|---|---|---|---|---|---|---|---|---|
| Tubular strip | 4 | – | 1 | 1 | 1 | – | – | 7 |
| Angle strip | 2 | 1 | – | – | 2 | – | 1 | 6 |
| Expanded strip | – | – | – | 3 | – | – | – | 3 |
| Foam strip | – | – | – | – | 3 | – | – | 3 |
| Fibre strip | – | – | – | – | – | 3 | – | 3 |
| Total | 6 | 1 | 1 | 4 | 6 | 3 | 1 | 22 |

*TAB. 5. Types and numbers of strips.*

### 4.2.4 Mounting of the weatherstrips

Leakage of air for tubular and angle strips was first studied using different mounting methods, as shown in FIG. 12–13. In the continued comparative investigations, Alternative a, which had the least air leakage for tubular strips, was chosen. Although Alternative a had a somewhat larger air leakage for angle strips than Alternative b, it was nevertheless chosen for the continued investigations in order that mounting for all types of strip may be the same.

In the investigations, all weatherstrips were mounted with the greatest possible degree of similarity. They were attached to the mating surface on the casement. Mounting was carried out with great care (FIG. 14).

Tubular strips of heights up to 6 mm could be mounted in an unbroken length around the whole of the window. Only one joint was obtained in this way.

The larger tubular strips had to be jointed in every corner. If they were bent, hard bulges were formed which made closing difficult and affected the seal adversely. It was, however, possible to obtain a good seal in the corners if care was taken to ensure that the joints in the strips were properly fitted together.

It was more difficult to mount the angle strips in a satisfactory manner. It was not possible to mount them in an unbroken length around the corners. There were four joints, and it was difficult to make these airtight.

Expanded and foam strips were mounted on the same place as the tubular and angle strips, i.e. on the mating surface of the casement, as far out as possible. These strips can be mounted very easily using a self-adhesive tape, but must be jointed in every corner. The quality of the tape may vary.

Fibre strips were also mounted in the same place as the other

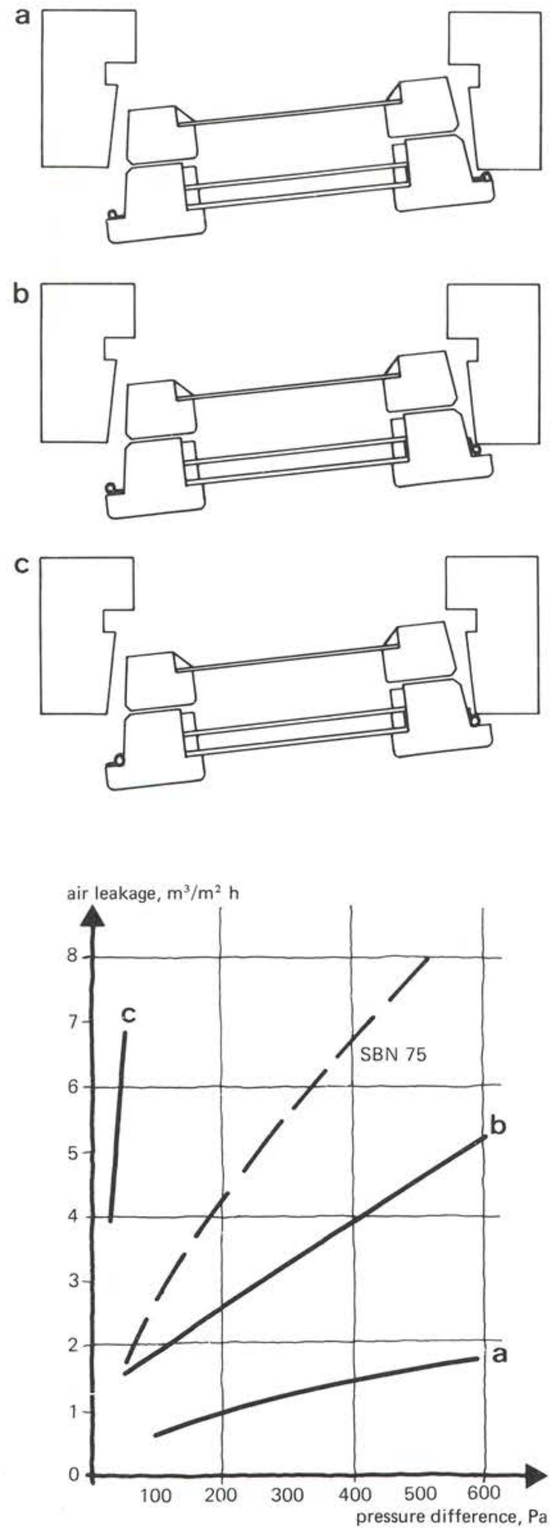



*FIG. 12. Tubular strip. Air leakage determined for different methods of mounting. The dashed curve indicates maximum acceptable air leakage according to SBN 1975.*

strips. They could be mounted in an unbroken line all round the window with only one joint, and were attached with staples. These strips can also be mounted by tacking or with a self-adhesive tape.

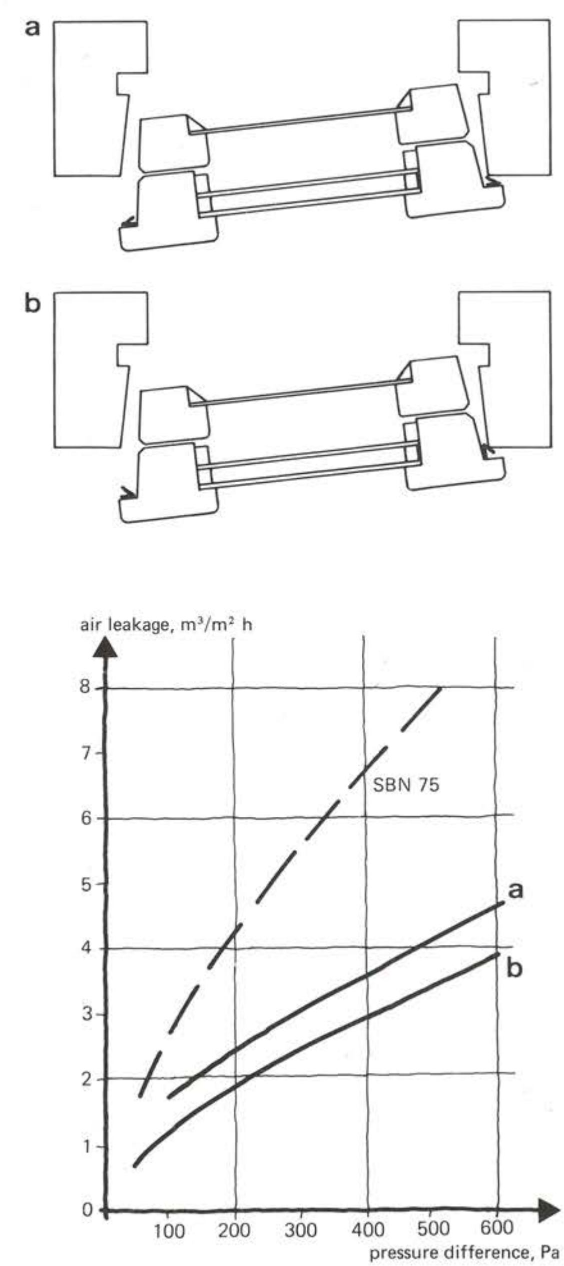



*FIG. 13. Angle strip. Air leakage determined for different methods of mounting. The dashed curve indicates maximum acceptable air leakage according to SBN 1975.*

*FIG. 14. Mounting of weatherstrip with staples onto window casement without a groove. According to HusAMA (Material and Workmanship Specifications for Building Construction), the spacing of the staples is to be 80 mm. In some cases work is made easier if the casement is taken off.*

### 4.2.5 Investigations

The investigations were made in the previously described guarded pressure box. The actual test procedure was largely in conformity with Swedish Standard SIS 81 81 26, Determination of the airtightness of windows. The difference was that measurements were made using a double box which gave more reliable values of air leakage. The pressure levels used were 100, 200, 400 and 600 Pa (FIG. 15).

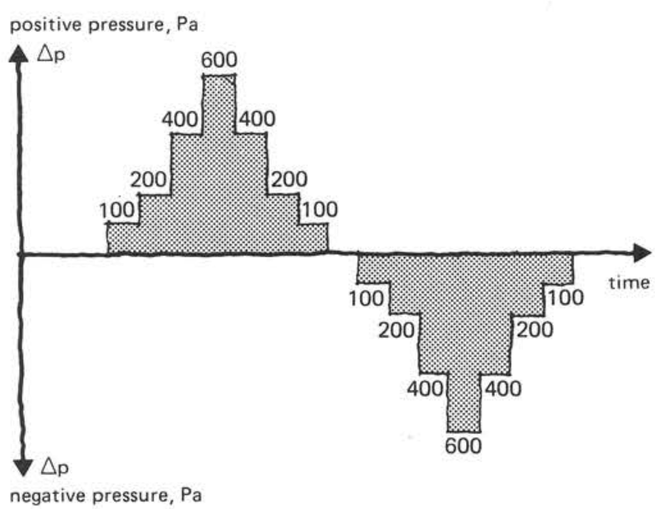



*FIG. 15. Schedule for investigation of weatherstrips for windows. Pressure was increased in steps to 600 Pa and reduced in steps to 0. Measurements were made for both positive and negative pressures (on the outside of the window).*

### 4.2.6 Test results

The values of air leakage determined are set out in FIG. 16–20. For purposes of comparison, these diagrams also show curves of the maximum acceptable leakage according to Swedish Building Regulations SBN 1975 which apply to new windows.

*Tubular strips*

All tubular strips had very good results in the test window with regard to airtightness (FIG. 16).

The lowest and best curve shows leakage for a silicone rubber strip, followed by a PVC strip, and then by five strips with fairly similar air leakage values. Four of these strips consist of EPDM rubber, and one of expanded EPDM (expanded rubber). On average, it was the larger tubular strips (h=7–8 mm) which had the best airtightness, in spite of their having to be jointed in four places. The smaller tubular strips (h=5–6 mm) did not provide quite such a good seal.

