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The Application of Structural Measures for Energy Conservation in Existing Buildings

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Swedish Council for Building Research

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Introduction

Increased energy costs, doubts about the future and imminent oil crises, Swedish Government Bill 1977/78:76 with the Energy Conservation Plan for existing buildings, etc., challenge us to reduce energy consumption in existing buildings. This can be effected by different energy conservation methods, e.g. changing patterns of living and savings brought about by installation engineering and structural measures.

In producing this publication, the Industrial Group for Light Construction Engineering illustrates the measures which can be carried out on building elements in order to save energy. The publication describes different methods and states advantages and disadvantages as well as suitable combinations of measures. The emphasis has been placed on the measures which are easiest to carry out and are consequently usually the most economical. However, the economics of different measures should be investigated for each individual case. The publication shows how this can be done.

It is not the purpose of this publication to give specifications for different types of structural measures, but is intended primarily as a review of current methods. The measures suggested comply in certain cases with current requirements and regulations, for example those in accordance with the Swedish Building Code (SBN –75) (1).* The reader is referred to the appropriate material manufacturers for detailed instructions. Furthermore, there is a vast amount of literature on different energy conservation measures.

One of the advantages provided by structural energy conservation measures in relation to other conservation measures is that many have a long service life and require very little maintenance. Furthermore, they produce positive side effects in the way of reduced draughts, warm external walls, etc., which improve the living environment. Changes in facade material and the design of windows can, in combination with carefully selected products, contribute to an improved environment.

This publication discusses only structural measures. From an energy conservation point of view, however,

* The figures within brackets indicate the reference.

it is important that these be combined with improvements in building services.

Structural measures should be followed up by an adjustment of the heating system and a reduction in temperature. Otherwise there is a risk that the measures will result in an increase in temperature and a loss of the intended energy savings.

1. Windows and doors

1.1 General description of structural measures

Windows and doors (entrance doors, etc.) are energy-sensitive parts of a building. Energy losses are caused by gaps and low thermal resistances of building elements.

Gaps occur primarily between frames and casements/doors. These gaps are easily eliminated by adjusting the opening operation and window/door furniture and by fitting new weatherstrips. Weatherstrips are available in many different materials and designs. According to investigations carried out at the Royal Institute of Technology, Stockholm (2) and Chalmers University of Technology, Gothenburg (3), weatherstrips manufactured from silicone or EPDM-rubber are to be preferred to strips manufactured from PVC. Strips made of textile material, foam plastics, etc., have an inferior resistance to ageing, do not seal particularly well and should therefore be avoided. Tubular strips provide the best seal. V-strips are preferred for doors since they normally require a lower closing pressure.

In the case of double windows, where there is a large gap between the two casements, energy savings can be made by fitting a pervious dust-sealing strip between the casements. The strip reduces the cooling effect of cold air circulation between the casements.

Gaps between frames and walls are best rectified in conjunction with internal or facade renovation since there is a risk that damage can occur around the joint when this is treated. The design of the joint is very important to the result. According to an investigation carried out by the Swedish Forestry Products Research Institute (4), the best material is polyurethane foam or packing strips supplemented with an internal joint filler plus sealant, a rubber tube or a plastics-coated internal packing strip.

Several measures can be employed to improve a window's thermal resistance. Venetian blinds, thermally insulating shutters, etc., are measures which function well, but whose effectiveness is very dependent on how they are looked after by the occupant. A certain energy saving can be achieved by applying solar reflective film to the glass or by using sealed units filled with special thermally insulating gases and by covering the glass with a thin film of heat-reflecting metal. These however affect the transmission of light into the room and have an unknown service life. In certain buildings with a large glazed area, display windows, roof lights, etc., a suitable solution may be to block off certain areas of glass with an insulated wall. The commonest solution is however to fit additional panes or to replace the existing windows with double or triple glazed ones, which improves thermal resistance.

1.2 Advantages and disadvantages of different measures

1.2.1 Airtightness

Lack of airtightness in windows and doors which causes unintentional ventilation in a building creates not only energy losses through unnecessary heat leakage, but also causes draughts. Such draughts must be compensated for by higher room temperatures which demand more energy. Draughty windows and doors also diminish the acoustic insulation properties of the facade.

However, buildings must not be made too tight and, in dwellings, a minimum ventilation rate of 0.5 air changes per hour is required. In buildings with both exhaust and supply ventilation there is little risk that sealing windows and doors will make the house too tight. In houses with heat exchanger systems, unintentional ventilation must be low for the system to work. In houses with natural ventilation or exhaust air ventilation, windows and doors often function as air inlets. In such cases, sealing measures must be carried out with a certain amount of caution and a break may be necessary in the sealing strips, or the use of pervious sealing strips (for example, textile strips) may be necessary in order to provide the necessary supply air.

The energy savings which can be achieved by sealing measures depend to a great extent on the perviousness of the building. Investigations carried out at the University of Technology, Lund (5), indicate that existing windows often admit a lot of air. Sealing measures on windows and doors between frames and casements/

doors are however considered one of the most worthwhile technical measures available for saving energy. If weatherstrips of good quality are used, the service life of such measures is currently estimated to be approximately 10 years.

1.2.2 Improvement of thermal resistance

The thermal resistance of primarily windows but also doors is low compared with that of external walls, etc. For this reason there is often a greater energy saving/m^2 through additional insulation of window areas than of wall surfaces. By changing from double to triple glazing, the thermal transmittance (U-value) is improved by approximately 1.0 W/m^2 °C. Improved thermal resistance also raises the temperature of the inner surface of the glass and thus reduces cold radiation from the window. This increases comfort conditions, particularly in rooms with large glazed areas, and allows the temperature to be reduced without discomfort. The acoustic insulation of the window is also improved and, in certain cases, its airtightness as well.

A disadvantage of triple glazing is that the existing window construction is subjected to greater loads. The number of window surfaces to be cleaned can also be greater and problems due to condensation on the glass surface can arise if fitting is carried out incorrectly. The use of sealed units increases costs since glass must be changed. By changing from double to triple glazing the light transmission through the window is reduced and the amount of solar gain in the building is reduced by approximately 10%.

1.3 Existing building stock

1.3.1 Airtightness between frames and casements/doors

Older weather strips in windows and doors are often in very bad condition and sometimes also incorrectly fitted. The textile strips and pervious foam plastics strips used to date quite often have very inferior sealing qualities and ageing resistance (2). Often the strips have been painted over and have therefore lost their sealing properties. Such weatherstrips on windows and doors should be replaced. Casements and doors are often warped so that windows and doors can only be opened and closed with difficulty. This must be remedied and window and door furniture must also be adjusted so that the window and door can be opened and closed easily.

1.3.2 Airtightness between frames and walls

Joints between window/door frames and walls are sometimes pervious. Cracks may have arisen through settling or shrinkage of the frames. There may be insufficient packing in the joint between the frame and the wall. Flexible sealant is often used from the outside to seal the joint. As a result, there is the risk of moisture on the inside being trapped in the joint, causing rot in wooden frames and adjacent walls.

1.3.3 Windows

The existing Swedish window stock is primarily double glazed in wooden casements. Single glazing is mostly found in shop windows and in a number of windows in industrial buildings. Triple glazed windows comprising three linked casements are found in a number of buildings from the 1950's. Triple glazing, comprising either a three-pane sealed unit or a single pane + a two-pane sealed unit, is again used more and more as a result of modern requirements for energy management (1).

Houses built before 1920 mostly have separate inward and outward opening wooden windows with glazing bars. The inner frame is either removable or mounted on hinges. These windows are usually of good quality but are unfortunately often replaced by modern linked triple glazed windows in conjunction with building renovation. In houses built after 1930, double windows are used almost exclusively. Frame and casement profiles are normally in accordance with SIS standards.

Lately, decay has been discovered in wooden windows, particularly those from the 1960's and later. As a result many windows have had to be changed, sometimes after only 5–10 years of use. The reasons for damage are many but the parts most often damaged are the window sill and bottom rail. In certain cases such damage has also led to consequential damage to window breasts. Damage to the bottom rail is often a result of inferior painting of the glazing rebate and the use of substandard putty. Water has been able to penetrate between the glass and the putty down to the stile and has therefore caused decay. The joint between the bottom rail and the stile is, to a great extent, untreated end-grain timber. As a result of movement in the joint, moisture can penetrate and cause decay. A permeable paint on window timbers on the inside allows the transmission of room moisture through to the cold side. This can give rise to moisture accumulation underneath the layer of paint on the outside if this is less permeable than the layer of paint on the inside, for instance because it has been repainted several times. Consequently, the moisture causes cracks and the paint flakes, creating the right conditions for decay to start.

1.4 Structural solutions

1.4.1 Airtightness between frames and casements/doors

Gaps between frames and casements/doors can often be detected by inspecting the opening and closing action and weatherstrips. Gaps can also be detected by using a candle, a smoke pistol or thermography. This is facilitated if the room is subjected to negative pressure, for example by starting the cooker extractor.

Resealing of windows and doors should include the following steps:

- **a** Inspect the windows/doors. Do they require repainting or the putty replacing?
- **b** Check that the casement/door can be closed and opened easily and adjust where necessary.
- **c** Check that the window/door furniture works properly and adjust and lubricate where necessary.
- **d** Check that the air gap between the casements of all double windows/doors has not been rendered ineffective as a result of repainting etc. A gap of 1–2 mm is required. If the gap between the casements is greater than 2 mm, a pervious dust-tight strip can be fitted in order to reduce the air circulation between the panes, thereby achieving certain savings in energy.
- **e** Always paint exposed wood surfaces (surfaces which lack finishing coat, glazing paint, etc.) before reapplying putty and fitting weatherstripping.

f Select suitable strip dimensions bearing in mind the width of the gap between the casement/door and frame. The size of the gap when the window/door is closed can be measured by using plasticine pressed onto a few places on the rebate in the frame.

g Select the weatherstripping. When selecting strip for use between the frame and the casement/door, the gap width measured in f) must be considered. When selecting weatherstrips, textile strips, foam plastics strips (pervious) and expended plastics strips (impervious) must be avoided. Even strips of PVC are not quite suitable. According to tests carried out at the Royal Institute of Technology, Stockholm (2), strips of silicone and EPDM-rubber have exhibited the best sealing and ageing properties.
Tubular strips provide the best seal but angle strips are also effective. Angle strips are recommended for doors where a low closing pressure is required.

h The way in which weather strips are fitted is important for their correct function. Special attention must be paid to the corners where gaps often occur.

Figures 1.1 illustrate how strips should be positioned.

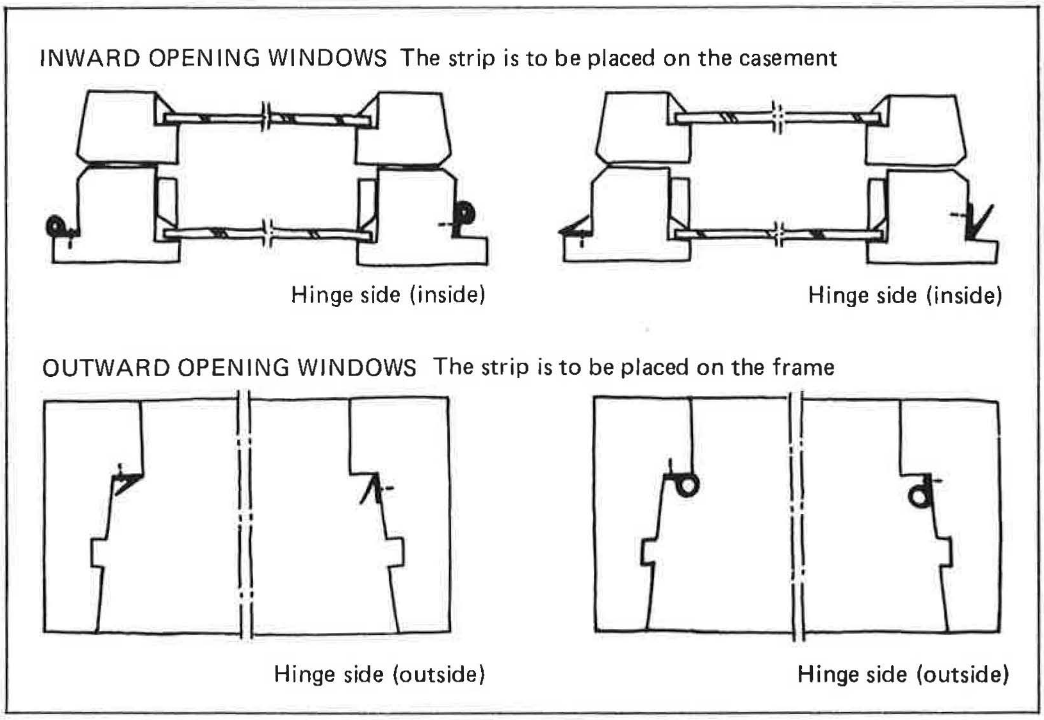
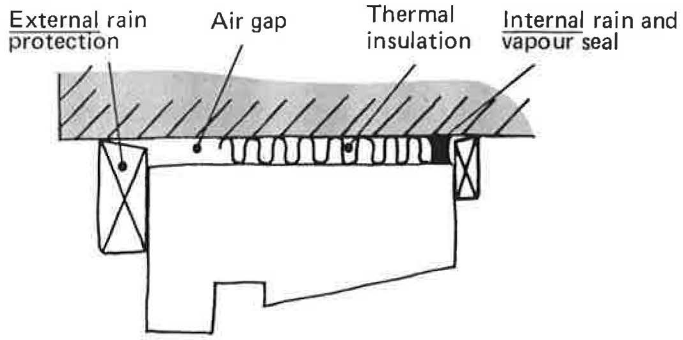


Figure 1.1. Positioning of sealing strips between casements and frames in inward and outward opening windows respectively.