*Angle strips*

The results for angle strips exhibited a larger scatter than for

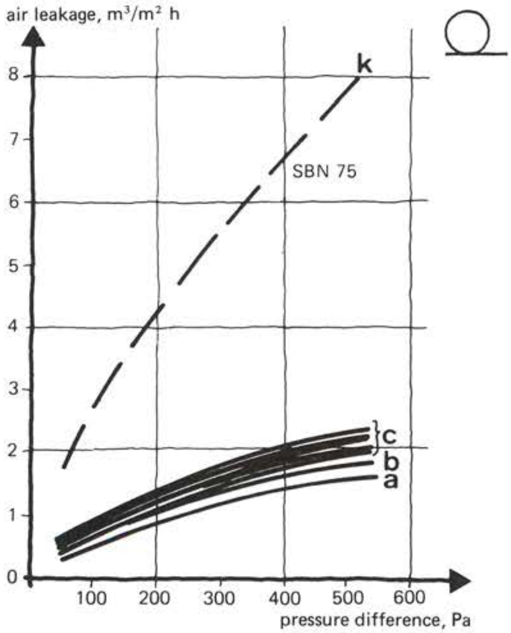



*FIG. 16. Air leakage determined for tubular strips.*

*a silicone rubber, h=7 mm, t= 0.7 mm*
*b PVC, h=7 mm, t=0.6 mm*
*c EPDM, h =5–8 mm, t=0.5–0.6 mm*
*k maximum acceptable air leakage according to SBN 1975.*

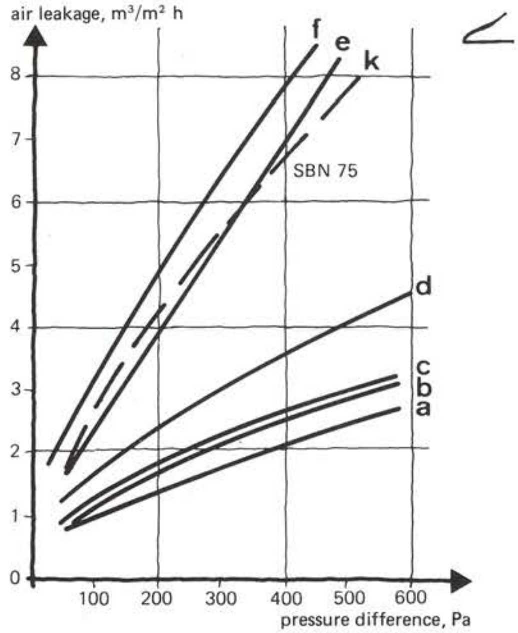



*FIG. 17. Air leakage determined for angle strips.*

*a PVC, h=6 mm, t=1 mm*
*b EPDM, h=9 mm, t=0.8 mm*
*c chloroprene, h=9 mm, t=1.3 mm*
*d PVC, h=9 mm, t=0.8 mm*
*e EPDM, h=9 mm, t=1 mm*
*f stainless steel, h=6 mm*
*k maximum acceptable air leakage according to SBN 1975.*

tubular strips. However, airtightness was on average fairly good. Air leakage curves for the investigated angle strips are shown in FIG. 17. The heights of these strips are between 6 and 9 mm, but it is impossible to determine in an unambiguous way which height is best for the test window from the airtightness standpoint. The scatter in the results may to some extent be due to the difficulty of obtaining a good and airtight joint in the corners.

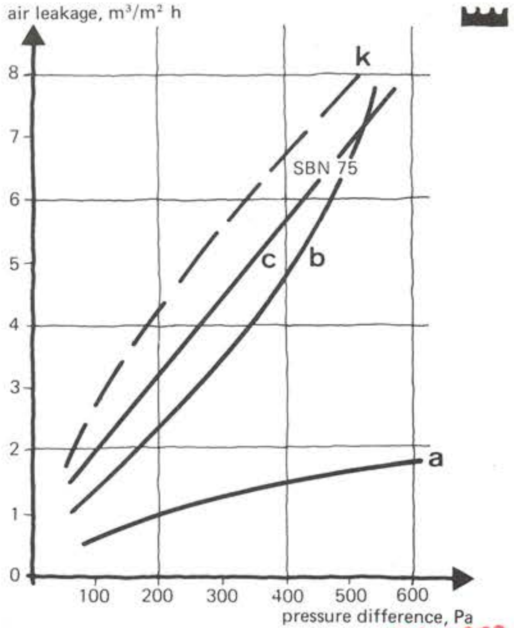
According to the measurements, it was a PVC strip of height h=6 mm and wall thickness t=1 mm which provided the best seal. This was followed by an EPDM strip of h=9 mm and t=0.8 mm, and then by a chloroprene strip of h=9 mm and t=1.3 mm. The fourth curve shows air leakage for a PVC strip of h=9 mm and t=0.8 mm. The results for an EPDM strip of h=9 mm and t=1 mm, and an angle strip of stainless steel sheeting of h=6 mm, were clearly inferior. In the case of the rubber strip it is assumed that the high air leakage is due to the angle being too large, with the result that the strip can bend the wrong way. Relatively large air leakage was found in the case of the stainless steel strip. A large proportion of leakage took place in the corners, which were very difficult to make airtight. This strip requires particularly thorough mounting.

*Expanded strips*

Three expanded strips were examined. They consisted of expanded EPDM with closed cells. FIG. 18 shows the measured leakage of air. An expanded strip of 7 mm height was the most airtight, followed by strips of 4 and 3 mm height. It was found that the thicker the expanded strips were, the better seal they provided. However, the closing force also increased, but since this has not been measured on windows, an optimum value of the strip height cannot be given.

*Foam strips*

Three foam strips of different heights were investigated. They consisted of different kinds of foam plastics with open cells, and the material was therefore permeable to air. The airtightness of the window depended on the permeability of the strip material and on the degree of compression of the strip. The test window therefore became the more airtight, the larger the foam strip (of the same make) that was being used. However, foam strips age more rapidly if they are compressed too much. FIG. 19 shows air leakage curves for three strips compressed according to the makers' instructions. The most airtight was a 4 mm strip of very impermeable material. This is followed by an ordinary 7 mm foam strip, and by one of 6 mm height. In the case of all these strips, leakage of air was very large.




EXPANDED

*FIG. 18. Air leakage determined for ~~angle~~ strips.*

- *a* *EPDM, h=7 mm*
- *b* *EPDM, h=4 mm*
- *c* *EPDM, h=3 mm*
- *k* *maximum acceptable air leakage according to SBN 1975.*

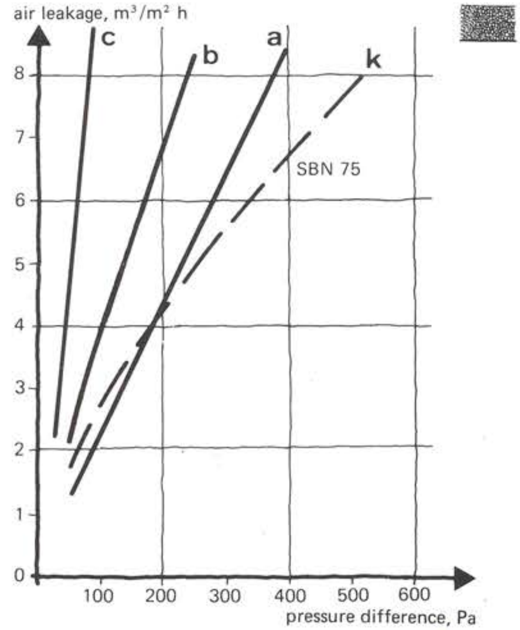



*FIG. 19. Air leakage determined for foam strips.*

- *a* *impermeable foamed plastics, h=4 mm*
- *b* *foamed plastics, h=7 mm*
- *c* *foamed plastics, h=6 mm*
- *k* *maximum acceptable air leakage according to SBN 1975.*

*Fibre strips*

Air leakage measured for three fibre strips is shown in FIG. 20. The most airtight in this group was a strip with a core of expanded EPDM (expanded rubber). The core had a diameter of 5 mm, and the height of the complete strip was 8 mm. The other two curves show air leakage for fibre strips of 8 mm height with and without a foam plastics core. Leakage was very high.

### 4.2.7 Conclusions and recommendations

The types which best satisfied the airtightness requirements in SBN 1975 were strips of tubular or angular profile. A properly chosen expanded strip could also provide satisfactory airtightness. Older types of strips, such as foam and fibre strips, in most cases did not satisfy the requirements laid down in the regulations (FIG. 21).

It was extremely important for mounting to be done with care. A good result was easier to reach with tubular strips than with angle strips.

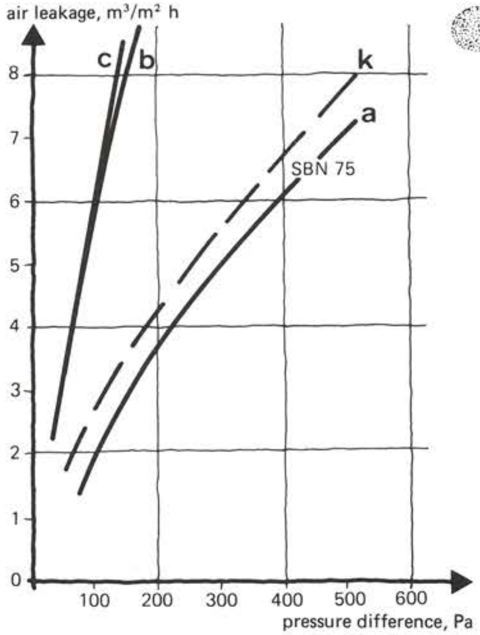



*FIG. 20. Air leakage determined for fibre strips.*
- *a with core of expanded EPDM rubber, h=8 mm*
- *b wool, h=8 mm*
- *c with core of foamed plastics, h=8 mm*
- *k maximum acceptable air leakage according to SBN 1975.*

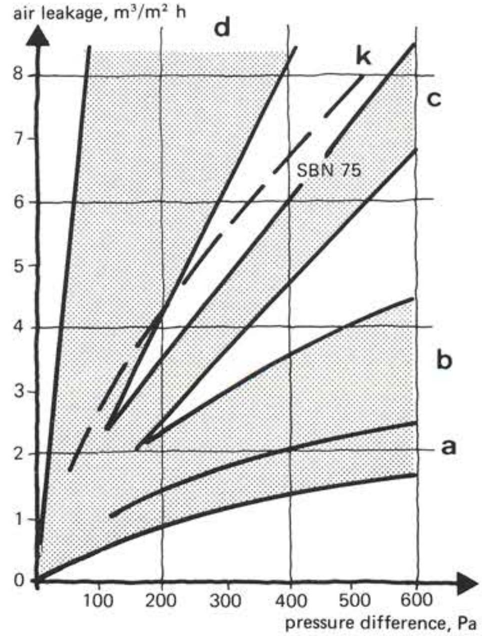



*FIG. 21. Summary of test results for weather-strips in windows.*
- *a tubular strips*
- *b angle strips*
- *c expanded strips*
- *d foam and fibre strips*
- *k maximum acceptable air leakage according to SBN 1975.*

## 4.3 AIRTIGHTNESS – DOORS

In new external doors of wood, strips made of solid synthetic rubber or PVC are exclusively used to provide a seal between the door leaf and the frame. The strips may be angular or tubular in profile, and different types of strips may be mounted at different places on the same door, mostly in grooves sawn or cut into the frame or door leaf.