1.4.2 Airtightness between frames and walls

Cooled surfaces and gaps between frames and walls can be detected by the appearance of dirt deposits or cracks. Detection can also be carried out with the aid of a candle, a smoke pistol or thermography. This is facilitated if the room is subjected to negative pressure, for example by turning on the cooker extractor. Defects are to be rectified *from the inside*, preferably when window painting or wall papering is carried out since damage to adjacent surfaces is easily caused during the work.

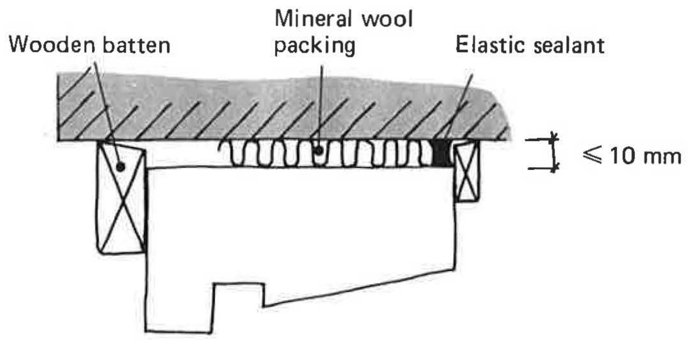
In order to function satisfactorily the joint should be built up as illustrated in figure 1.2.



ure 1.2. Sealing of joint tween frame and wall.

Figures 1.3–1.6 illustrate some construction methods.

Packing with mineral wool, supplemented on the inside with a carefully constructed joint using elastic sealant, provides an air and vapour tight seal which prevents warm, moist air penetrating the joint where it can condense and form water.



igure 1.3.

Where the joint width is greater than 10 mm, a bottoming strip should be positioned as a support for the sealant (figure 1.4).

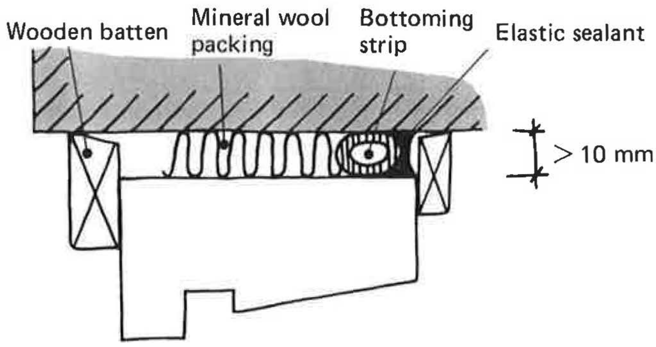


Figure 1.4.

Packing using glass wool + glass enclosed in thin plastic foil. Where possible the foil should be placed in an unbroken strip around corners and past adjustment wedges. This provides an air and vapour tight seal which prevents warm, moist air from penetrating the joint and condensing to water (figure 1.5).

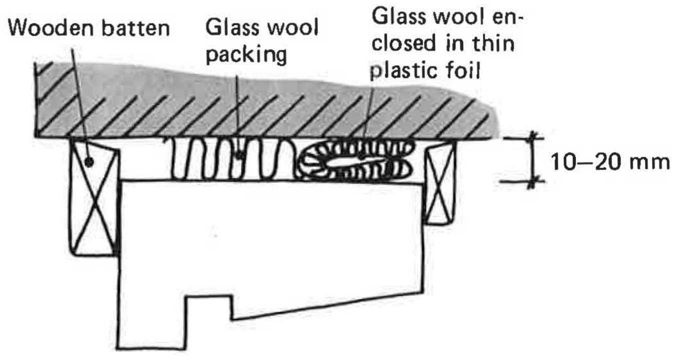


Figure 1.5.

Filling the joint with expanded polyurethane (figure 1.6).

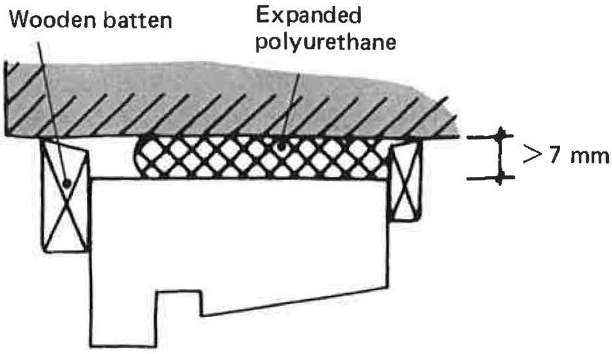


Figure 1.6.

1.4.3 Additional insulation of doors

Additional insulation of external doors is best carried out from the inside by placing insulation between battens on the inside of the door panel after which a plastic foil which provides a vapour barrier and a new internal facing sheet is nailed in position.

Thermal insulation and airtightness can also be improved if the external door is supplemented with an internal door or a wind break.

1.4.4 Additional insulation of windows

There are several different technical solutions available today for additional insulation of windows. Most solutions are based on the principle of increasing the number of panes/air gaps in the window, thus improving thermal resistance.

A few examples are:

- □ *Adding a third pane to double windows.*
- □ *Replacement of a single pane by a sealed double glazed unit.*
- □ *Replacement of two single panes by a sealed triple glazed unit.*
- □ *Replacement of double glazing by triple glazing.*
- □ *Blocking-off an existing glass area by an insulated wall.*

There are several other methods. During an energy crisis or in premises of lower standard, a thin plastic foil (figure 1.7) can be taped between the two windows

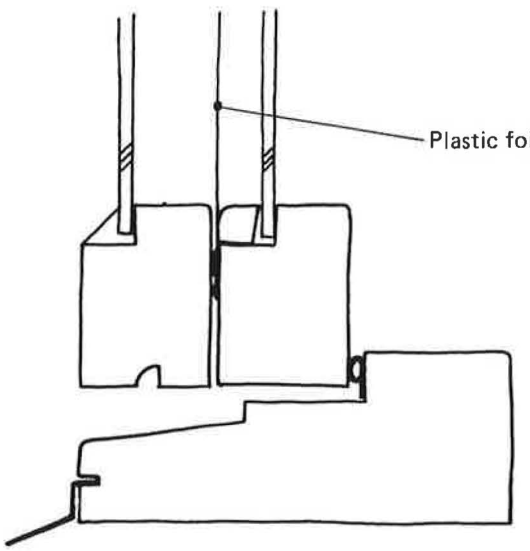


Figure 1.7. Plastic foil taped between casements.

in order to increase the number of air gaps and thus the thermal resistance. Other measures are to use venetian blinds or external, insulating shutters but the effect of these measures depends to a great extent on how they are looked after by the occupier.

Additional of third pane to double window

Figure 1.8 shows how a fixed third pane is added to an inward opening double window. It is a requirement for this design to work that the window does not need to be opened and is accessible from outside for cleaning. The advantages are ease of fitting, improved airtightness and a certain amount of protection for external woodwork. If the external wooden frame is also clad with factory-painted sheet metal, it is protected against weather and wind and the cost of its future maintenance painting will be lower.

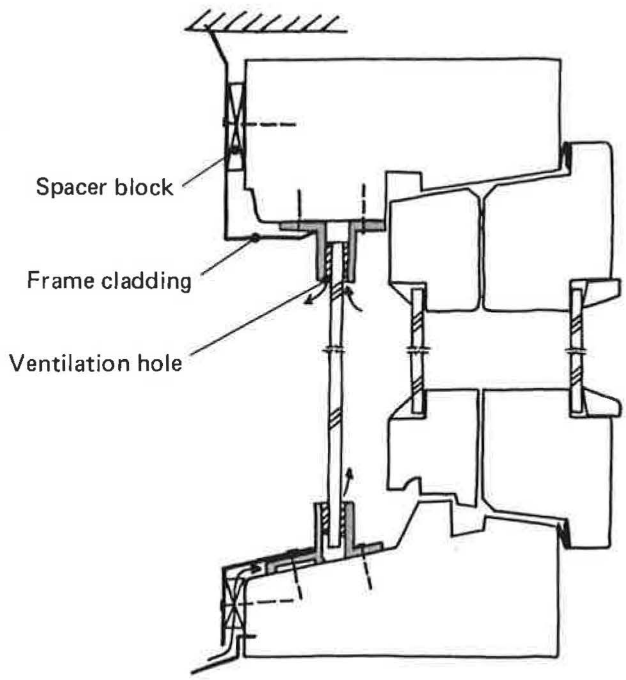


Figure 1.8. Fitting an external fixed pane to an inward opening double window and cladding of the external wooden frame.

If it is necessary to open the window, it is possible to fit a single pane mounted in an openable casement on the outside, as illustrated in figure 1.9. This casement is fitted on hinges and is fixed by locking screws. This design is also easy to fit. Both the methods discussed above should allow for a certain amount of ventilation between the outer panes of glass in order to prevent condensation on their surfaces.

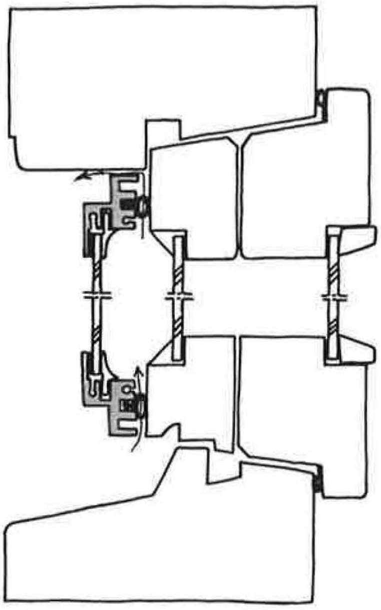


Figure 1.9. Additional pane fitted in openable casement on the outside.

The additional single pane can also be fitted to the inside of the inner casement. The simplest method is illustrated in figure 1.10 where the glass is placed directly on the inner casement. The joint between the glass and the inner casement is sealed with a sealing strip, silicone compound or similar. The pane is fixed with sheet metal clips and must be removed when the intermediate glass surfaces are to be cleaned.

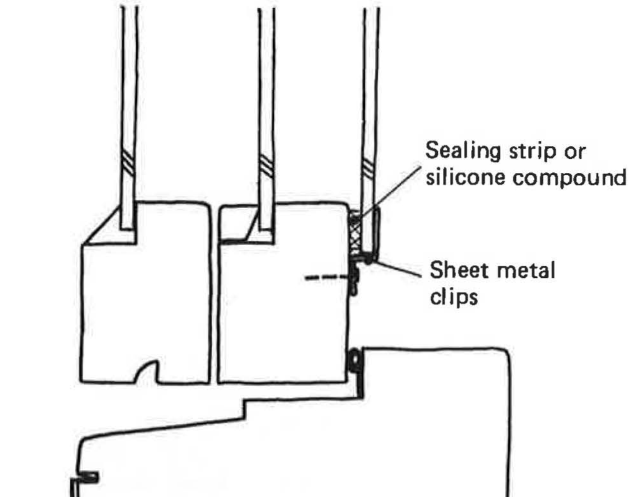


Figure 1.10. Fixed additional pane fitted to the inside of the inner casement.

Additional glazing can also be fixed in an openable casement. The casement is then mounted on the inner casement. Several different systems are available and the principle is illustrated in figure 1.11. When fitting additional single glazing on the inside it is important to ensure that the joint between the additional pane and the inner casement is airtight. Moist indoor air can otherwise penetrate between the panes and cause condensation.

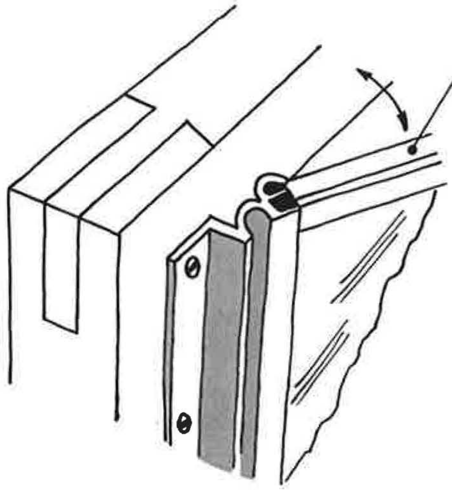


Figure 1.11. Additional pane fitted in an openable casement on the inside of an existing inner casement.

Replacement of a single pane by a sealed double glazed unit

It is also possible to convert a double window to a triple glazed window by replacing one of the single panes by a sealed double glazed unit. A sealed unit comprises two or more panes which are sealed by gluing or soldering to a metal strip. There is dustfree, dry air or a special thermally insulating gas between the panes of glass. The advantage of this type of glazing is that there are only two surfaces to clean.

Several methods are available where the glass in the inner casement is replaced by a sealed double glazed unit.

The principle is illustrated in figure 1.12. The sealed unit is fixed between battens of wood or plastics or aluminium sections. It is essential that fitting is carried out in accordance with the instructions issued by the manufacturers of the sealed unit, otherwise the glass guarantee may be invalid. It is also important that the joint forming the seal between the indoor air and the air between the casements is airtight, otherwise air leakage from the room will cause condensation on the glass surfaces between the casements.

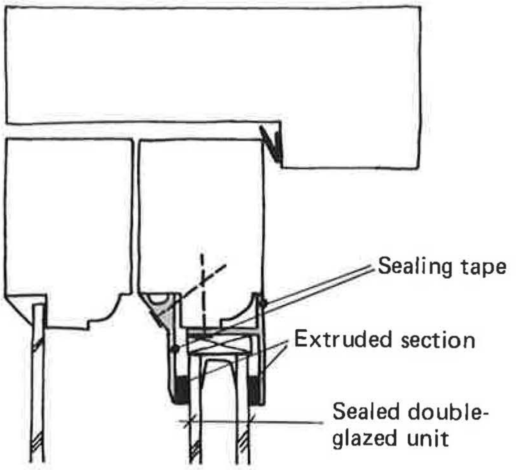


Figure 1.12. Replacement of a single pane in the inner casement by a sealed double glazed unit.

Instead of replacing the single pane in the inner casement, it is possible to replace the whole of the outer casement by an aluminium casement comprising a sealed double glazed unit or sealed double glazed panel, i.e. a sealed unit bonded to an aluminium frame. The principle is illustrated in figure 1.13. The

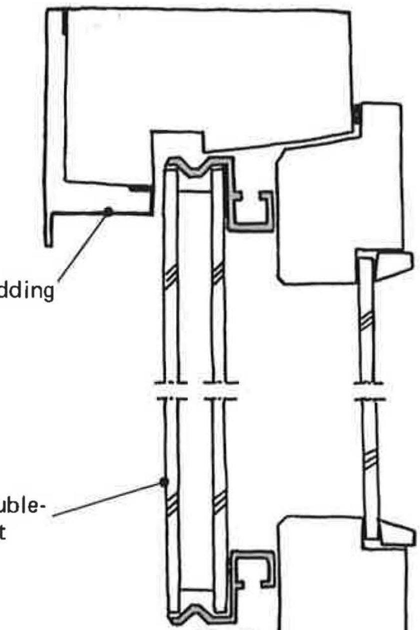


Figure 1.13. Replacement of outer casement by a sealed double glazed unit and cladding of external wooden frame.

advantage of this solution is that the outer casement needs no maintenance painting. If the external wooden frame is given a sheet metal cladding at the same time, the windows will be considerably less expensive to maintain.

Replacement of two single panes by a sealed triple glazed unit

By removing both panes from a double window and then screwing the casements together as illustrated in figure 1.14 it is possible to fit a sealed triple glazed unit in the existing casement. An alternative would be to have a new casement comprising a sealed triple glazed unit made and to fit this in the existing frame.

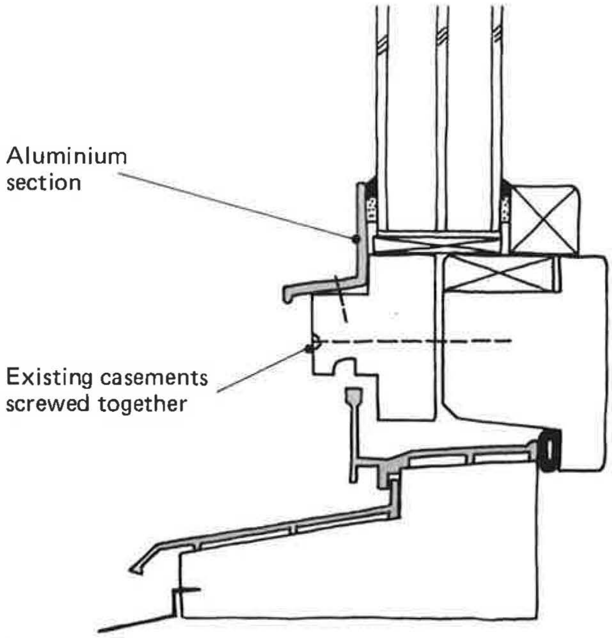


Figure 1.14. Replacement of two single panes by a sealed triple glazed unit.

A further alternative, if it is acceptable to convert the window to a fixed window, is to remove the casement and to fit the sealed unit directly in the existing frame, figure 1.15. This method produces a tighter window construction. The cost of a sealed triple glazed unit is however relatively high and the cost effectiveness of the above alternative is low.

Replacement of double glazing by triple glazing

In addition to improving the thermal resistance, another reason for replacement is that the window may

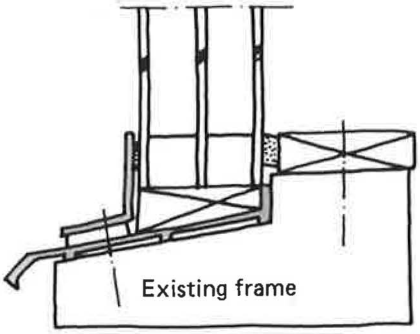


Figure 1.15. Fitting a new sealed insulating triple glazed unit in an existing frame.

be in bad condition. Separate windows are often replaced by modern double windows in conjunction with modernization but if the property is in a noisy area windows are also replaced by ones which provide better acoustic insulation.

When replacing windows it is possible to replace the whole window including the frame, but this often causes extensive damage to the surrounding plaster work and reveals. The usual practice is to retain the old frame and fit a new window inside this, i.e. the new window frame is placed in the old frame as shown in figure 1.16. One can use either a 1+2 pane window, i.e. a window which has a single pane plus a sealed double glazed unit, or a window with a sealed triple glazed unit fitted either in a non-openable frame,

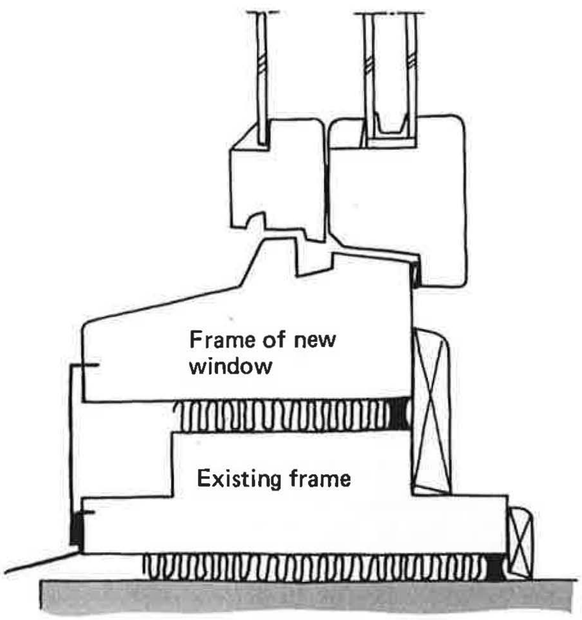


Figure 1.16. Fitting a new openable window inside an existing frame.

figure 1.17, or in an openable casement. A non-openable window is often tighter than an openabl window and also somewhat cheaper to maintain. When choosing replacement windows one should be in mind future energy and maintenance costs and select a window of high quality. From the point of view of energy, it is also important that the joint be tween the frame and the wall and between the old and the new frame be properly sealed.

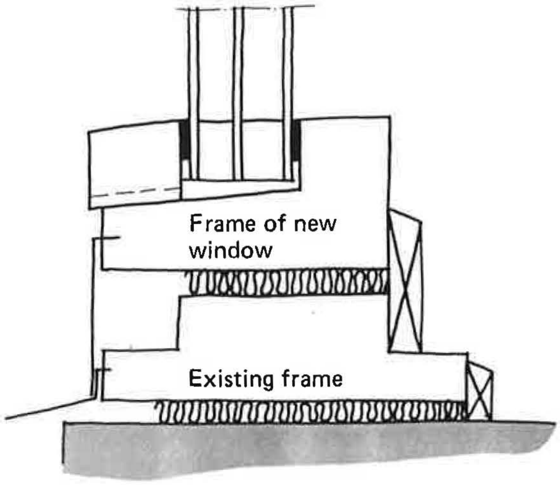


Figure 1.17. Fitting a new fixed window inside an existing frame.

Blocking off existing glass areas by an insulated wall

In offices, shops and industrial buildings there is often an unnecessarily large amount of window area, which is often single-glazed and thus gives rise to considerabl energy losses apart from discomfort from cold radiation, heat radiation and the cost of cleaning etc. Where possible, these window areas can be reduced by replacing or supplementing the window by a thermally insulated wall. Additional glazing using sealed units is a possible solution in certain cases as illustrated in figure 1.18.

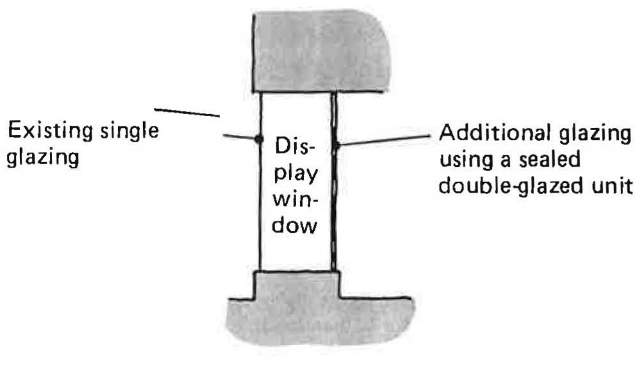


Figure 1.18.

2. Attic floors/roofs

2.1 General description of structural measures

Depending on the appearance of the structure, *floor structures* (attic floors, attic ceilings) can be provided with additional insulation from above or below. It is best if the insulation can be carried out from above. This is cheaper and does not encroach on the living space.

When carrying out insulation from above where there is no insulation, the work should be commenced by laying a plastics foil as a vapour barrier. It should lie as tight as possible against the ceiling panels (or secondary spaced boarding). Insulation can then be carried out. Joints and holes for services must be airtight. The vapour barrier must always be laid on the warm side.

The following applies to insulation:

- □ *Insulation is usually carried out with mineral wool either in the form of sheets, matting/strips or granules.*
- □ *The insulation must fill the space between joists completely and must be in good contact with the warm side. Cracks and gaps must be avoided.*
- □ *At the junction with the roof, a ventilation gap of the same size as that before insulation must be provided. (The National Swedish Board of Physical Planning and Building recommends 0.2 m^2 per 100 m^2 floor area and a minimum gap of 20 mm in accordance with SBN –75 (1).)*

If there is a floor in the loft, it must be removed and if necessary raised. An alternative is to engage a contractor who can inject mineral wool in the form of granules. Then it is only necessary to remove one or two floorboards.

Insulation can also be carried out from inside the room. This is done by providing a new false ceiling using beams which can, for example, be suspended from hangers.

If there is no acceptable vapour barrier or if the thermal resistance (m_t) of the additional insulation (see Section 6.1.3) is greater than 1/3 of the total thermal resistance (M_{tot}) of the construction after insulation, the new false ceiling must be provided with a vapour barrier laid on the warm side next to the inside face.

In certain buildings (primarily in industry) measures may have to be carried out on the *roof* instead of the attic floor. There are three fundamentally different ways of carrying out these measures:

- □ *Insulation from the outside for instance using mineral wool overlain by roofing felt.*
- □ *From the underside, tight against the roof.*
- □ *From the underside, suspended from the roof (this also reduces the total heated volume of the building).*

2.2 Advantages and disadvantages of different measures

Additional insulation of an *attic floor structure* is always profitable if the optimum method and insulation thickness are selected, see calculation method in Chapter 7.

The reduced fabric losses achieved by additional insulation of a floor structure can be calculated in accordance with section 6.1.3.

Apart from reduced fabric losses, the measures also make the construction more airtight (vapour barrier). This results in fewer draughts and warmer inner surfaces which in turn means that the air temperature can be reduced without discomfort.

The measures also makes possible elimination of cold bridges in the construction to a certain extent. This reduces the risk of local cooling which can result in dirt deposition and cold convection currents. This also may result in a reduction in the indoor air temperature.

If the loft is not fitted with a floor it is often quite easy to apply thick layers of additional insulation to the floor structure. The reduction in volume does not normally constitute any ploblem. In many cases the work has a »do it yourself» character. There are exceptions however in areas which are restricted or awkward to get at where the work is difficult to carry out satisfactorily. There are special spray methods for such areas (see section 2.4).

Measures carried out on the outside of the *roof* disturb activities inside the building to a very minor extent. If the roof covering (e.g. roofing felt) requires renovation in any case, provision of the new roof covering is not charged to the energy conservation account. If this is the case, insulation from the outside is preferable since profitability is nearly always good.

Measures carried out from the inside have the advantage that the building may be provided with a new characteristic, that of noise-absorption. However, when carrying out measures from the underside, moisture and airtightness aspects must be given particular attention.

2.3 Existing building stock

Approximate values of thermal transmittance (U-value) for some common floor and roof constructions are given in table 2.1. It is very difficult to determine the U-value in old houses to any greater degree of accuracy. The standard of workmanship is of great significance and material properties may have changed over the years.

The values given in table 2.1 can however be used for preliminary calculations of the savings (see section 6.1.3).

Problems which may have arisen in existing floor and roof structures are primarily those associated with moisture, i.e. water may in unfavourable circumstances have been absorbed into the insulation material (primarily wood shavings and sawdust). If the existing insulation is completely dry there is no reason for removing it. If, on the other hand, it is moist, it should be replaced in conjunction with additional insulation and the cause of the dampness rectified. Crushed aerated concrete (blue) should also be removed in view of radiation risks.

Floor

Construction	*Year of construction*	*U-value $W/m^2\,°C$*
Non-insulated floor structure		1.0
Floor structure with heavy fill, i.e. sand or coke ash	–1920	0.8
Lightweight concrete floor	1945–	0.6

Floor (cont.)

Construction	*Year of construction*	*U-valu W/m²*
Concrete floor with crushed aerated concrete or granulated blast furnace slag	1935–1960	0.6
Floor with wood shavings or coke ash	1935–1960	0.6
Simple timber attic floor construction with approximately 150 mm sawdust or wood shavings	1940–1960	0.6
Timber floor with floorboards, counter floor and ceiling panel plus 150–200 mm lightweight fill of sawdust or moss litter mixed with lime	1900–1945	0.4
Timber floor with fire resistant counter floor and 200 mm medium fill (granulated blast furnace slag) and plastered ceiling panel	1910–1945	0.4
Timber floor with approximately 250 mm sawdust or wood shavings	1940–1960	0.4
Timber floor with mineral wool matting	1955–	0.4
Mineral wool-insulated lightweight concrete floor	1945–	0.4
Mineral wool-insulated concrete floor	1950–	0.4

Roof

Construction	*Year of construction*	*U-value W/m² °C*
100 mm lightweight concrete, grade 500 plus roofing felt	1945–	1.0
150 mm lightweight concrete, grade 500 plus roofing felt		0.8
200 mm lightweight concrete, grade 500 plus roofing felt		0.6

Roof (cont.)