There is no standard for the width of gap. Each door manufacturer employs the gap he considers appropriate. The gap width is normally between 4 and 8 mm.

In order that the performance range of the strips may be determined, air leakage and closing force were determined for four gap widths, the mean values of which were measured as 4.6, 6.0, 7.8 and 8.3 mm. The four different gap widths were obtained by using four frames on which hinges and striking plates had been mounted in different positions. The gap width was then determined by placing modelling clay on the mating surface at eight places before closing the door. Measurements were made with a sliding gauge on the modelling clay which remained in position.

### 4.3.1 The test door

The external door used in the investigation had the modular dimension 21 x 10 M (the dimension ~ 2100 x 1000 mm), and the weatherstrips were mounted in a sawn groove in the frame.

### 4.3.2 Investigation samples — weatherstrips for doors

A total of 17 strips of different heights and profiles (TAB. 6), of which 11 were tubular strips and 5 angle strips, were investigated in the door. They were made of EPDM, chloroprene

| Profile | Height h, mm | Wall thickness t, mm | Material and colour |
|---|---|---|---|
|  | 7.5 | 0.60 | Silicone, white |
|  | 8 | 0.70 | Silicone, white |
|  | 8 | 0.75 | EPDM, black |
|  | 8 | 0.80 | EPDM, black |
|  | 8 | 0.80 | EPDM, grey |
|  | 8 | 0.85 | Chloroprene, black |
|  | 8 | 0.60 | EPDM, grey |
|  | 10 | 0.60–1.80 | EPDM, black |
|  | 10 | 0.95 | EPDM, black |
|  | 10 | 0.80 | EPDM, black |
|  | 12 | 0.95 | EPDM, grey |
|  | 12 | 0.60 | EPDM, grey |
|  | 11 | 0.50–1.40 | PVC, black |
|  | 11 | 0.80–1.70 | Chloroprene, black |
|  | 12 | 1.00–1.80 | EPDM, black |
|  | 12 | 0.80–1.60 | Chloroprene, black |
|  | 14 | 0.90–1.60 | Chloroprene, black |

*TAB. 6. Investigated weatherstrips for doors.*

rubber, silicone rubber and plasticised PVC. One strip, designated a D strip, which is intermediate between a tubular and an angle strip, was also investigated. This strip is made of EPDM.

The 17 strips could be placed into 10 groups, the values of air leakage and closing force within the groups being similar (TAB. 7).

| Strip group | Type | Height, h, mm | Wall thickness t, mm |
|---|---|---|---|
| 1 | Tubular strip | 7.5 | 0.60 |
| 2 | Tubular strip | 8 | 0.70 |
| 3 | Tubular strip | 8 | 0.80 |
| 4 | Tubular strip | 10 | 0.80 |
| 5 | Tubular strip | 10 | 0.95 |
| 6 | Tubular strip | 12 | 0.60 |
| 7 | Tubular strip | 12 | 0.95 |
| 8 | D strip | 10 | 0.60 |
| 9 | Angle strip | 11–12 | |
| 10 | Angle strip | 12–14 | |

*TAB. 7. Grouping of weatherstrips for doors.*

### 4.3.3 Mounting of the weatherstrips

The strips were mounted in the groove sawn into the frame with a special tool consisting of a roller with a handle which was pressed against the strip. The strips were »rolled» into place (FIG. 22).

*Tubular strips* were mounted on the top and bottom members of the frame right up to the side members. On the strips laid on the side members, a piece of the toe was cut away, and the strips were made to project over the strips laid along the top and bottom members. A good joint was obtained in this way in the corners (FIG. 23).

*Angle strips* were mounted on the hinge side so that the angle was »open» towards the outside, and on the top and on the lock side so that the angle was »open» towards the inside. On the bottom member (the doorstep) the strips were mounted in an aluminium section (FIG. 24).

All angle strips did not fit into this, so a tubular strip was mounted in this place. For a gap width of 6.0 mm an 8 mm strip of small material thickness was mounted, and for a gap width of 7.8 and 8.3 mm a 12 mm strip of small material thickness.

On the upper and bottom pieces of the door the strips were fitted all the way up to the side pieces of the frame. On the side pieces the strips were fitted according to FIG. 24 with an overlap of 15 mm.

*FIG. 22. Mounting of weather-strip with toe in the groove. The tool is a ball bearing with a handle.*

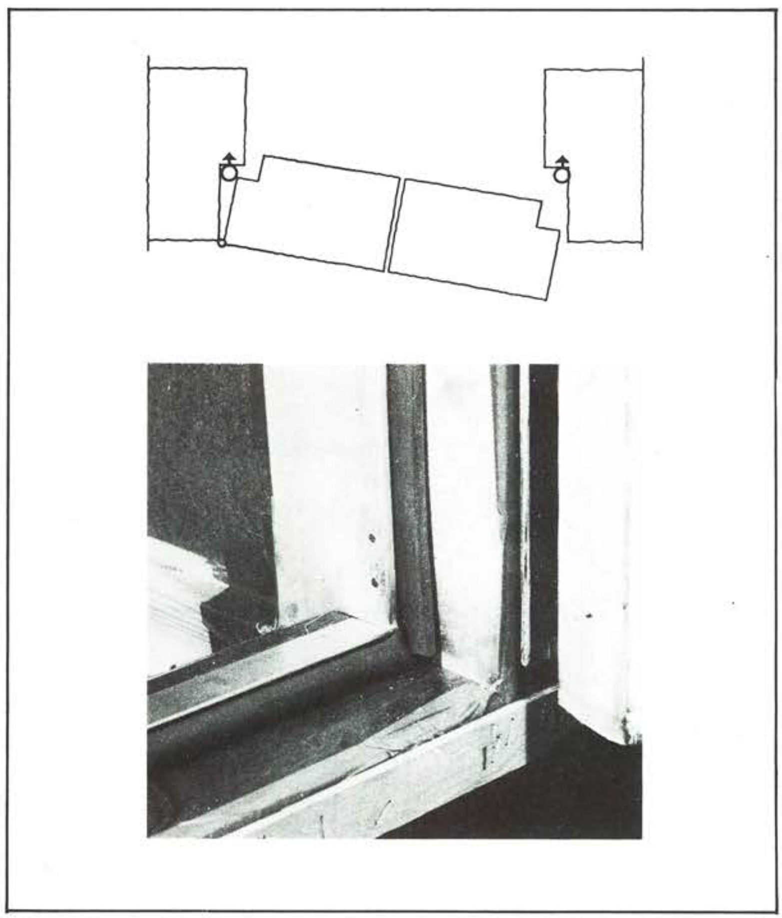


*FIG. 23. Mounting of tubular strips on doors.*

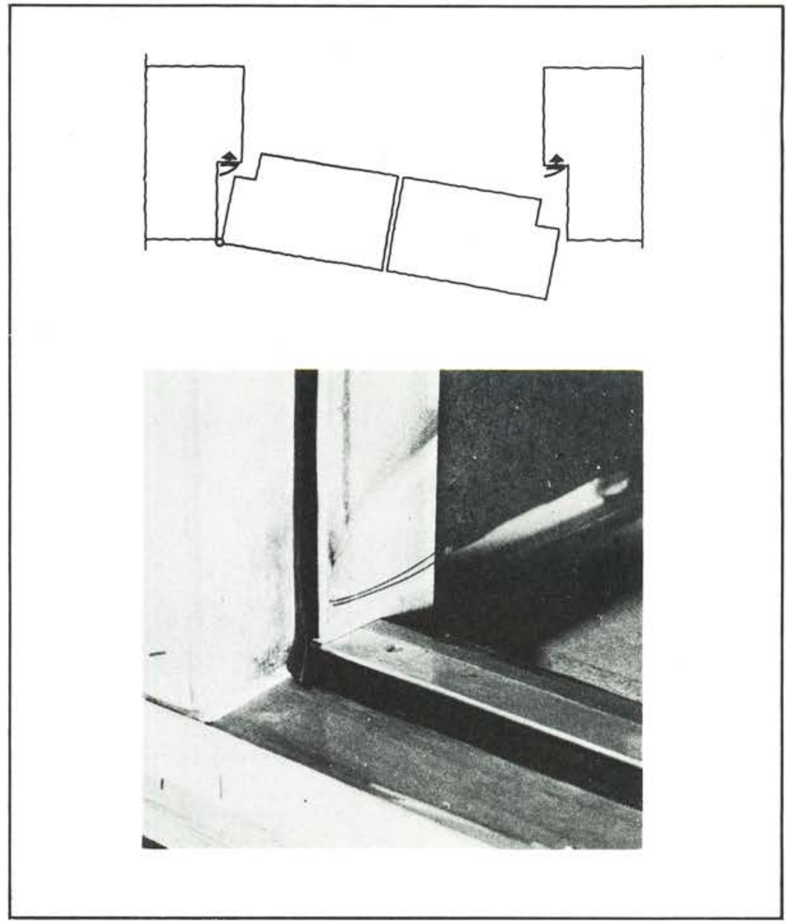


*FIG 24. Mounting of angle strips on doors.*

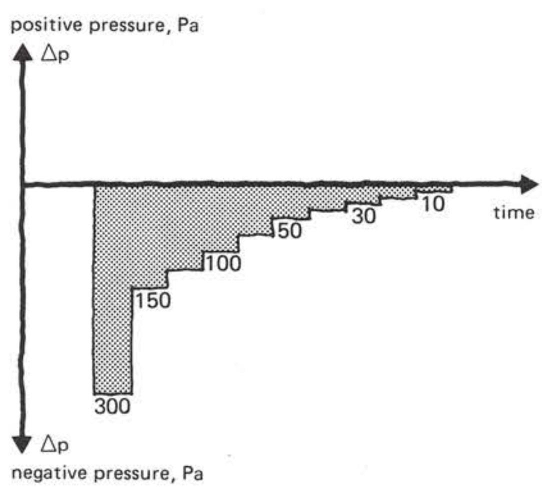



*FIG. 25. Schedule for investigations of weatherstrips for doors. Leakage was measured at a negative pressure (on the outside of the door) while pressure was reduced in steps from 300 Pa to 0.*