Construction	*Year of construction*	*U-value W/m^2 °C*
160 mm concrete plus 40 mm insulation plus roofing felt		0.8
Trapezoidal metal sheeting plus 50 mm insulation plus roofing felt	1965–	0.6
Trapezoidal metal sheeting plus 70 mm insulation plus roofing felt		0.5
Trapezoidal metal sheeting plus 100 mm insulation plus roofing felt		0.4
25 mm wood panel plus 50 mm insulation covering whole area plus roofing felt	1940–	0.6
25 mm wood panel plus 95 mm mineral wool insulation between joists at 1200 mm centres plus ventilation gap plus 25 mm wood panel with roofing felt or corrugated sheeting		0.4

Table 2.1. Approximate U-values for older floor structures and roof constructions.

2.4 Structural solutions

Insulation of the *upper surface of the attic floor* (figure 2.2) is normally carried out with mineral wool sheets or strips. These products are made to suit normal joist spacing, but can also be supplied in non-

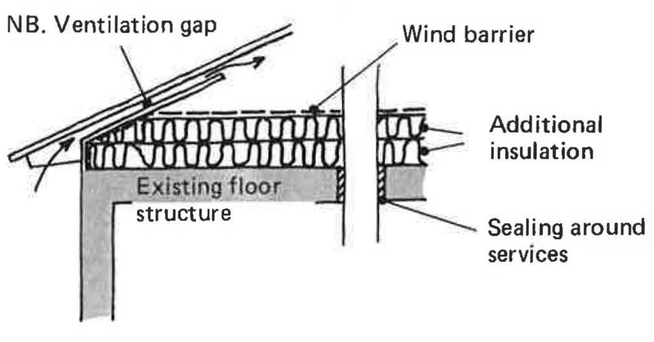


Figure 2.2. Additional insulation of attic floor from above.

standard sizes. It is important that the insulation product fills completely the space to be insulated (figure 2.3).

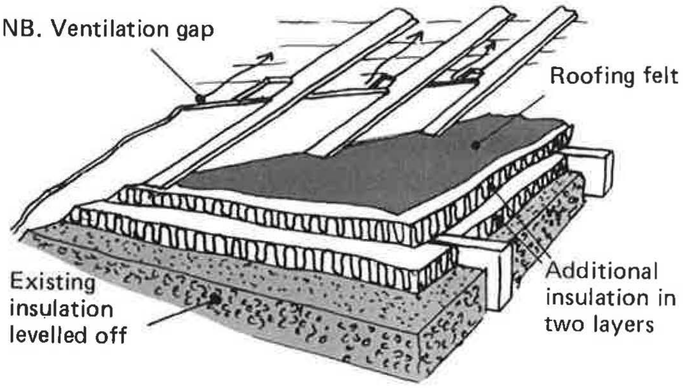


Figure 2.3. Additional insulation of attic floor from above.

As an alternative, mineral wool insulation can be sprayed over the area. In this case, the material is sprayed via a hose from plant on the ground. This method ensures satisfactory filling of the space even where it may be difficult using other methods. This method is also preferable if the transport of insulation material to the loft area is difficult.

Irregularities in the existing layer should be smoothed out using granulated mineral wool or a similar product prior to laying sheet products.

When attic floors are being insulated, insulation which is not enclosed in foil should be given wind protection. This can be done either by using paper-coated sheet products, or by laying separate paper-coated mats on top of the main insulation of uncoated mineral wool sheets. When mineral wool is sprayed, the wind barrier may be replaced by 20–30 mm extra insulation.

When insulation is applied to the *underside of the attic floor structure* (figure 2.4) the insulation is placed

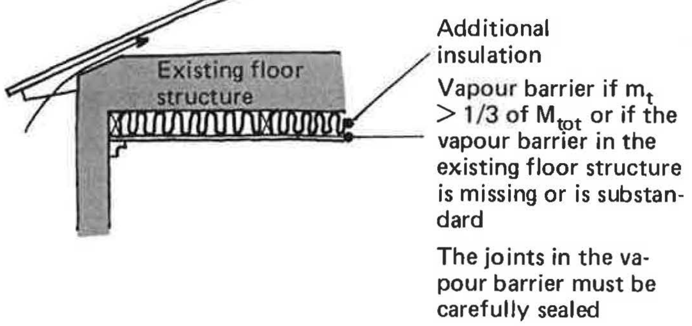


Figure 2.4. Additional insulation of attic floor structure from the underside.

between studs which are either nailed to or suspended from the existing ceiling. The studs constitute the ground for attaching the new ceiling finish.

Vapour barriers should be fitted on the warm side when insulation is applied to the underside.

The vapour barrier is to be positioned as illustrated in figure 2.4. It is important that vapour barriers, where provided, or the underlying sheet material are laid with tight joints and overlaps. This is primarily to increase the tightness of the construction.

Measures carried out from the *outside of the roof* may be applied directly to the existing roof if the surface is even. No air gaps, which reduce the insulation effect, are allowed between the new and the old insulation. For example, a roof covered with roofing felt can be insulated without the existing felt layer having to be removed.

Alternative solutions:

- ☐ *Mechanically attached insulation plus roofing felt over the entire area. Figure 2.5.*
- ☐ *Mineral wool between Z-bars plus surface cladding of sheet metal or similar. Figure 2.6.*

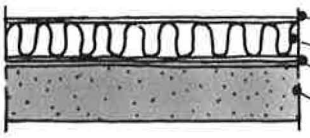


Figure 2.5. Additional insulation on the outside, mechanical fitting.

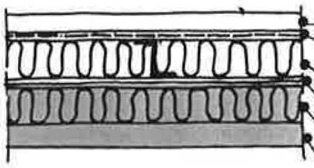


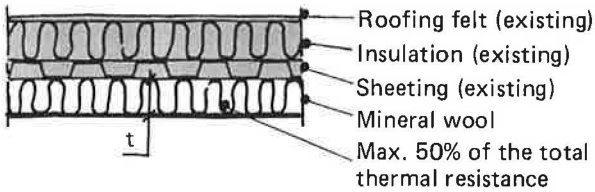
Figure 2.6. Additional insulation on the outside, laid between Z-bars.

Provision of a vapour barrier must always be considered. It can be positioned on the outside (on roofing felt), on the inside, or between layers of insulation. Its positioning depends on the conditions in each individual case.

When insulation is applied from the *inside of the roof*, the insulation can be fitted tightly to the ceiling and fixed mechanically. The mineral wool is to consist of sheets with a surface finish intended for exposed positions.

To avoid moisture problems, the following recommendations apply when the new insulation is fitted onto the existing one *without* a vapour barrier. In figures 2.7 and 2.8, the λ_n values (see Chapter 6) are given for different methods of fitting.

»DRY» premises (vapour pressure $P < 1.15$ kPa)



»MOIST» premises (vapour pressure $P \geqslant 1.15$ kPa)

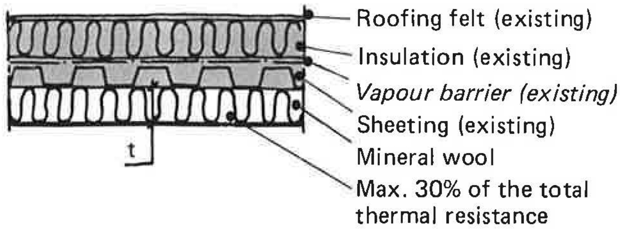


Figure 2.7. Maximum insulation thickness and λ_n values for additional insulation applied to inside of trapezoidal sheet metal roof.

t mm	λ_n W/m °C, in accordance with certificate 77030, 36 from the Swedish Institute for Testing and Metrology
50	0.045
80	0.048
100	0.050

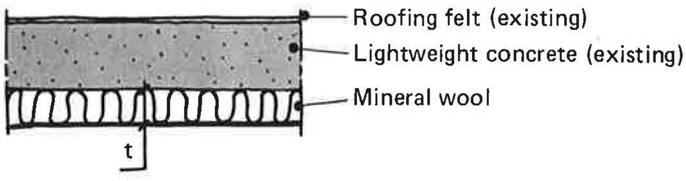


Figure 2.8. Maximum insulation thickness and λ_n values for additional insulation applied to inside of lightweight concrete roof.

Zone (according to Swedish Building Code)	t_{max} mm	λ_n W/m °C
I, II	80	0.040
III, IV	100	0.040

In *other cases* (other materials in the roof or other conditions) it may be more suitable to suspend the new construction from a suspension framework to allow more simple fitting of the necessary vapour barrier.

Figure 2.9 shows *one* example of how the insulation can be suspended.

The most suitable method of applying insulation on the inside of a roof must be decided from case to case since accessibility and the scope for reducing the volume of the premises also affect the choice.

The manufacturers of insulation materials and other affected materials manufacturers can provide further information.

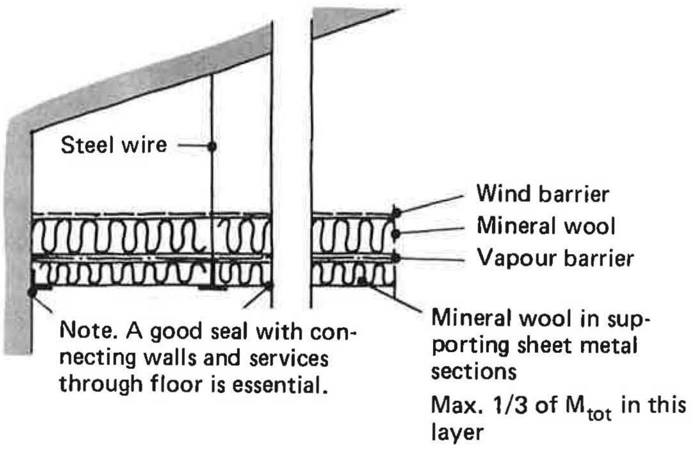


Figure 2.9. Example of suspended additional insulation on the inside.

3. External walls

3.1 General description of structural measures

In principle, additional insulation can be applied on both the outside and the inside of an external wall. From a technical point of view, additional insulation on the outside provides the best solution and does not reduce the internal volume. In the case of cavity wall constructions, additional insulation can be applied by filling such cavities.

Additional insulation on the outside is particularly effective since it disrupts all cold bridges at junctions with partitions and floor structures. Additional insulation applied on the inside, using the same insulation thickness, has an inferior effect according to investigations carried out at the Department of Building Technology at the University of Technology, Lund (6).

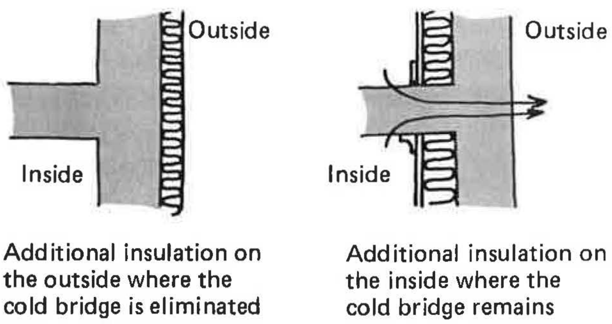


Figure 3.1.

Additional insulation on the outside usually consists of mineral wool. In order to qualify for a government energy conservation grant, the minimum insulation thickness is approximately 100 mm at present, but attempts should be made to achieve a final result which corresponds to the requirements for new buildings. However, even greater thicknesses of insulation can be profitable from the point of view of energy costs.

When additional insulation is applied on the outside, the facade line is moved outwards and this also affects adjacent parts of the building. For example, windows will be set further back in the wall unless they are moved outwards. Moving the facade line as a result of additional insulation is partly a question of appearance and this can affect the choice of insulation thickness. There is also the technical aspect. Windows set further back in a protected position can stand up to the effects of climate better than windows which are flush with the line of the facade.

Additional insulation on the inside is advantageous if the work is to be carried out in stages and without being affected by weather and wind. If the external facade is of cultural and historic interest, additional insulation should be applied on the inside. The problem is, however, that cold bridges cannot be insulated and these cause energy losses – such cold bridges exist where partitions and floor structures meet external walls. Another disadvantage is that the living area is reduced. This is outweighed to a certain extent by the fact that the occupation zone increases since the external walls become warmer.

3.2 Advantages and disadvantages of different measures

The profitability of additional insulation measures on an external wall is not generally self-evident. If the facade is already in need of renovation and the facade finish is not charged to the energy saving account, it is always profitable to carry out additional insulation on external walls if the optimum insulation thickness (Chapter 7) is selected.

Reduced transmission losses make up the large, relatively simply calculated energy savings due to additional insulation. An improvement in the U-value of a wall from 1.0 to 0.25 W/m^2 °C, corresponding to approximately 150 mm additional insulation, results in annual energy savings of approximately 90 kWh/m^2 in Central Sweden. If a detached house has approximately 100 m^2 external wall, excluding windows, this means an annual energy saving of approximately 9000 kWh. The reduced transmission losses which are theoretically provided by additional insulation of an external wall can be calculated as shown in section 6.1.3.

Apart from reduced transmission losses, additional insulation on the outside of external walls can produce one or more of the following advantages:

☐ **Tighter facade surfaces**
Additional insulation carried out in the correct manner makes the construction more airtight. This can be measured through the reduction in the number of unintentional air changes per hour. Of course the result depends on the original airtightness of the wall and the volume and insulated area of the building.

☐ **Reduced cold bridges**
As a result of additional insulation on the outside, parts of the wall construction where insulation is less than elsewhere, for instance wall–floor junctions, are covered and cold bridges are disrupted. Cold bridges cause heat losses through the wall and furthermore contribute to keeping down the temperature of internal floor and wall surfaces. The heat losses can be calculated in accordance with Swedish Building Code, Chapter 33:248K (1) if the length of the wall–floor junction in relation to the facade area is known.

☐ **Dryer walls**
A new facade functions in the same way as a raincoat on walls of brick and lightweight concrete. The original wall becomes warmer and the equilibrium moisture ratio drops. The thermal conductivity is also reduced and the insulation of the old wall increases.

☐ **Warmer inside surfaces**
Additional insulation causes a rise in the surface temperature of internal walls and the indoor temperature becomes more even. Thus the air temperature can be reduced without discomfort, resulting in significant energy savings.