### 4.3.4 Test procedure – doors

The strips were examined with regard to airtightness for four gap widths. In the airtightness test the pressure in the box was raised from 0 to 300 Pa and was then again reduced to 0. The pressure levels used were 10, 20, 30, 40, 50, 75, 100, 125, 150 and 300 Pa. Measurement of air leakage was first of all made at both positive and negative pressures. After a large number of strips had been tested, it was found that leakage was at all times greatest at a negative pressure (outside the door) when pressure was reduced from 300 Pa to 0. At 300 Pa, pressure was applied on the inside of the door, and leakage increased. The difference in leakage between pressure rise and pressure drop was not so great, but since the pressure drop case was always found to provide the design criterion, only the pressure drop from 300 Pa to 0 is shown here (FIG. 25).

Leakage of air measured at different values of pressure difference and gap width is shown in FIG. 26–35 for the 10 groups of strips. For purposes of comparison, the curve showing the highest permissible air leakage according to SBN 1975 is also given.

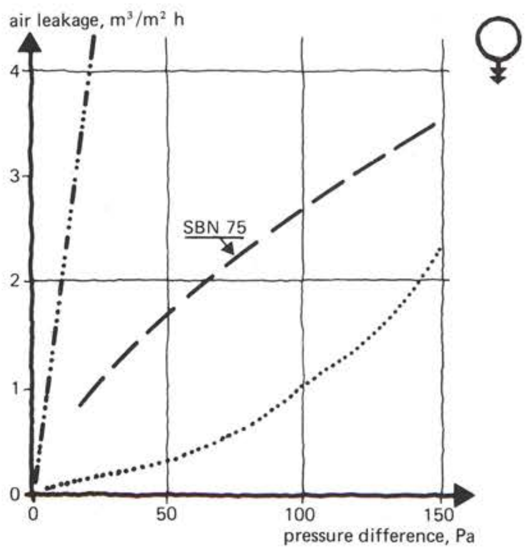



*FIG. 26. Air leakage determined for different gap widths for tubular strips h=7.5 mm and t=0.6 mm (Group 1).*

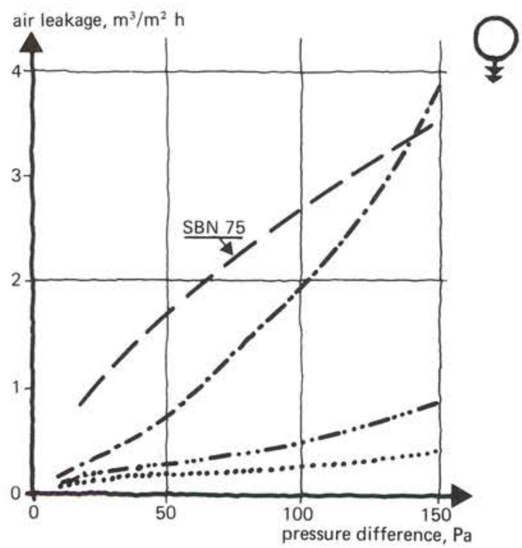



*FIG. 27. Air leakage determined for different gap widths for tubular strips h=8 mm and t=0.7 mm (Group 2).*

*gap width 4.6 mm*
*gap width 6.0 mm*
*gap width 7.8 mm*
*gap width 8.3 mm*
*maximum acceptable air leakage according to SBN 1975*

*Where the curves coincide, only the air leakage for the larger gap width has been shown.*

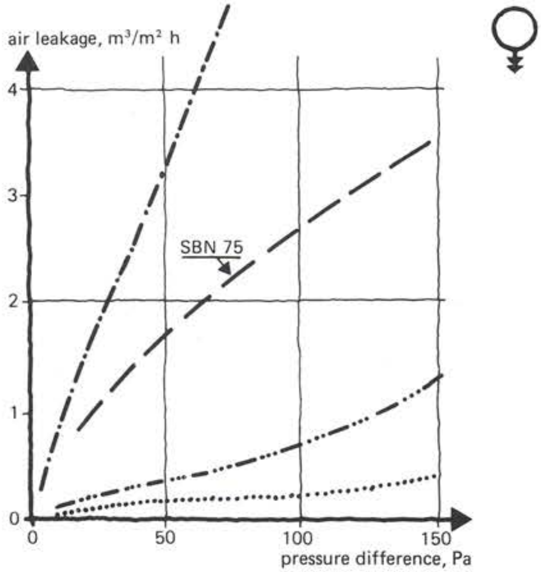



*FIG. 28. Air leakage determined for different gap widths for tubular strips h=8 mm and t=0.8 mm (Group 3).*

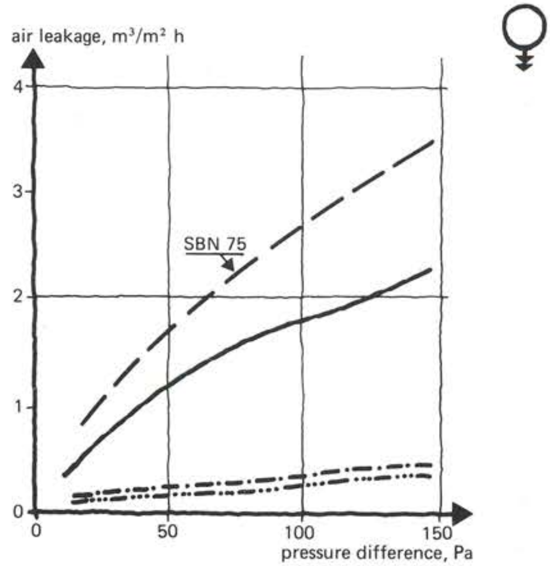



*FIG. 29. Air leakage determined for different gap widths for tubular strips h=10 mm and t=0.8 mm (Group 4).*

*gap width 4.6 mm*
*gap width 6.0 mm*
*gap width 7.8 mm*
*gap width 8.3 mm*
*maximum acceptable air leakage according to SBN 1975*

*Where the curves coincide, only the air leakage for the larger gap width has been shown.*

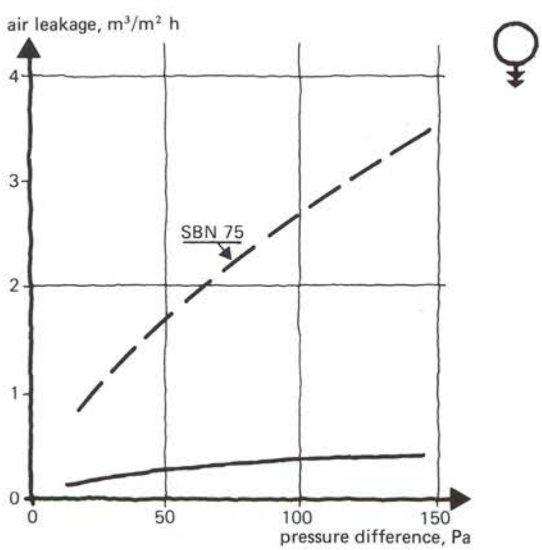



*FIG. 30. Air leakage determined for different gap widths for tubular strips h=10 mm and t=0.95 mm (Group 5).*

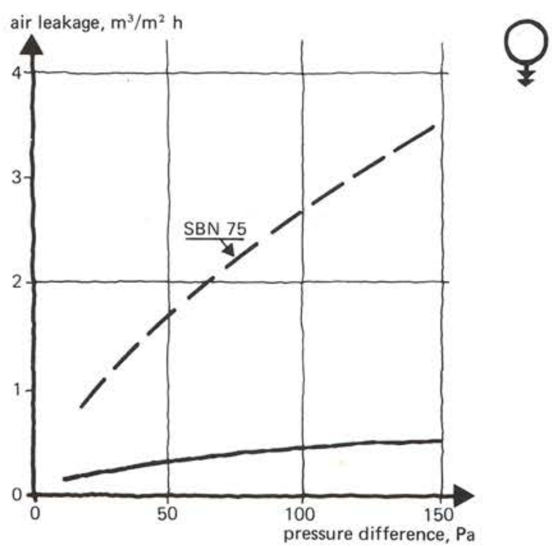



*FIG. 31. Air leakage determined for different gap widths for tubular strips h=12 mm and t=0.6 mm (Group 6).*

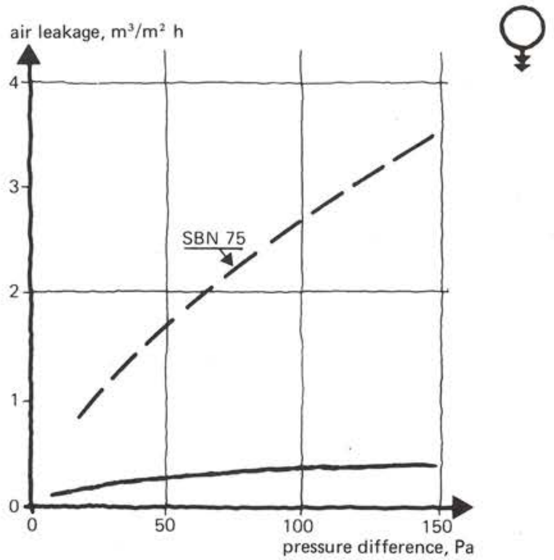



*FIG. 32. Air leakage determined for different gap widths for tubular strips h=12 mm and t=0.95 mm (Group 7).*

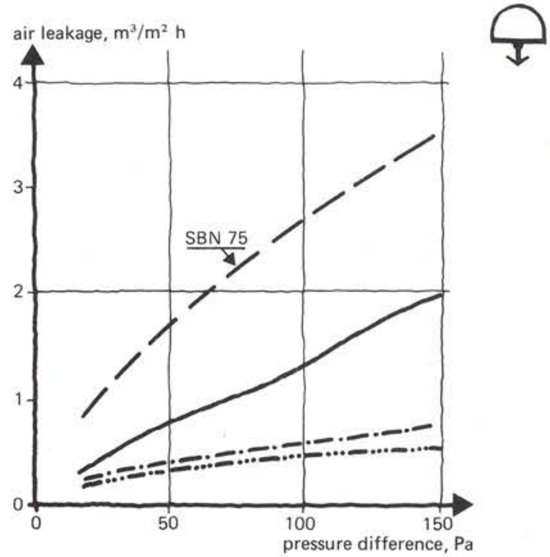



*FIG. 33. Air leakage determined for different gap widths for D strip h=10 mm and t=0.6 mm (Group 8).*

| | | | |
|---|---|---|---|
| ·············· | *gap width 4.6 mm* | ———— | *gap width 8.3 mm* |
| —··· — | *gap width 6.0 mm* | — — — | *maximum acceptable air leakage according to SBN 1975* |
| —·—·· | *gap width 7.8 mm* | | |

***Where the curves coincide, only the air leakage for the larger gap width has been shown.***

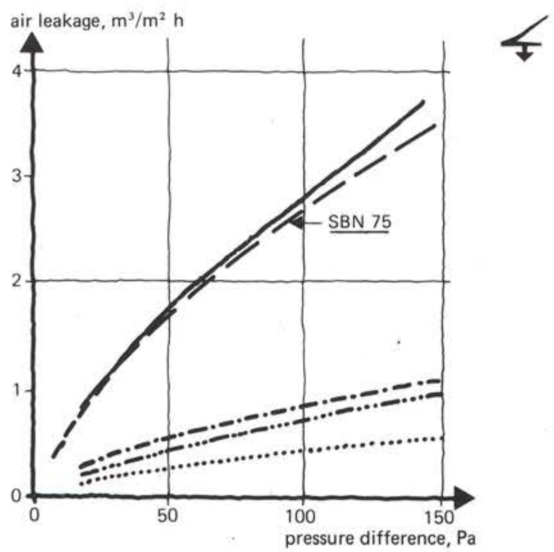



*FIG. 34. Air leakage determined for different gap widths for angle strips h=11–12 mm (Group 9).*

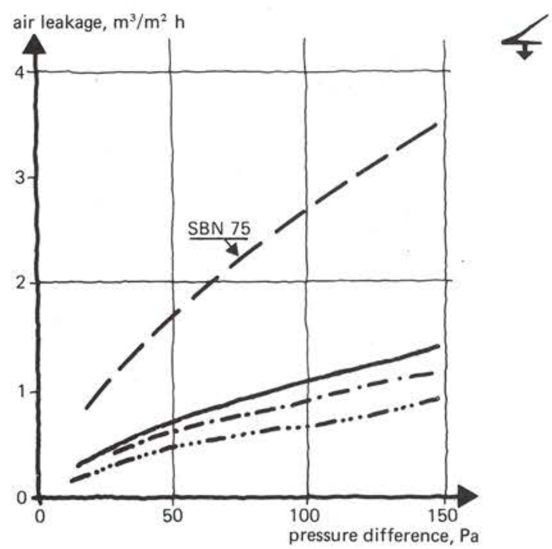



*FIG. 35. Air leakage determined for different gap widths for angle strips h=12–14 mm (Group 10).*

## 4.4 CLOSING FORCE – DOORS

SBN 1975 specifies values of the highest permissible air leakage for doors, but nothing is said about the maximum closing force which is acceptable or can be considered reasonable. Since most weatherstrips become the more airtight the more they are compressed, even bad strips will satisfy the requirements in the regulations provided that they are sufficiently compressed. A large compression, however, gives rise to a high closing force. A satisfactory weatherstrip must therefore provide a good seal even when it is only moderately compressed.

There are different views concerning the magnitude of the closing force. Values up to 500 N have been quoted.

In tests, values between 85 and 400 N have been obtained. A door which required a closing force of 250 N was, in our opinion, difficult to close. The Swedish Institute for the Handicapped states that the desirable value of the highest acceptable closing force should be 25 N.

In a test performed in collaboration with the Institute a person sitting in a wheelchair had to close a door with a closing force measured as 30 N according to Method No. 1 below. This person had normal bodily strength, and opening and closing the door caused him no problems. Our opinion, which was aiso shared by representatives of the Swedish Institute for the


*FIG. 36. Handicapped persons, as well as small children and aged people, should also be able to open and close the door.*

Handicapped, was that a person with a certain degree of physical impairment should also be able to open and close this door.

It may thus be stated that the value given by the Swedish Institute for the Handicapped as the highest desirable closing force is realistic from the point of view of the handicapped.

For the sake of comparison, we decided to use three test methods in our performance studies.

### 4.4.1 Methods of measurement

*Method No. 1 (FIG. 37)*

The closing force was measured by suspending weights from a wire which was attached to the door handle and passed over a pulley. The door was opened 200 mm and released. The loads were 5, 10, 15, 20, 25, 30 N etc. The door lock normally engaged at loads between 10 and 50 N. The locking arrangement and hinge of the door increased the closing force by about 5 N.

*Method No. 2 (FIG. 38)*

The equipment was the same as for Method No. 1 (FIG. 38). In Method No. 2 the door leaf was brought up to the weatherstrip, and application of load was begun after this. The lock normally engaged at loads between 50 and 350 N. The lock-

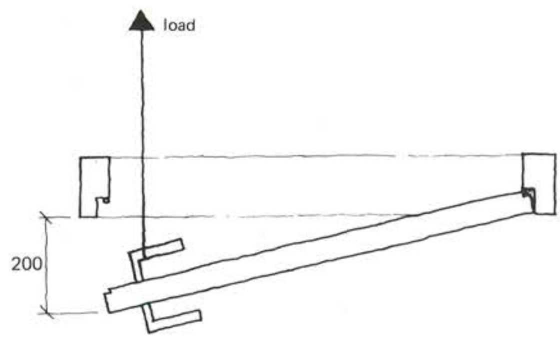



*FIG. 37. Initial position in the investigation of the requisite closing force for doors, according to Method No. 1 (Department of Building Technology, KTH).*

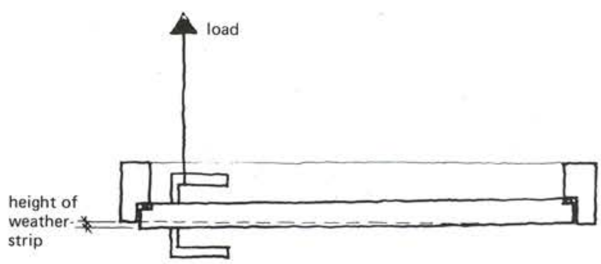



*FIG. 38. Initial position in the investigation of the requisite closing for doors, according to Method No. 2 (Department of Building Technology, KTH).*

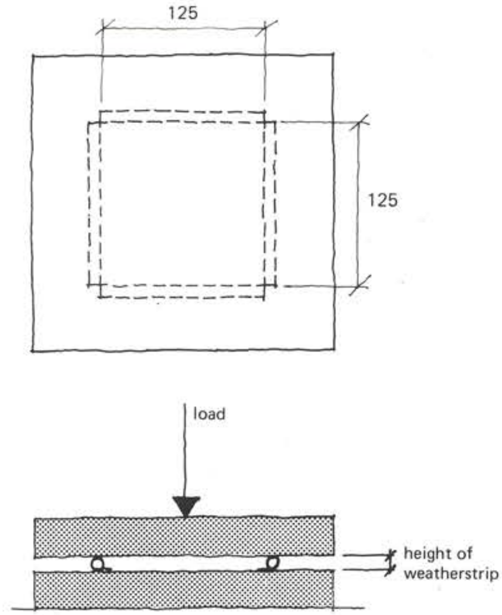



*FIG. 39. Initial position in the investigation of the requisite closing force[1] for doors, according to Method No. 3 (Building Standards Institution).*

ing arrangement and hinge of the door increased the closing force by about 30 N.

*Method No. 3* (FIG. 39)

This corresponds to the draft submitted by the Building Standards Institute to the Swedish Standards Institute for the testing of weatherstrips, SIS 36 71 10. The closing force[1] was measured in a test apparatus on four 125 mm long samples of the weatherstrip (FIG. 40). The apparatus has a rigid flat bottom plate with wooden battens for the mounting of the weatherstrips, and on this is placed a detached rigid flat top plate.

Unsymmetrical strips were aligned the same way seen from the centre of the plate. When the top plate was loaded, its movement relative to the bottom plate was measured with a dial gauge. The loads were 5, 10, 20, 30, 40, 50, 60, 80, 100, 125 and 150 N per 0.5 m strip (4 x 125 mm).

### 4.4.2 Test results

TAB. 8 sets out the results of the three different test methods. As may be seen, the methods give different results.

Conversion formulae have therefore been constructed on the basis of the different results yielded by the three methods. Using these, the methods can be approximately compared:

[1] The Building Standards Institution uses the term »closing pressure».