☐ **Acoustic insulation**
An external wall with additional insulation also has improved acoustic insulation.

☐ **Aesthetic aspects**
Additional insulation on the outside often changes the appearance of the house. There are cases where environmental and cultural-historical interests must be satisfied. As shown in the following, there are methods for preserving plastered environments, timbered structures etc. even after additional insulation.

Structures with additional insulation on the inside are subjected to greater temperature variations during the year and during the day than those which are insulated on the outside or not insulated at all. This may mean that temperature stresses and deformations increase in the original construction when additional insulation is applied on the inside.

There is also the risk that application of additional insulation on the inside may give rise to moisture problems in a building element. A reduced temperature in a material causes an increase in the moisture content. This results both in a reduction of thermal resistance in the existing construction and an increased risk of damage, bursts, etc.

3.3 Existing building stock

The design of the old wall, its thermal transmittance (U-values) and the energy savings to be achieved, together with practical and aesthetic viewpoints, determine the choice of insulation thickness. Approximate values of the thermal transmittance (U-values) for some common wall constructions in existing buildings are given in table 3.2 and the U-value after additional insulation can be calculated in accordance with the directions given in section 6.1.3.

Measurements must be carried out if the exact U-value for an existing building construction is to be determined. Typical U-values may contain inaccuracies since the standard of workmanship is significant and the material properties may have deteriorated with age. However, typical values provide sufficient accuracy in most cases and the values stated in table 3.2 can be used for a preliminary calculation of the conservation effect (see section 6.1.3).

External walls

Construction	*Year of construction*	*U-value W/m² °C*
Boarded walls (75 mm boards, 2 x 25 mm timber panel)	1910–45	1.0
Plastered brick-and-a-half wall	–1940	1.0
Wall of horizontal timbers	–1900	0.8
Single brick wall plus wood wool sheets	1930–50	0.8
Lightweight concrete wall (250 mm)	1935–	0.8

External walls (cont.)

Construction	*Year of construction*	*U-value W/m^2 °C*
Lightweight concrete insulated concrete shell	1945–65	0.8
Boarded wall with insulation mats	1930–40	0.8
Stud wall with lightweight fill (e.g. wood shavings)	1900–40	0.6
Stud wall with lightweight fill (e.g. wood shavings)	1930–55	0.6
Cavity wall with insulation	1940–55	0.6
Precast lightweight concrete units	1965–	0.6
Wood wool wall units	1940–50	0.6
Stud wall with mineral wool insulation	1930–40	0.4
Stud wall with mineral wool insulation	1950–	0.4
Cavity wall with mineral wool insulation	1955–	0.4
Concrete shell with cast-in mineral wool or expanded plastics	1960–	0.4
Precast concrete units with mineral wool or expanded plastics	1960–	0.4

Table 3.2. Approximate U-values for older wall constructions.

3.4 Structural solutions

The next section has been divided up into the following structural solutions:

☐ *Additional insulation on the outside.*
☐ *Additional insulation on the inside.*
☐ *Additional insulation by filling cavities.*

3.4.1 Additional insulation on the outside

Prior to additional insulation the surface should be as even as possible so that no air gaps are formed behind the new insulation. Cracks and gaps may give rise to air movements which have a disastrous effect on thermal insulation. Broken plaster may need to be repaired and loose plaster knocked off. Furthermore, cover pieces over secret nailing in timber panels and battens should be removed. Any air gaps in the old wall should be filled in or carefully sealed. Pervious walls should be clad with fibre board, gypsum plaster board or building felt with overlapped joints before additional insulation is fitted.

Undulations in the old facade can be straightened by using the studs supporting the additional insulation and the new facade.

The following gives an account of the methods used for additional insulation on the outside, divided up according to the cladding of the facade (sheet metal, timber, brick, plaster). Suggestions are then given regarding detailed solutions for eaves, barge boards, window surrounds, skirtings and different types of fasteners.

Sheet metal facades

Aluminium sheeting and hot dip galvanized steel sheeting are tried and tested facade materials which are suitable for cladding facades in conjunction with additional insulation on the outside. The materials provide a non-combustible facade cladding which is specified for houses with more than two floors. They are of low weight and furthermore require little maintenance. Sheet metal allows many variations with respect to profile and colour and, when coated with PVF_2 Kynar 500, the sheet metal has a surface finish which is very colour stable.

Sheet steel is protected against corrosion by zinc and paint. Oxygen in the air provides aluminium sheeting with an oxide layer which protects the underlying metal, and corrosion protective treatment is not normally necessary.

Different paint types can be selected depending on the colour stability required.

Supplementary fittings are available as standard or can be made to order from flat sheet metal.

Further information on the use of sheet metal in conjunction with additional insulation can be obtained from the respective sheet metal manufacturers, e.g. Ahlsell Profil, Dobel, GavleVerken, Gränges Aluminium Korrugal, Plannja, etc., and in the publication issued by the Swedish Institute of Steel Construction, »Facade renovation using sheet metal» (7).

Timber facades

Timber is a tried and tested facade material which, as a result of its low weight, small thickness and simple maintenance, is well suited for use as a new facade cladding in conjunction with additional insulation applied on the outside.

Timber blends well with the Swedish environment and building tradition. In older housing areas the material seldom gives rise to any aesthetic conflict if the type of facade and surface finish are selected to blend with other houses. Timber facades can be designed in a large number of ways, with vertical or horizontal panels, by using different timber dimensions and different designs. Timber facades on modern buildings are often quite rugged in appearance and surface treated with bright colours, in many cases varnished. Older timber facades are often more finely cut and painted in sombre colours. When renovating older houses the result is often best if the new panel is as similar to the original as possible. Where the existing timber facade is well preserved, it can in some cases be removed and re-used after additional insulation.

Surface finish for timber panels should be selected so that intervals between maintenance are as long as possible. The Swedish Timber Information Centre has published booklets on timber facades (8) and the surface finish of timber facades (9) which provide useful information for the fitting of additional insulation and new timber facades and the choice of surface finish.

Studs and metal bars

The insulation and the new sheet metal or timber facade can be attached to the existing wall using studs or metal bars. Battens can be of either steel or wood. Steel bars are made from cold-formed sheet metal sections, usually Z-profiles or special profiles which reduce thermal transmittance. Steel profiles must be hot dip galvanized.

Studs or bars used for additional insulation and facade renovation are normally fitted horizontally since this is advantageous from the fire protection aspect and furthermore allows easier fitting.

In residential buildings of more than three floors, combustible studs, if used, must be terminated at fire compartments boundaries (Swedish Building Code 1975, Chapter 37:34 and Chapter 37 Rebuilding Regulations :34) (1).

Steel bars make for easier fitting, particularly when the insulation is thick, but on the other hand give rise to larger cold bridges than wooden studs (see figure 6.2). The old wall constitutes a certain break in the cold bridge but steel bars normally need further cold bridge insulation on the outside. This is normally mineral wool or fibre board.

In order to reduce the length of the fastener outside the line of the existing wall, it may be advantageous to employ one of the following stud combinations when studs are formed into a frame to support thick insulation:

- □ *Crossed studs, figure 3.3.*
- □ *Two studs laid on top of each other, figure 3.4.*
- □ *Studs with countersunk fasteners, figure 3.5.*
- □ *Attachment of studs to fittings which are in turn attached to the wall using short fasteners, figure 3.6.*
- □ *Insulation between studs + insulation covering*

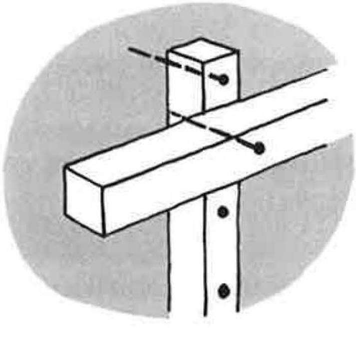


Figure 3.3. Crossed studs.

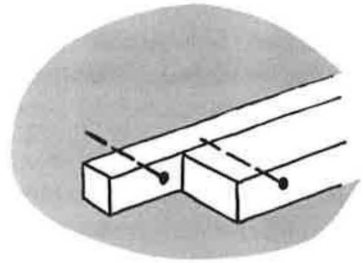


Figure 3.4. Two studs laid on top of each other.

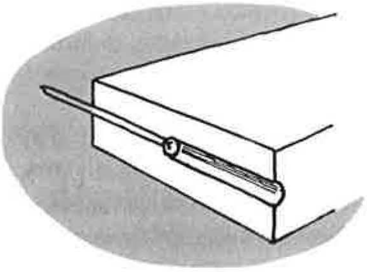


Figure 3.5. Studs with countersunk fasteners.

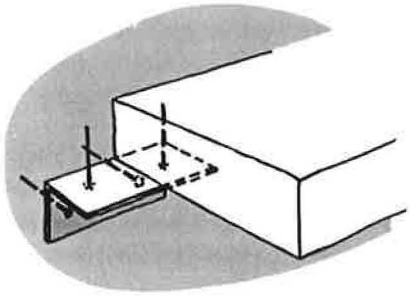


Figure 3.6. Attachment of studs to fittings which are in turn attached to the wall with short fasteners.

whole area + nailing grounds on spacers, figure 3.7.

☐ *Insulation covering whole area on the inside + insulation between nailing grounds on spacer blocks, figure 3.8.*

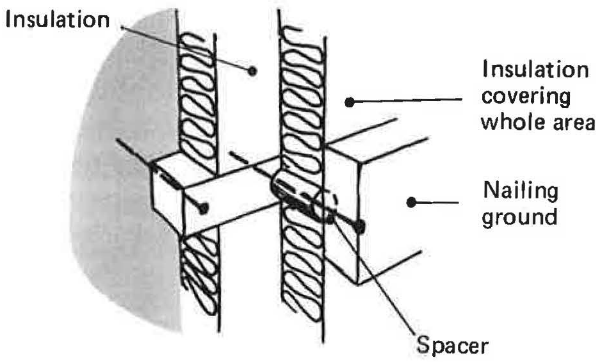


Figure 3.7. Insulation between studs + insulation covering whole area + nailing grounds on spacers.

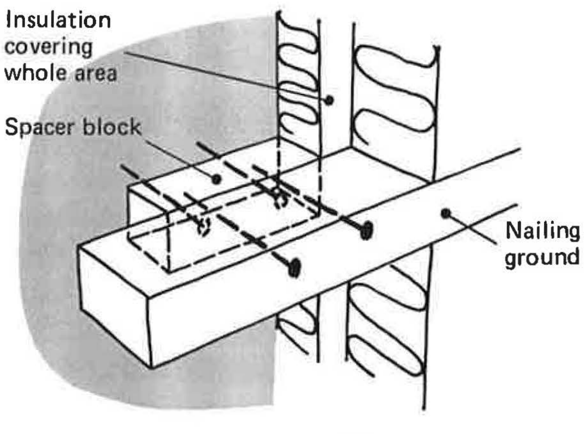


Figure 3.8. Insulation covering whole area on the inside + insulation between nailing grounds on spacer blocks.

The spacing of the studs should be adapted to the type of facade cladding and the size of the insulation sheets. The insulation shall be fitted so that there is a minimum number of joints. The normal spacing of horizontal studs is

1000–1500 mm for sheet metal cladding
600 mm for timber cladding.

Thermal insulation

Mineral wool is the commonest and most suitable material for additional insulation on the outside. Mineral wool allows the passage of moisture so that there is no risk of moisture damage caused by condensation. Non-combustible insulation is specified for additional insulation of buildings of more than three

floors. This requirement is satisfied by mineral wool.
There are two fundamentally different ways of fitting the insulation:

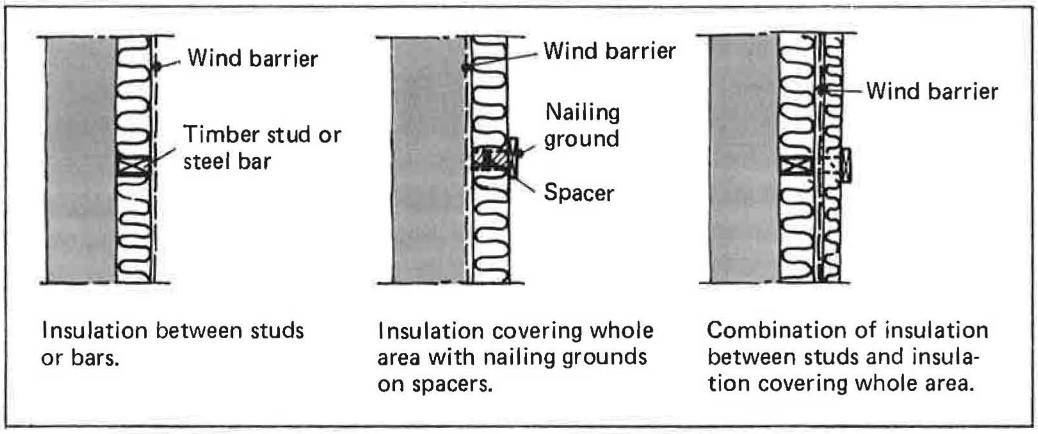


Figure 3.9. Insulation between studs and insulation covering whole area + nailing grounds on spacer blocks.

The method using insulation covering the whole area creates fewer cold bridges and thus its insulation properties are better.

Insulation between studs or bars

Insulation is carried out with sheets as illustrated in figures 3.10 and 3.11. The insulation thickness must be equal to the thickness of the stud or bar.