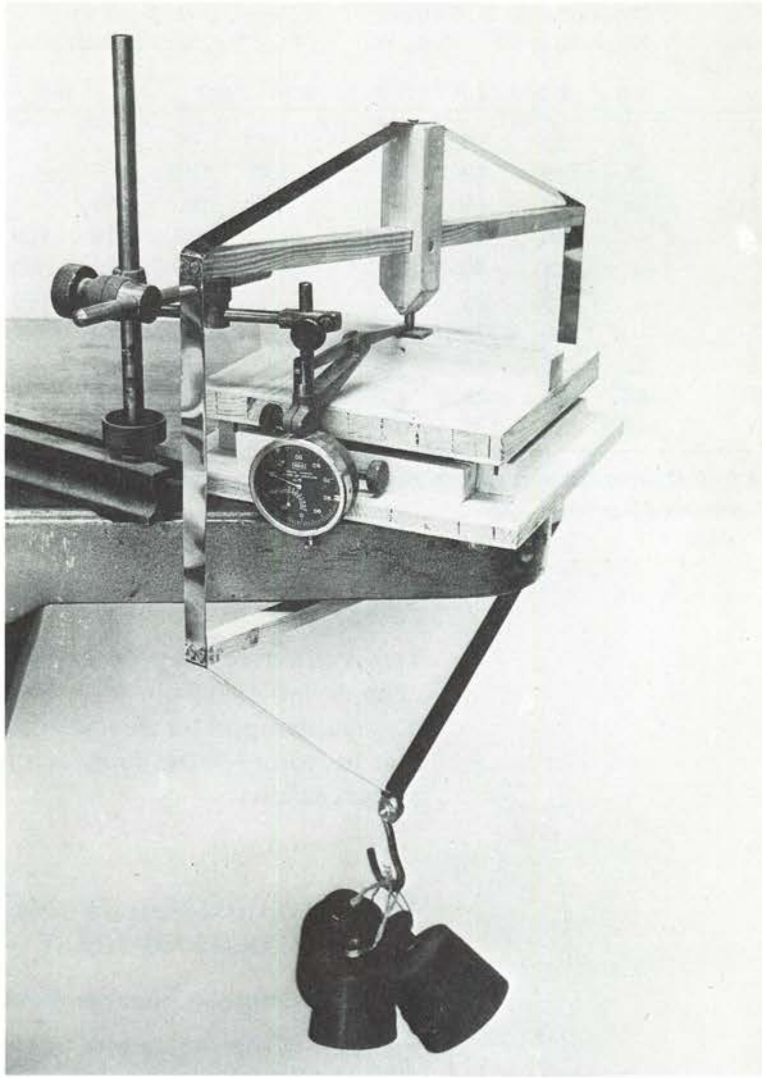


*FIG. 40. Test equipment for investigation of the closing force according to Method No. 3.*

$R \sim 0.32 \cdot B + 5$ [N]
$K \sim 3 \cdot B + 30$ [N]
$R \sim 0.1 \cdot K + 2$ [N/m]

where

R = closing force according to Method No. 1
K = closing force according to Method No. 2
B = closing force according to Method No. 3

If the wishes of the Swedish Institute for the Handicapped are observed and R is put equal to 25 N, then according to these formulae,

$K \sim 230$ N
$B \sim 63$ N/m

| Strip group (see Tab. 7) | Closing force, N, Method No. 1, for gap width of, mm | | | | Closing force, N, Method No. 2, for gap width of, mm | | | | Closing force, N/m, Method No. 3, for gap width of, mm | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 4.6 | 6.0 | 7.8 | 8.3 | 4.6 | 6.0 | 7.8 | 8.3 | 4.6 | 6.0 | 7.8 | 8.3 |
| 1 | 10 | 10 | 10 | – | 90 | 40 | – | – | 23 | 6 | – | – |
| 2 | 25 | 15 | 10 | – | 200 | 125 | – | – | 51 | 32 | – | – |
| 3 | 55 | 30 | 15 | – | >350 | 250 | 110 | – | 110 | 80 | 30 | – |
| 4 | – | 30 | 20 | 15 | – | 270 | 230 | 160 | – | 75 | 50 | 45 |
| 5 | – | 55 | 40 | 35 | – | >350 | >350 | >350 | – | 148 | 102 | 90 |
| 6 | – | 35 | 25 | 25 | – | 175 | 135 | 160 | – | 36 | 27 | 25 |
| 7 | – | 90 | 70 | 45 | – | >350 | >350 | >350 | – | 75 | 57 | 52 |
| 8 | 85 | 20 | 15 | 15 | >350 | 150 | 130 | 125 | 116 | 80 | 36 | 30 |
| 9 | 55 | 20 | 15 | 10 | >350 | 150 | 100 | 70 | 95 | 60 | 25 | 20 |
| 10 | 45 | 30 | 15 | 15 | >350 | 320 | 135 | 90 | 86 | 34 | 22 | 21 |

*TAB. 8. Closing forces measured for the four gap widths. The figures are mean values for the strips included in each group.*

*Comparison*

The method which probably measures the force required to close external doors in the most realistic manner is No. 1. This method incorporates an element where kinetic energy contributes to closure of the door. This is similar to the way in which a door is closed.

## 4.5 PERFORMANCE RANGES FOR AIRTIGHTNESS AND CLOSING FORCE – DOORS

### 4.5.1 Presentation of experimental results

FIG. 41–50 set out the airtightness and closing force of the different weatherstrips. The dashed curve indicates air leakage at 50 Pa and the chain line curve that at 300 Pa. The full curve indicates the force required to close the door (according to Method No. 1).

The horizontal full line in the diagrams is the upper limit where the air leakage corresponds to the maximum permissible value quoted in the SBN, and where the closing force is 25 N. Therefore, when a weatherstrip type is being selected, the curves should not go above this limit but be situated within the shaded area.

The horizontal dashed line indicates the limit for a closing force of 35 N. With the help of this line, the increase in the performance range of a weatherstrip, when a higher closing force can be allowed, can be determined.

In the diagrams the relationship between air leakage and gap width is shown by only one curve (applicable to pressure differences of both 50 and 300 Pa) in those cases where air leakage conformed to a continuous exponential function. When the process was discontinuous, separate curves have been used for the two pressure differences.

### 4.5.2 Experimental results

The smallest type of tubular strip, Group 1, is barely sufficient for the investigated gap widths (FIG. 41). However, the air-tightness requirement in SBN 1975 was satisfied at a pressure of 50 Pa for gap widths up to about 5.7 mm. At higher pressures and larger gaps the air leakage was very high. Since the weatherstrip was small (h=7.5 mm), the closing force was low.

Groups 2 and 3 each contained tubular strips 8 mm high (FIG. 42–43), but the wall thicknesses of the strips in Group 2 were smaller. The performance range of Group 2 was large at 50 Pa (gaps from about 4.5 mm to about 8.0 mm), but only half as large at 300 Pa. The closing force was appreciably higher for strips of greater wall thickness (Group 3). Since the air-tightness was not improved correspondingly, this meant that the performance range was small at both 50 and 300 Pa.

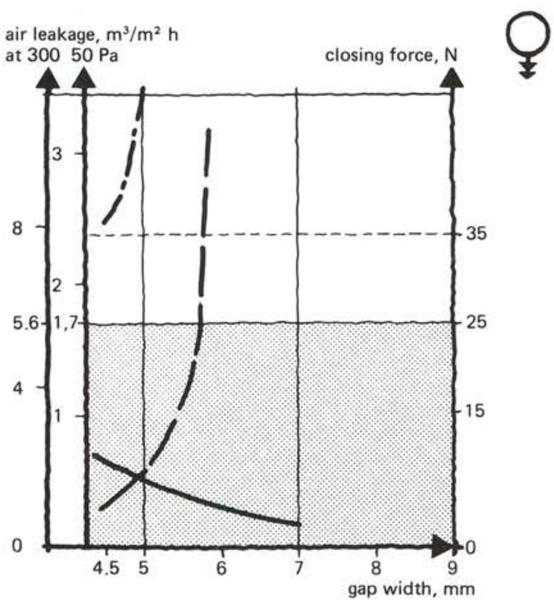



*FIG. 41. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=7.5 mm and t=0.6 mm (Group 1).*

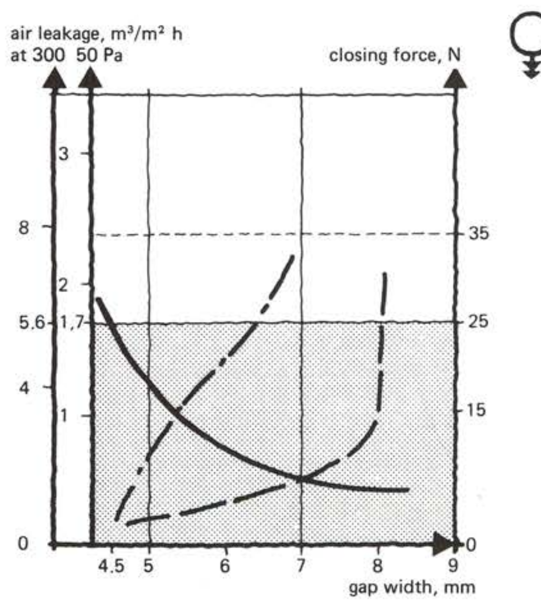



*FIG. 42. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=8 mm and t=0.7 mm (Group 2).*

*air leakage at 50 Pa*
*air leakage at 300 Pa*
*requisite closing force*

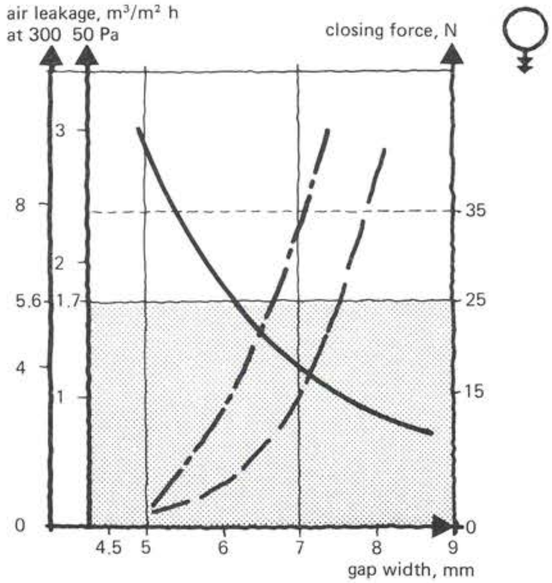



*FIG. 43. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=8 mm and t=0.8 mm (Group 3).*

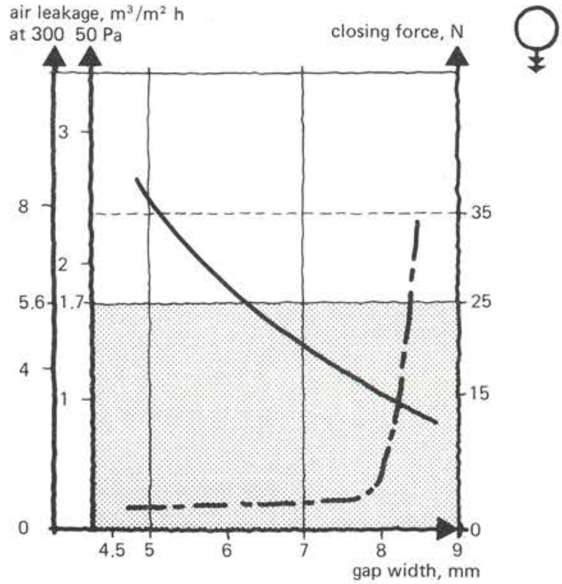



*FIG. 44. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=10 mm and t=0.8 mm (Group 4).*

The investigated 10 mm tubular strips (FIG. 44–45) are in Groups 4 and 5, the wall thicknesses in Group 4 being smaller than in Group 5. Both groups of strips were very airtight over the greater part of the investigated gap width range. The investigations showed, however, that the closing force required for Group 5 was appreciably higher than that for Group 4, and its performance range could not be determined as it was situated above the investigated gap widths.

In spite of the fact that 12 mm tubular strips are unusually large for use in ordinary standard doors, two strips were included in the investigation (FIG. 46–47), Group 6 which had small wall thicknesses, and Group 7 which had large thicknesses. It was found that the strip with a large wall thickness was altogether too stiff. It required a very high closing force, and the entire performance range was above the investigated gap widths. Owing to their small wall thickness, the strips in Group 6 required an appreciably lower closing force. The airtightness of both groups was very good, and for this reason the upper limit for the performance range of Group 6 could not be determined.

Group 8 (FIG. 48) had a profile which resembled both tubular and angle strips. On a base similar to that of the angle strips, there was a half tube of small wall thickness. Because of its appearance, this is called a D strip. Because the wall thickness in the half tube was so small, this strip required a

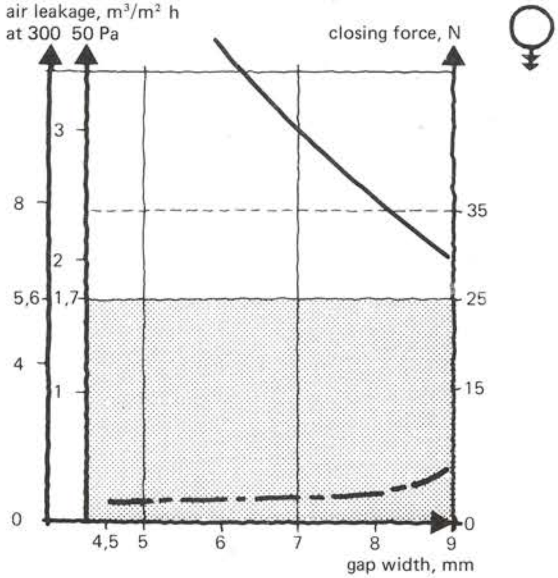



*FIG. 45. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=10 mm and t=0.95 mm (Group 5).*

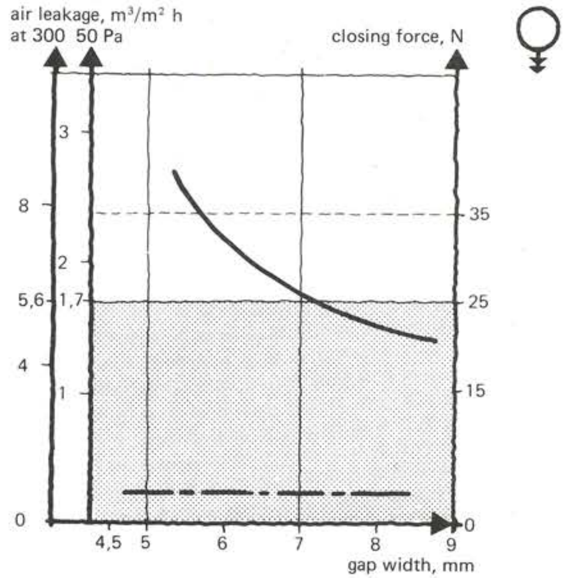



*FIG. 46. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=12 mm and t=0.6 mm (Group 6).*

*air leakage at 50 Pa*
*air leakage at 300 Pa*
*requisite closing force*

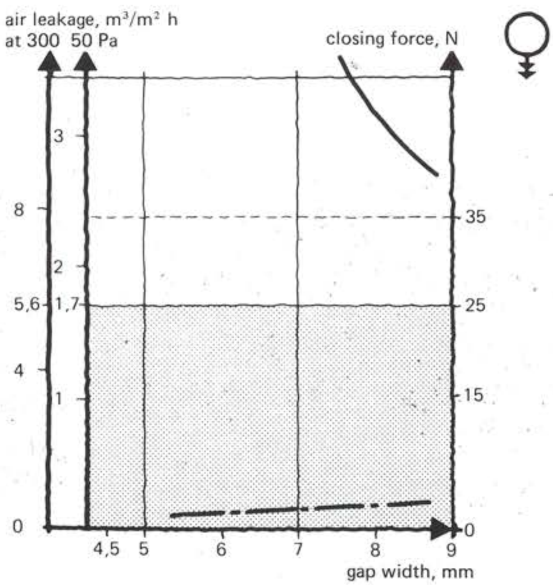



*FIG. 47. Relationship between determined air leakage and requisite closing force for different gap widths for tubular strips h=12 mm and t=0.95 mm (Group 7).*

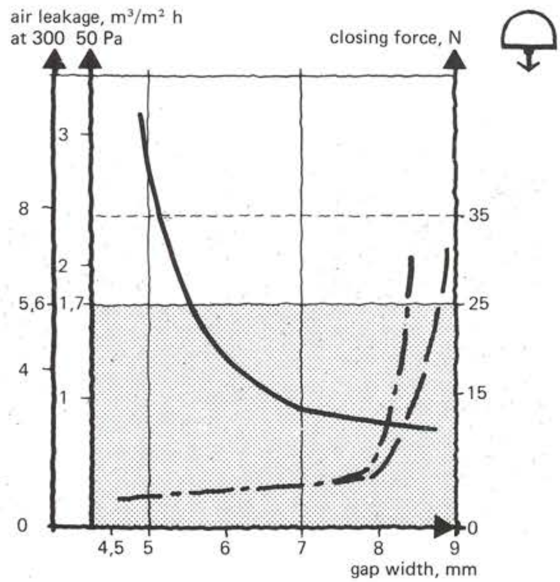



*FIG. 48. Relationship between determined air leakage and requisite closing force for different gap widths for D strips h=10 mm and t=0.6 mm (Group 8).*

fairly low closing force. The strip had a large performance range as it was also relatively airtight. Probably because of the small wall thickness, compliance of the strip with the airtightness requirement was somewhat worse at 300 Pa than at 50 Pa.

The angle strips which were investigated were classified in Groups 9 and 10 (FIG. 49–50). Classification into groups took place on the basis of size and, to some extent, the profile. Group 9 includes strips of 11–12 mm height, and Group 10 strips of 12–14 mm height. All angle strips had a large performance range. The strips required a relatively low closing force, but air leakage was greater than in the case of tubular strips. The upper limit for the performance range of the larger angle strips could not be determined since it was situated above the investigated gap width range.

### 4.5.3 Summary

The performance ranges of all ten groups of strips have been shown in FIG. 51.

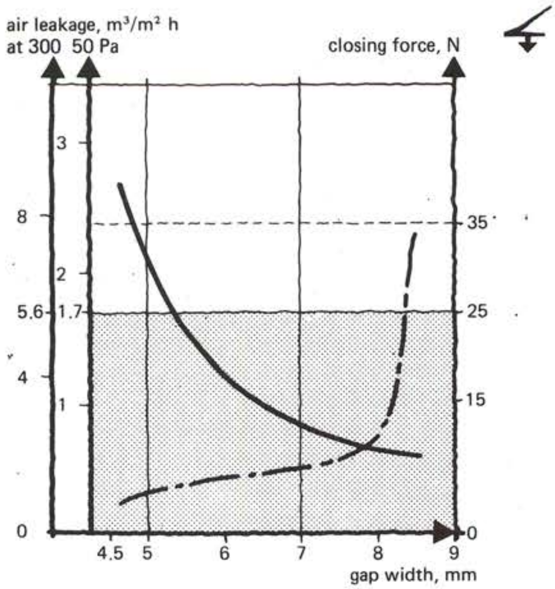



*FIG. 49. Relationship between determined air leakage and requisite closing force for different gap widths for angle strips h=11–12 mm (Group 9).*

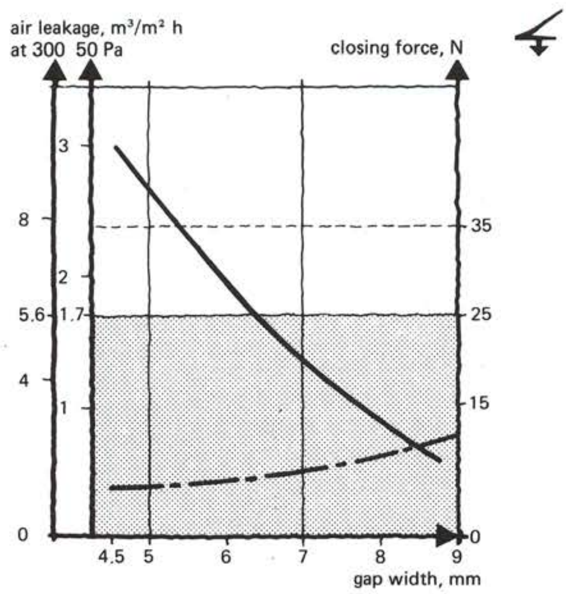



*FIG. 50. Relationship between determined air leakage and requisite closing force for different gap widths for angle strips h=12–14 mm (Group 10).*

*air leakage at 50 Pa*
*air leakage at 300 Pa*
*requisite closing force*

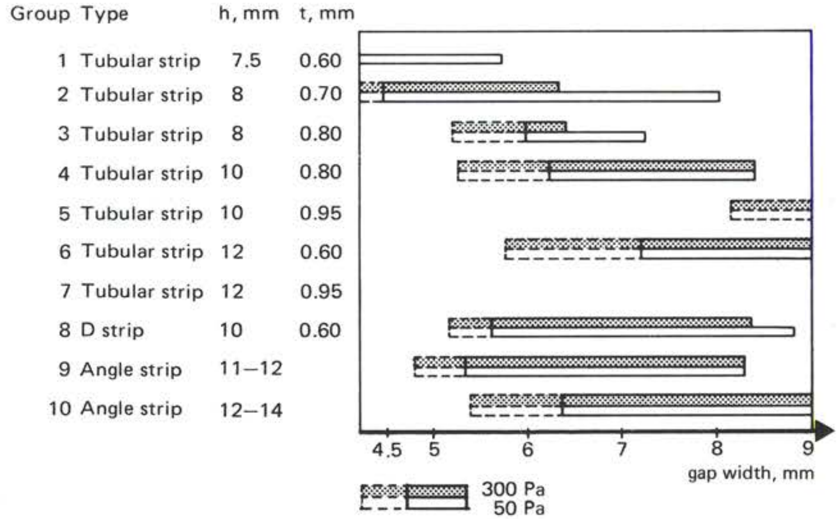



*FIG. 51. Performance ranges of weatherstrips for doors, with regard to airtightness and closing force. Comprises all groups of weatherstrips whose air leakage has been measured.*
*The full bar refers to a closing force of 25 N, and the dashed bar to the increase for 35 N.*

At the upper limit of the acceptable closing force, 25 N, the best strips had a performance range of over 3 mm. These were tubular strips of small wall thickness, and angle strips. The conclusion could be reached in the case of tubular strips that a smaller wall thickness resulted in a lower closing force, but not in a corresponding increase in air leakage. However, if the wall thickness was too small, airtightness at a high pressure was sometimes lower. A value of the wall thickness which is appropriate in view of both airtightness and closing force appears to be about 0.7 mm.