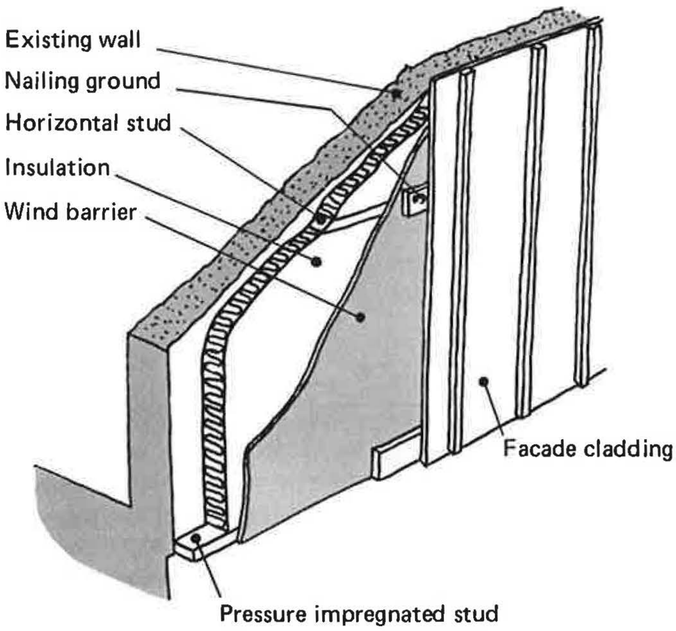


Figure 3.10. Insulation between horizontal wooden studs.

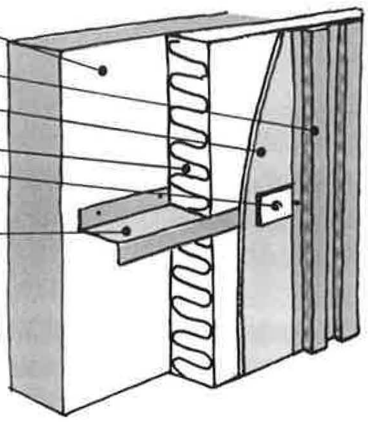


Figure 3.11. Insulation between horizontal steel bars.

The sheets of insulation must fill the space between the studs completely. This type of insulation must be provided with an external wind barrier in order to achieve the intended insulation effect. There must be no air gaps behind the insulation or between the insulation layer and the wind barrier. Gaps between the sheets of insulation and adjacent to studs must be avoided (see figure 3.12). The insulation effect is reduced considerably by large gaps. The insulation sheets must be cut accurately, preferably using a plank as a guide.

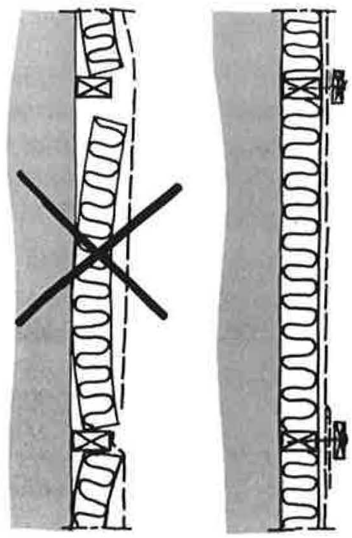


Figure 3.12. The insulation must fill the space between studs completely. The joints in the wind barrier must be airtight.

Insulation covering whole area with nailing grounds

The insulation is to be carried out as illustrated in figure 3.13. The sheets of insulation must be fitted carefully edge to edge so that there are no gaps.

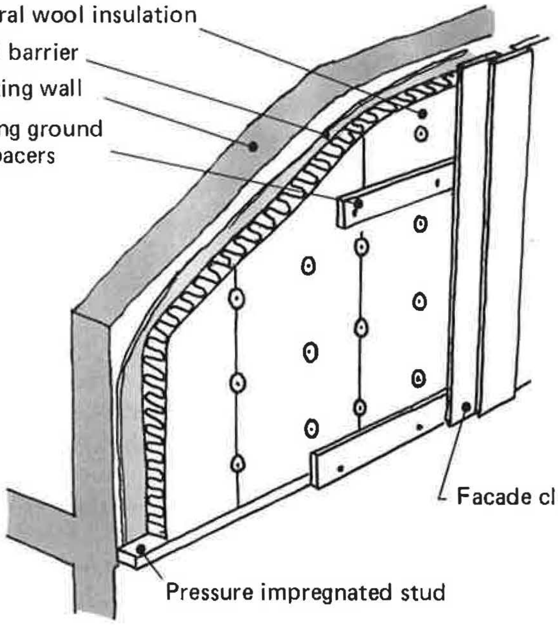


Figure 3.13. Insulation covering whole area with external nailing grounds mounted on spacers.

The sheets are to be fitted temporarily, to begin with using suitable fasteners and washers. The final fitting is to be done with external nailing grounds nailed to the old facade (figure 3.9).

The nailing grounds are mounted on special spacers which are lightly pressed into the insulation sheets and form a foundation for the grounds. Insulation covering the whole area provides a greater insulation effect than the method using insulation between studs, since the number of cold bridges is reduced.

Wind barriers

If the existing construction is airtight, such as concrete, insulation with a permeability of $l \leqslant 0.1$ m^3/hm Pa can be fitted over the whole area without the use of a special wind barrier.

Insulation with a permeability of > 0.1 m^3/hm Pa between studs must be provided with a wind barrier in order to prevent air movements which can reduce the insulation effect.

In cases where the airtightness of the construction must be increased and where paper-covered insulation is laid over the whole area ($l \leqslant 0.1$ m^3/hm Pa), either directly on existing walls or on top of insulation between studs, the wind barrier paper must face the wall.

The following can be used as a wind barrier:

- ☐ *AC 150/200 felt or similar*
- ☐ *Billeruds Tätofol*
- ☐ *Rascos system Vänertät*
- ☐ *Vänerply*
- ☐ *Hard or semi-hard fibre board*
- ☐ *9 mm gypsum board*
- ☐ *Asphalt board*
- ☐ *Gullfiber fibre board*
- ☐ *Gullfiber facade sheeting with or without paper-covering (insulation over whole area)*
- ☐ *Rockwool west coast sheeting with or without paper-covering (insulation over whole area).*

The last four also break cold bridges for example at the ends of steel bars.

The wind barrier must be fitted carefully and with as few joints as possible. The overlap between sheets of felt must be at least 100 mm.

A ventilated air gap of at least 20 mm should be provided between the facade material and the wind barrier. Nailing grounds are necessary to achieve this unless the panel profile allows such ventilation. The air gap must allow dryings of any moisture which may penetrate the construction, for instance as a result of driving rain.

Where the facade cladding, the insulation material and the wind barrier adjacent to the air gap are non-combustible (non-combustible construction), the air gap in the wall need not be broken for fire compartment boundary walls or floor constructions. Such non-combustible wind barriers are gypsum and mineral wool intended for insulation covering the whole area (with paper, if any, on the inside).

Brick facades

Brick facades have the advantage that they require almost no maintenance. However, the scope of using thick insulation is limited when additional insulation is applied. This is partly due to the fact that the brick itself takes up more room than other facade materials.

Furthermore, the facade cladding must be supported on angles or brackets attached to the existing facade or wall base, see figure 3.14.

However, it is possible to use narrower bricks than is traditional.

The following thicknesses are available:

60 mm
87 mm (modular bricks)
120 mm.

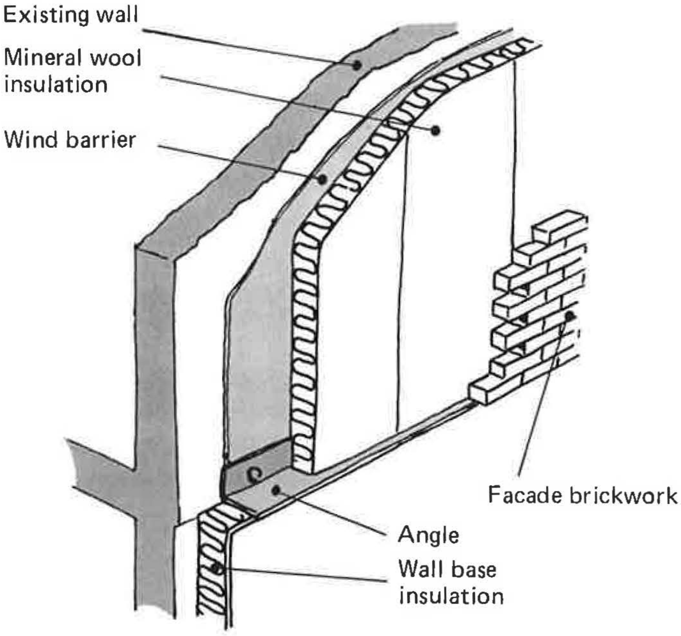


Figure 3.14. Additional insulation with brickwork as surface finish.

The commonest brickwork thickness used for additional insulation of detached houses is 60 mm. Special corner bricks are manufactured to give the impression that a normal brick thickness of 120 mm has been used. Designs using 60 mm bricks, which have been given general approval, are available for facade heights up to 12 metres.

The design must not permit penetration of rainwater into the wall construction. Where additional insulations is combined with facing bricks, it is only where the brickwork is interrupted, at wall bases, windows or door openings, etc., that it is necessary to ensure that the water will be drained to the outside face of the facade by metal flashing or building felt.

The support needed for the facing brickwork must be designed for the load imposed by the brickwork. Some of the load is transmitted to the existing wall by wall ties, but this should not be taken into consideration during design.

As noted above, the new facade is attached to the existing surface by wall ties. This means that the wind load is transmitted and the facing skin is stiffened against buckling.

The Central Office of the Swedish Brick and Tile Industry in Stockholm can provide further information concerning facing brickwork used in conjunction with additional insulation.

Thermal insulation

Insulation in the form of mineral wool sheets is attached with nails (to a timber base) or with TEFAB nails, etc. (to a lightweight concrete or concrete base) and washers to the old facade. It is important that the insulation lies tightly against the existing wall and that the sheets are fitted edge to edge so that no gaps can occur.

During design, it is advisable to allow for a gap of approximately 20 mm between the insulation and the brickwork (the permeability of the insulation being $l \leqslant 0.1$ m^3/hm Pa).

Wind barrier

If mineral wool with a permeability of $l > 0.1$ m^3/hm Pa is used, it should be supplemented with a wind barrier. If $l \leqslant 0.1$ m^3/hm Pa, the wind barrier can be left out. It is best if the wind barrier is a separate sheet of paper placed on the outside of the insulation.

If the house needs to be made more airtight, a weatherproofing layer (paper on mineral wool or a separate, hard fibre board or gypsum board) is to be used between the new insulation and the existing wall. See figure 3.14.

Plastered facades

Primarily in town environments, there are a number of plastered facades which need additional insulation. Approximately 25% of Swedish houses built before 1960 are plastered.

A certain amount of research has been carried out ever since 1940 with regard to plaster on insulation. However, it is only of late that interest has been aroused in the additional insulation of plastered facades. In this context the interest shown in maintaining a plastered finish on houses after additional insulation has also grown. This in turn has led to a number of methods being introduced during the last few years. These methods are all different to a certain extent and can be classified as follows on the basis of the method of attachment:

☐ *Rigid attachment* to existing walls. This can be done by using steel brackets or strips of wood to carry the plaster and plaster base.

☐ *Flexible attachment*, which is based on the principle that the plaster layer is attached by ties which allow movement in the plane of the plaster layer.

☐ *Bonded insulation* using lightweight plaster. This plaster which has a plastics binder is of low weight and is usually applied to expanded plastics insulation.

☐ *Insulating plaster* in which expanded plastics granules are mixed with cement plaster in order to achieve a certain degree of insulation.

The following methods can be given as examples of some of the applications:

☐ *TM-method* (Rigid attachment, Träullsplattfabrikernas Försäljnings AB). Comprises a mineral wool slab covering the whole area + wood wool sheet + metal lathing fixed to fasteners. The pricking-up and finishing coats are applied to the lathing. See figure 3.15.

☐ *G+R-method* (rigid attachment, Gullfiber AB and Stråbruken AB). Comprises a mineral wool slab between studs. Sheathing felt and metal lathing are placed on the outside, and Rhodipor plaster and finishing coat are applied on top of this. See figure 3.16.

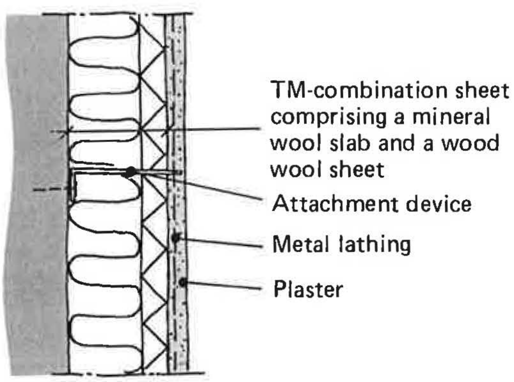


Figure 3.15. TM-method (rigid attachment).

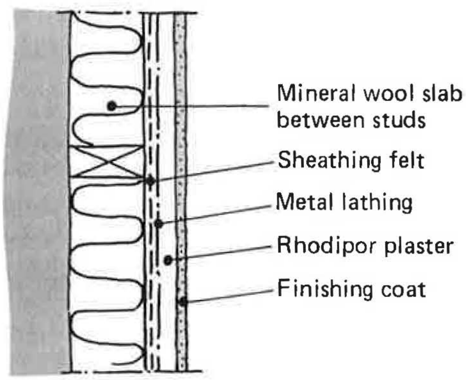


Figure 3.16. G+R-method (rigid attachment).

□ *Serporock method* (flexible attachment, Ernström & Co AB and Rockwool AB). Comprises a mineral wool slab covering the whole area and metal lathing suspended from fasteners carrying flexible ties. Pricking-up and finishing coats are applied onto the lathing. See figure 3.17.

□ *ISPO Insulation System* (bonded attachment, Snöland AB). The system is based on bonding of expanded plastics insulation and plaster to the existing wall. Glass fibre roving is used as reinforcement. The sheet of expanded plastics is bonded with synthetic resin-based cement adhesive to the existing backing and the metal lathing to the expanded plastics, after which the finishing coat is applied. See figure 3.18.