Apart from their height and wall thickness, the performance range of the angle strips also depended on the shape of the profile.

If a higher closing force, 35 N, can be allowed, then all strips have a wider performance range. It is naturally the lower limit which is lowered. A smaller gap can be allowed. The greatest increase occurs in the case of tubular strips of small wall thickness, and large angle strips.

The greater the original height of a strip, the greater the increase in its performance range. Unfortunately, the upper limit for the performance ranges of the two groups where the increase is largest (Groups 6 and 10) could not be determined. It is above the gap width range investigated. It may, however, be supposed that they will now have a performance range in excess of 4 mm.

In relation to their original heights, the degree of compression of the strips at the upper and lower limits of the performance ranges was the same in percentage terms. If a closing force lower than 25 N is to be achieved, then tubular strips of small wall thickness should not be compressed to less than 60% of the height h. However, they must be compressed to at least 80% of the original height in order to provide a sufficient seal. Angle strips should be compressed to between 50 and 70% of the height h, while the corresponding values for the D strip are 55–80%.

If it can be accepted that the closing force will occasionally exceed 25 N, and the door has a gap width of e.g. 6 mm, then the following strips should be selected:

Tubular strip $\frac{6}{0.60} = 10$ mm

Angle strip $\frac{6}{0.50} = 12$ mm

D strip $\frac{6}{0.55} = 11$ mm

Since the performance range is situated within certain percentage values of the compression of the weatherstrip, it follows that the range in mm will be the wider, the greater the height of the strip. It is thus best to make doors with a large gap width and to choose a weatherstrip of large height.

For an optimally selected gap width, the best tubular strips had an air leakage which was only about one third of that of the best angle strips. Therefore, if the airtightness requirements in Swedish Building Regulations are made more stringent some time in the future, this can be complied with easier if tubular strips of good quality are used.

## 4.6 DEFORMATION AND WARPING OF DOOR LEAVES

The investigations demonstrated that, even when weatherstrips now available are used, there is no major difficulty in complying with both the airtightness requirements laid down for external doors in the Swedish Building Regulations, and the wishes concerning the highest closing force which have been put forward by the Swedish Institute for the Handicapped. However, the requirements in SBN 1975 are intended to be satisfied in the laboratory under very favourable conditions.

Laboratory testing of a completely flat new door is not duplicated particularly well by a door in use. Doors are deformed as a result of climatic action. In the case of wood doors it is primarily the relative humidity of the air on the two sides of the door which exerts an influence. The door is both deformed and gets warped (deformation is deviation from flatness over the faces of the door leaf, while warping is deviation of the corners from the vertical plane).

Tests at the National Institute for Testing and Metrology and the Norwegian Building Research Institute show that, in simulated autumn and winter weather, door leaves are in most cases deformed by 3–5 mm. These values are within the tolerances specified in the manufacturing standard[1)] for doors, but are unacceptable in view of airtightness.

In conjunction with airtightness tests at the larger gap widths, some tests were also made to see to what extent deformation of external doors can be tolerated. The door was deformed using a tensioning device shown in FIG. 52 when the pressure in the measuring box was 50 Pa, until air leakage reached the value specified in SBN 1975. Deformation was measured with a feeler gauge between a tensioned wire and the door leaf at the midheight of the leaf. For the larger tubular strips

1) The present manufacturing standard for door leaves for use in blocks of flats, detached houses etc., SIS 81 73 02, specifies, for a door leaf of width exceeding 926 mm, a permissible deviation from flatness of 4.0 mm on delivery and 6.0 mm at the guarantee inspection one year after the door has been put into service. For similar doors of widths up to 926 mm, the corresponding figures are 3.0 and 4.0 mm respectively.

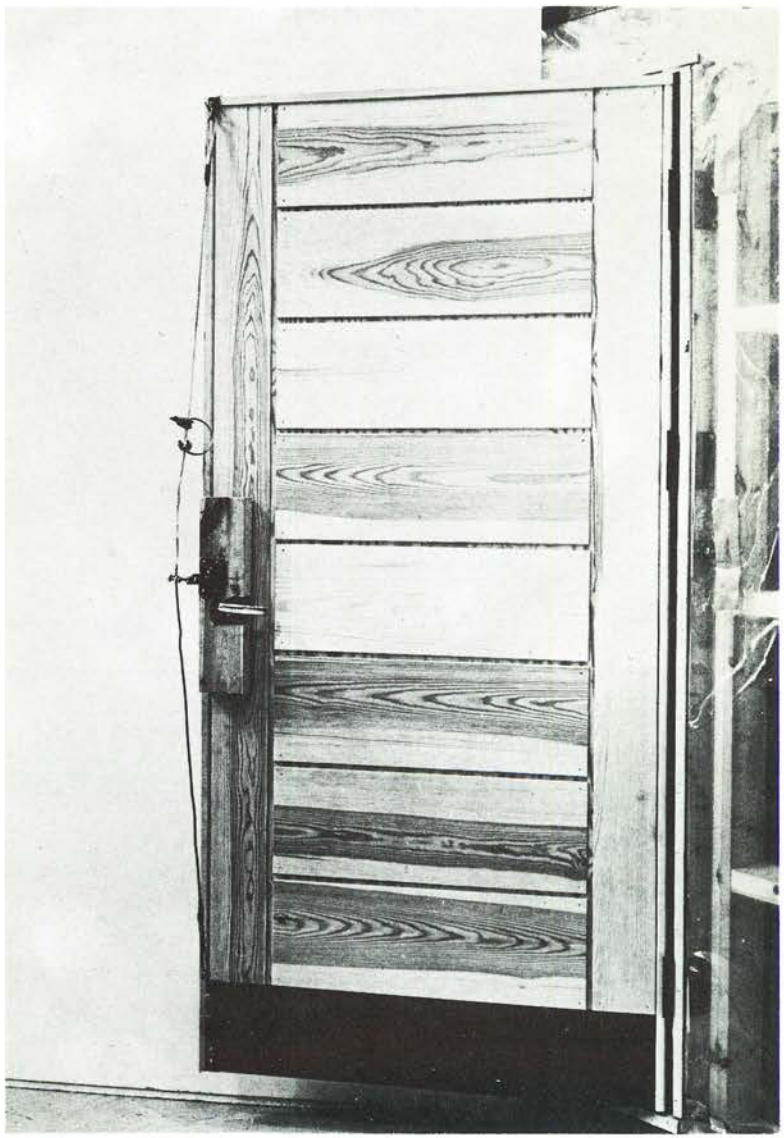


*FIG. 52. Tensioning device for investigation of the air leakage through a deformed door (deformation due to climatic action).*

(h=10–12 mm) and for the angle strips, values between 1.5 and 3.5 mm were measured. Thus, not even normal climatic stresses could be accommodated using technology available today.

When doors are granted general approval, the stresses encountered in practice should be taken into consideration. Instead of the tests which precede general approval and which yield far too good values of the airtightness, tests should be carried out while the doors are simultaneously subjected to climatic stresses. A probable development in consequence of this will be that door leaves must be made stiffer, gaps made larger and weatherstrips given larger heights. None of these measures should present any difficulty. A deformation of between 2 and 3 mm can probably be accepted if, at the same time, an appropriate weatherstrip according to this publication is used.

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# Summary


Weatherproofing of doors and windows is an inexpensive and effective measure for the reduction of energy consumption in a building. This also improves the indoor climate.

At the Department of Building Technology, Royal Institute of Technology, Stockholm, a method for the testing of weatherstrips etc. was developed at an early date. Different weatherstrips for windows and doors were investigated with regard to airtightness, closing force and ageing properties. The studies were made by full-scale tests on windows and doors of normal design. The ageing properties of the strip material (primarily permanent deformation) were investigated by means of the application of heat.

The tests showed that a tubular strip correctly chosen in view of the gap width provides the best airtightness for both doors and windows. The airtightness performance of angle strips was somewhat inferior. An appreciably higher air leakage was determined for expanded strips, foam strips and fibre strips. The latter two did not satisfy the new airtightness requirements in Swedish Building Regulations SBN 1975.

The closing force for doors was determined by three methods. Tubular strips required a higher closing force than angle strips. It is thus possible to select an angle strip and accept a somewhat higher air leakage in exchange for greater ease of closing the door by handicapped people, the elderly and small children.

The ageing tests indicated that the synthetic rubber types silicone rubber (QR), EPDM and chloroprene rubber (CR), in that order, are most suitable for use in weatherstrips.

Field tests showed that a measure as simple as replacement of weatherstrips in doors and windows in a naturally ventilated block of flats dating from the 40s was sufficient to cut the air change rate, on average, from 0.9 to 0.5 change per hour. Pressure testing of the building at 50 Pa showed that points of leakage mainly occurred at the windows. Pressure testing showed that the new weatherstrips increased the airtightness of the building by about 40%. It has therefore now an airtightness of the same order as that specified for new buildings in Sweden. Both the energy conservation effect and profitability of the measure were satisfactory. There are no more complaints about draughts.