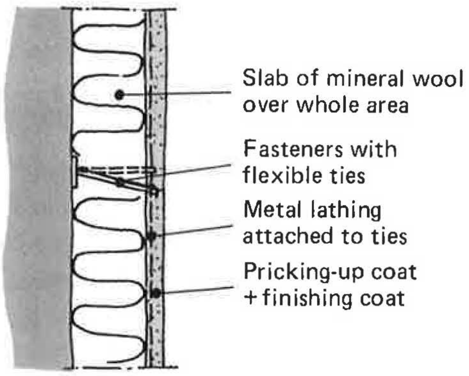


Figure 3.17. Serporoc method (flexible attachment).

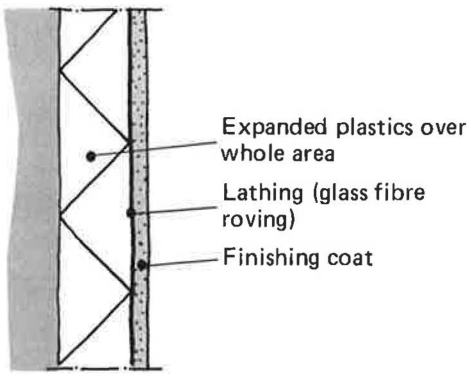


Figure 3.18. ISPO Insulation system (bonded insulation).

□ *Gyproc method* (flexible attachment, Gyproc AB). This is based on the AJ method in which the weight of the plaster layer is carried at the base of the wall via brackets across which a suspension line has been laid. The metal lathing and insulation are attached to eye belts which are grouted into the existing wall. The facade is plastered with textured gypsum plaster.

□ *Rhodipor method* (insulating plaster, Stråbruken AB). This is built up of insulating plaster containing polystyrene granules. The finishing coat is applied to this. The thermal insulation of 80 mm Rhodipor plaster corresponds to approximately 50 mm mineral wool. See figure 3.19.

Long-term experience of the different methods is quite limited. A systematic follow-up of the plaster systems is being carried out at the initiative of the

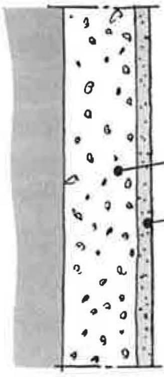


Figure 3.19. Rhodipor method (insulating plaster).

Swedish Council for Building Research. Experience gained so far shows that the methods function well from a technical point of view but it should be pointed out that correct working methods and detailed design are important if the risk of cracking in plaster is to be avoided. Bengt Elmarsson, the University of Technology, Lund, has presented and analysed the methods quoted here in »Plastering on top of additional insulation» (10).

Plaster manufacturers and insulation material manufacturers are able to provide further information.

Eaves and barge boards

Aesthetic and practical problems can arise at eaves and barge boards when the line of the wall is moved outwards in conjunction with additional insulation applied on the outside. The existing roof overhang can be extended as suggested in figures 3.20 and 3.21.

Window surrounds

A well-maintained window surround is important to the appearance of the facade and can, in certain cases, disguise the impression of windows set far back. Whether the window surround is to be made wide or narrow depends on the character of the building and must be decided from case to case.

Figures 3.22, 3.23 and 3.24 illustrate examples of some solutions.

Materials manufacturers often have ready-made detailed solutions for different designs of window surrounds and attachments.

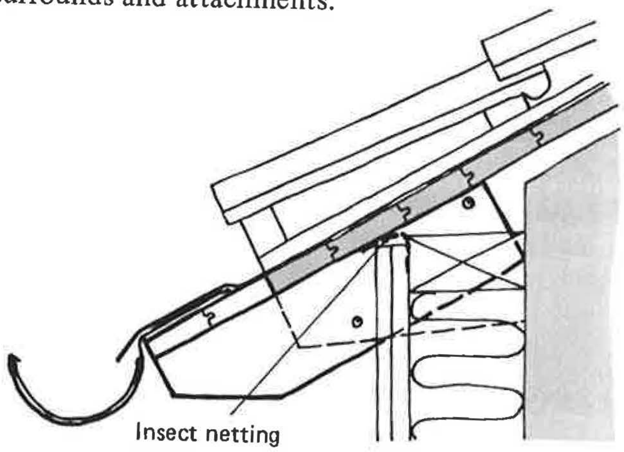


Figure 3.20. Extension of the eaves.

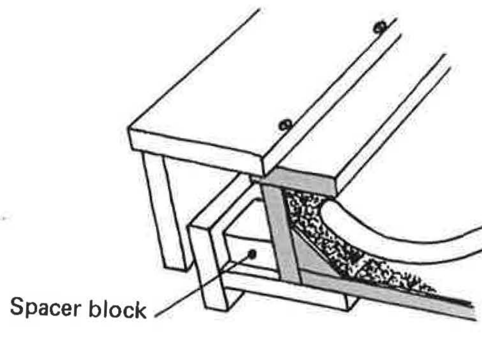


Figure 3.21. Extension of barge board.

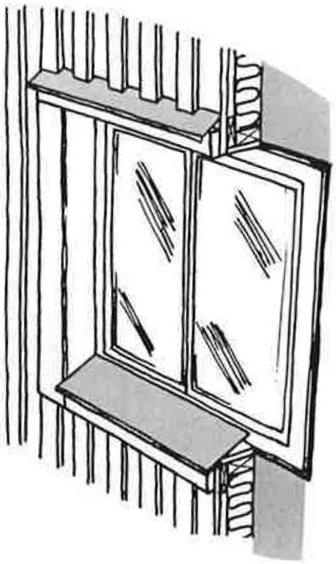


Figure 3.22. Window surround of timber.

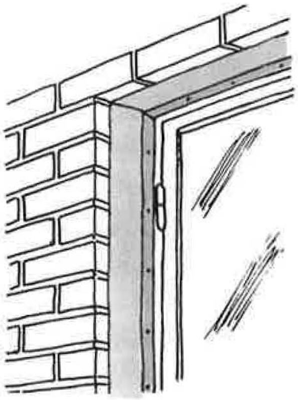


Figure 3.23. Window surround of sheet metal.

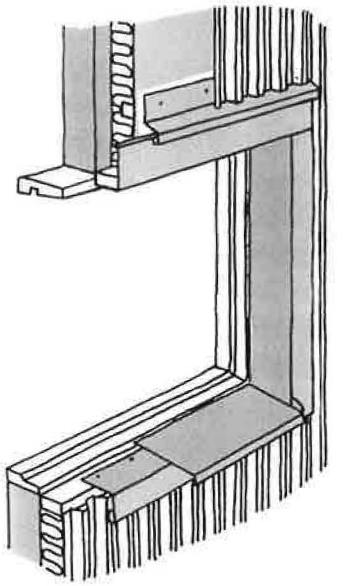


Figure 3.24. Window surround of sheet metal.

Wall bases

Additional insulation of the outside of an external wall can be discontinued where the base begins but may also comprise the base. An advantage of insulating the base as well is that cold bridges which can give rise to cold floors on the ground floor are reduced. Insulation of the base is also preferred from an aesthetic point of view. See figure 3.25.

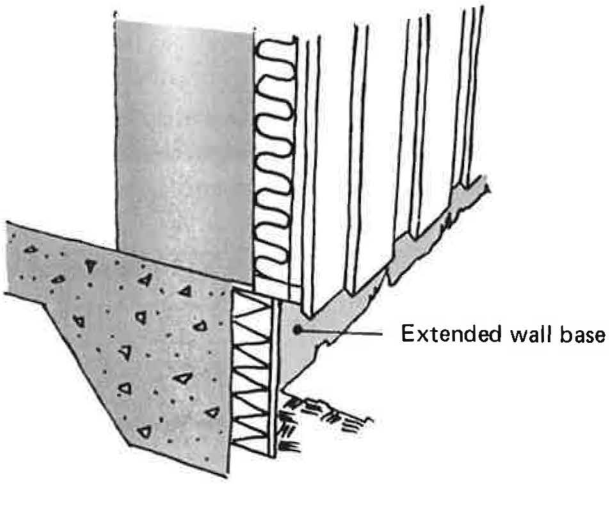


Figure 3.25. Additional insulation and extension of wall base.

When carrying out additional insulation, plaster can be used as a new surface finish on house bases. Methods available differ with respect to attachment, type of insulation, type of lathing for the plaster and types of plaster. See the section on plastered facades. There are also prefabricated wall base units available as an alternative method of additional insulation.

Manufacturers of plaster and insulation material can provide further information regarding additional insulation of wall bases.

Fasteners

All additional insulation must be attached to existing walls. Attachment to timber facades requires different types of nails and screws and does not constitute any serious problem. However, it may be quite difficult to fix attachment devices to stone and concrete and particularly to lightweight concrete. The appropriate manufacturer should be contacted with regard to the right type of fastener for each individual material. A large number of systems are available on the market and the appropriate manufacturer can advise on his material's requirements with regard to attachment methods. When fixing to lightweight concrete, tensile tests on the fastener are often required in order to ascertain the pull-out force of the fastener in the existing wall. Suppliers of fasteners sometimes help with such tests. Table 3.26 gives details of suitable fasteners for different existing wall materials.

	Light-weight concrete	*Solid brick*	*Perforated brick*	*Concrete*	*Timber*
Expansion bolt/screw	●	●		●	
Plastics plug	●	●	●	●	
Screw nail	●				
Sleeved ring shanked nail	●				
Wood screw					●
Ring shanked nail					●
Cut nail	●				
Anchor nail	●				
Soft-grouting nail	●	●	●	●	

Table 3.26. Suitable fasteners for different existing wall materials.

3.4.2 Additional insulation on the inside

Some precast units for additional insulation are available for internal fitting but the commonest method is to fix a wooden framework on the wall. If thin insulation (50 mm) is used, the studs are fixed directly to the old wall surface at a spacing determined by the sheet material to be placed between them, which normally comprises chipboard, wood fibre board or gypsum board. If greater insulation thicknesses are used, the framework is fixed at some distance from the wall and sheets of insulation covering the whole area are fitted between the framework and the wall. A vapour barrier which seals the wall should be applied between the cladding sheet and the insulation/framework. Where possible, the wall behind radiators should also be insulated.

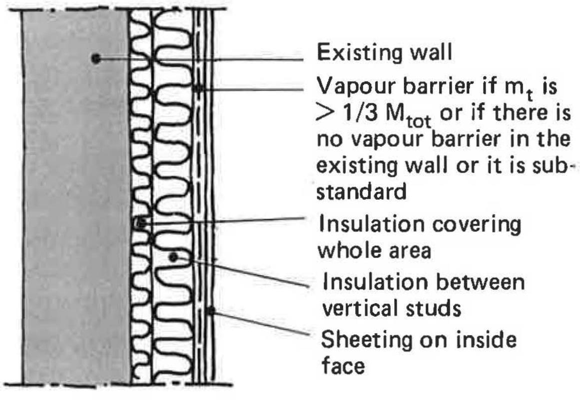


Figure 3.27. Additional insulation on the inside.

More details concerning additional insulation on the inside and its consequences for different constructions are given in »Additional insulation on the inside» by Ann-Charlotte Andersson (6), University of Technology, Lund.

3.4.3 Additional insulation by filling of cavities

Older houses may have cavities in external walls and floors, as a result of either sunken insulation or lack of insulation. These cavities can be filled with insulating material but difficulties often arise in achieving the intended result. This has been indicated in an investigation of urea formaldehyde foam application carried out by the Department of Building Technology at the University of Technology, Lund. The material used must be non-water absorbent, vapourtight, and shall not support the growth of micro-organisms. Materials which satisfy these requirements are mineral wool, polystyrene granules, expanded clay granules and urea formaldehyde foam. However, the use of urea formaldehyde foam can in certain cases introduce harmful quantities of water into the wall construction.

Cavity insulation is normally carried out by specialist firms. Only well-known companies should be engaged in view of the difficulties in checking the result.

4. Other building elements

4.1 General description of structural measures

Apart from the building elements discussed so far, there are other elements the additional insulation of which may be considered in specific cases:

□ *Inclined attic ceilings*
□ *Brace walls*
□ *External basement walls*
□ *Floors.*

However, it may only be possible to carry out one measure to improve airtightness. This applies primarily to buildings of cultural and historic interest or where it may be difficult to carry out extensive measures for other reasons.

4.2 Advantages and disadvantages of different measures

In the case of the insulation measures mentioned above, the energy conservation effect can be calculated in the same way as for attic floors and external walls (section 6.1.3).

The disadvantage of internal measures carried out on the above building elements is that they encroach on the living area and, at the same time, any existing cold bridges are retained.

Measures on the undersides of floors and the outsides of external basement walls are difficult to carry out and seldom profitable. However, these types of measures have little effect on the appearance of the building.

Additional insulation of the foundation structure reduces heat flow to the ground. This means that frost penetration in the ground around the building increases. If the subsoil contains a soil susceptible to frost the building can be damaged. The insulation thickness must be considered with this in mind.

A building which is more airtight and has a reduced air change rate may have a lower energy consumption. As a rough estimate, a change of 0.1 change/h corresponds to approximately 1200 kWh/year in a normal sized detached house.

4.3 Existing building stock

4.3.1 Inclined attic ceilings

Inclined attic ceilings are normally insulated with the same insulation material as that used in external walls.

Examination of table 3.2 (valid for external walls) may provide an estimated U-value for existing inclined attic ceilings.

4.3.2 Brace walls

If the brace wall is insulated at all, its insulation is usually slight. Calculation of the existing U-value (see Swedish Building Code 1975 (1)) should be carried out from case to case.

4.3.3 External basement walls

Table 4.1 gives approximate U-values for some existing external basement walls.

4.3.4 Floors

Table 4.1 gives approximate U-values for some existing floor constructions.

Building element	*Year of construction*	*U-value $W/m^2\,°C$*
External basement walls		
2 course brick wall or wall of natural stone	–1940	1.2
Hollow concrete blocks/concrete	1920–	0.9
Hollow concrete blocks/concrete plus 50 mm mineral wool externally or internally	1965–	0.4
Lightweight concrete/expanded clay	1950–	0.5

(cont.)

Building element	*Year of construction*	*U-value W/m² °C*
Lightweight concrete/expanded clay plus 50 mm mineral wool externally or internally	1965–	0.4
Crawling space or basement ceilings		
Fill of sawdust between 6" x 10" joists, 600 mm spacing Counter floor	–1910	0.4
Fill of sawdust or mass litter mixed with lime between floor 4" x 9" or 3" x 8" joists, 600 mm spacing	1900–45	0.4
Timber floor structure (2" x 8") plus 150 mm mineral wool	1960–	0.3
Precast lightweight concrete units, 200 mm	1945–	0.6
Concrete floor slab plus 45 mm mineral wool on top or underneath	1960	0.7
Slabs laid directly on the ground or cellar floors		
Concrete slabs with insulation 100 mm concrete plus 70 mm (top) or 50 mm (underside) mineral wool	1965–	0.3

Table 4.1. Approximate U-values for older external basement walls and floor structures.

4.4 Structural solutions

4.4.1 Inclined attic ceilings

The insulation thickness must in this case be adapted to the special conditions dictated by the construction. If this insulation method takes up too much living space, it is possible to apply the corresponding amount of insulation to the tie beams instead. Where attic ceilings lack insulation, ensure there is a ventilation gap adjacent to the roof of approximately 25 mm. Sheets of mineral wool can be used for insulation and it is necessary to make sure that the sheets fill the space completely between studs and the vapour barrier.

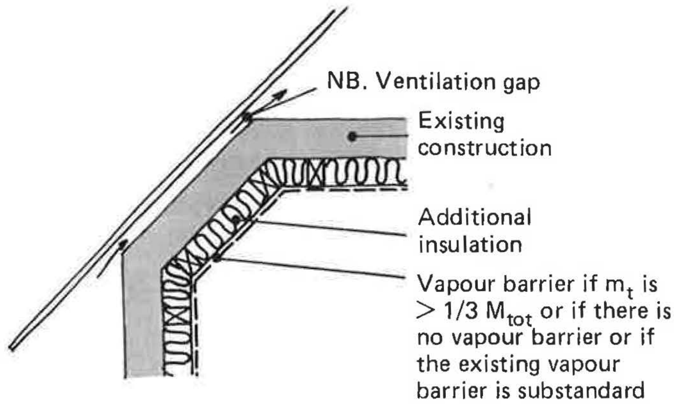


Figure 4.2. Additional insulation of an inclined attic ceiling.

4.4.2 Brace walls

These can be provided with additional insulation from the loft side. Insulation can be attached in different ways to the existing wall. Make sure however that the junction with the adjacent insulation is satisfactory. The junction between the vapour barrier in the brace wall and the intermediate floor is normally poor. Make sure that this is satisfactory.

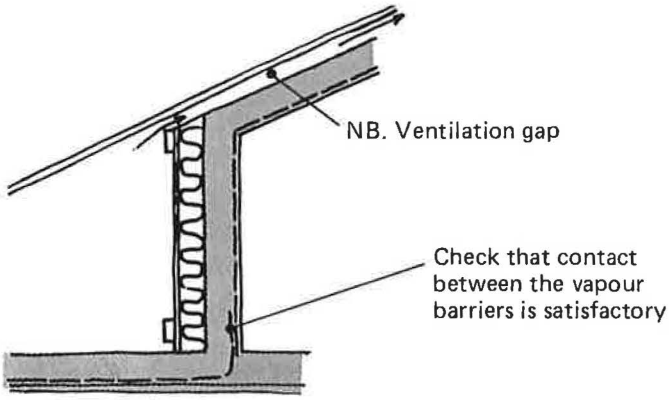


Figure 4.3. Additional insulation of brace wall.

4.4.3 External basement walls

Insulation of external basement walls can be carried out from the outside or from the inside.

Insulation on the inside should be carried out only when the wall is dry, otherwise there is a risk of mould or fungus growth in the structure.

The construction alternatives which can be used are the same as for additional insulation of external walls on the inside. For safety's sake, timber should be pressure impregnated and the plastics foil should be omitted so that drying out can also take place towards the inside.

Insulation on the outside is normally a little more difficult to carry out. A trench is dug along the cellar wall and hard mineral wool sheets are fitted against the wall. In this way a thermally insulated layer is formed which prevents capillary action, thus making the existing cellar wall dry. Above ground the mineral wool can either be plastered according to one of the plastering methods or precast wall base units can be used (see section 3.4.1).

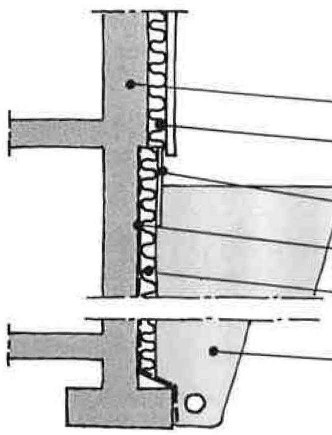


Figure 4.4. Additional insulation of basement walls on the outside.

4.4.4 Floors

The insulation of floors must be adapted to the existing construction. The choice of method depends on whether the floor is of timber or concrete. In the case of timber structures, the insulation can be applied either in, above or below the existing floor structure. In the case of concrete structures, the insulation must be laid above the concrete. However, the concrete must first be covered with a plastics foil in order to avoid moisture problems.

Floor units comprise a surface layer and insulation of mineral wool or expanded plastics. The units are laid on even surfaces. The manufacturers' recommendations should be followed since the design of units can vary.

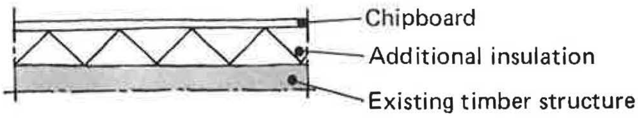


Figure 4.5. Insulation with floor units.

Insulation with a separate surface layer is another construction method where the insulation is made up either of expanded plastics or hard mineral wool. Chipboard is normally used as a surface layer. Figure 4.6.

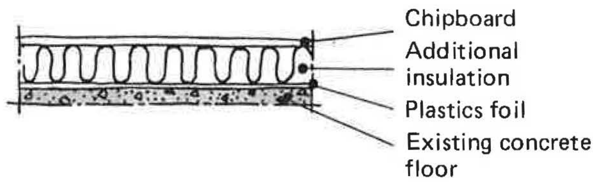


Figure 4.6. Insulation with a separate surface layer.

Framed timber floors are a common construction but care must be taken to ensure that moisture problems do not arise. The space between the timber studs, the existing floor and the new floor surface is filled completely with insulation.

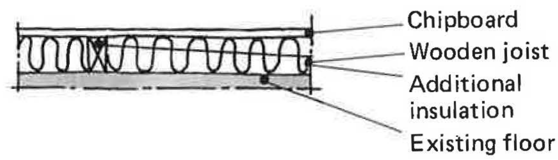


Figure 4.7. Insulation underneath framed timber floor.

Floors can be insulated from underneath if there is a crawling space under the floor. Insulation must fill the space between studs and the underside of the existing floor structure completely. Thicker insulation is possible if the insulation is applied directly to the floor. Secondary spaced boarding nailed to spacers keeps the insulation in place.

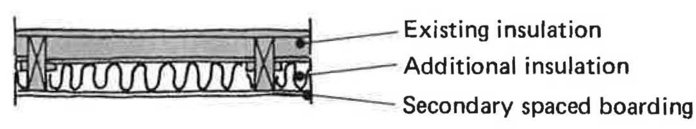


Figure 4.8. Insulation of floor from underneath.

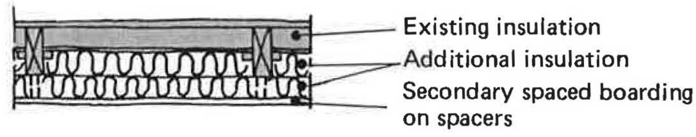


Figure 4.9. Insulation of floor from underneath.

Insulation inside floor structures can be carried out by injecting insulation material. Mineral wool, polystyrene granules or urea formaldehyde foam can be injected through drilled holes. However, in certain cases, urea formaldehyde foam can introduce harmful amounts of water into the structure. The work is normally carried out by specialist firms. Only well-known companies should be engaged in view of the difficulty of checking the results.

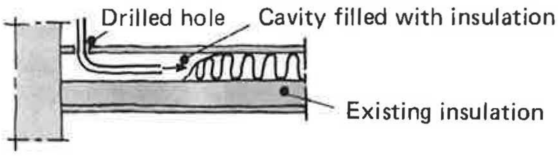


Figure 4.10. Insulation of floor structures by the injection of insulation material.

4.4.5 Airtightness

In a building there are many joints. It is extremely important for these to be airtight. A tight joint can be achieved by making the vapour barrier overlap joints between parts of the construction or by using different sealing systems and materials. The following systems which provide either insulation or an air and vapour seal or both, are available at present:

- *Sealants* provide an air and vapour seal. These can be supplemented at the bottom of the joint with a mineral wool strip or a tubular strip.
- *Sealing strips* of EPDM rubber which, when folded double and pressed into the joint, provide an air and vapour seal.
- *Mineral wool strips* of glass or mineral wool which are pressed into the joint. They provide only insulation and must normally be supplemented with a sealant. Mineral wool strips enclosed in plastics foil also function as air and vapour seals.
- *Jointing foam*, normally polyurethane foam, is available in a single-pack version and fills, seals and insulates the joint satisfactorily.

5. Combination of different methods

The way in which the energy conservation measures are combined and the order in which they are carried out is of great importance to the final result. Views are given below on the combination of both structural measures and structural and other energy conservation measures.

5.1 Combination of structural measures

The structural energy conservation measures which are often the most profitable are the elimination of natural air leakage through windows and doors and, where possible, *around* windows and doors. Other energy conservation measures should therefore always be preceded by or combined with measures to increase airtightness. Additional insulation of an easily accessible and badly insulated attic floor structure is profitable but even here gaps and points of air leakage must be eliminated when the existing insulation is augmented. When additional insulation of external walls is carried out, the airtightness of the building must also be improved. Joints in walls and between walls and frames must be sealed and the risk of air passing through the insulation at eaves and wall bases must be eliminated in order that the required result of additional insulation may be achieved.

Maintenance of other building elements on the facade must also be carried out in conjunction with additional insulation on the outside and the fitting of new facade cladding. Examples of suitable measures are the maintenance painting of gutters, downpipes, barge boards, windows etc.

5.2 Combination of structural and other measures

When structural and installation engineering measures are combined, it is important that the measures be carried out in the right order. A good rule is to begin by carrying out sealing and/or insulation measures and then to make adjustments of the heat supply and ventilation in the building. *Note that balancing of the heat supply (and thus the room temperature) in the different parts of a building is important in order that the desired effect may be achieved by structural measures.* If balancing is not carried out the result will be merely a few degrees rise in room temperature (this encourages opening of windows more often) and the energy consumption will remain unchanged. The reduction of the air temperature indoors results in an energy saving of approximately 5–7% per degree.

6. Calculation of the energy conservation effect of structural measures and the experience gained in their application

6.1 Calculation

Calculation of the *true* effect of different energy conservation measures is complicated. Several factors affect the result. Examples of such factors are the estimation of the thermal resistance and airtightness of existing building elements, the standard of workmanship in carrying out the energy conservation measures and side effects which often result from different measures and combinations of measures.

6.1.1 Measures to increase airtightness

The effect of measures to increase airtightness between casements/doors and frames on windows and doors depends to a great extent on the state of the existing doors and windows. An investigation of windows carried out at the University of Technology, Lund (5) indicated that only approximately 15% of the windows investigated were acceptably airtight. Windows and doors where the furniture is badly adjusted and where weatherstripping comprises textile strips or foam plastics strips are very pervious.

Rectification of such windows and doors and the consequent reduction in natural ventilation can cut the number of air changes in a flat or house by an estimated 0.1– 0.3 changes per hour. What this means in terms of energy conservation can be calculated using the formula:

$$\boxed{W = n \times V \times c \times \varphi \times Q}$$

W = annual energy saving in kWh
n = reduction in air change rate per hour
V = volume of flat/house in m^3

c = specific heat of air (Wh/°C kg)
φ = density of air (kg/m^3)
$c \times \varphi = 0.36$
Q = number of degree hours per year, i.e. the integrated product of the number of hours and the difference between indoor and outdoor temperatures when heat must be supplied, divided by 1 000. See figure 6.1.

An example shows that for each reduction of 0.1 in the air change rate in a 125 m^2 house in the Stockholm area (zone III) there is a saving of:

$0.1 \times 125 \times 2.4 \times 0.36 \times 110 \approx 1200$ kWh/year

Taking the cost of energy as Skr. 0.15/kWh, this gives an annual saving of Skr. 180 which exceeds the cost of good quality weatherstripping for a house of this size.

It is difficult to assess the potential savings resulting from other sealing measures between frames and walls, around floors, roofs, etc.

6.1.2 Additional insulation of windows

By fitting an existing double-glazed window with a third pane, the thermal transmittance (U-value) of the glazed area is improved from approximately U = 3.0 to U = 2.0 W/m^2 °C. The annual saving is thus the improvement in U-value multiplied by the number of degree hours for the area as shown in figure 6.1. For example, in Stockholm where Q is approximately 110, the saving is:

$(3.0–2.0) \times 110 = 110$ kWh/m^2 of glazed area annually

It must be remembered that glass is a transparent building element which allows the transmission of solar energy during the day. Thus the resulting energy losses are dependent on insolation and thus on the position of the window. Calculations carried out by Professor Bo Adamson at the University of Technology, Lund (11) give the following approximate values for energy savings as a result of the third pane (see table). This table assumes that the heat gain due to insolation is used for heating the house, which in turn assumes that room thermostats are fitted. If the heat gain is not utilized or if the windows are shaded by thick curtains, the energy savings will approximate to the values for north facing walls.

Town	*North facing wall*	*East/West facing wall*	*South facing wall*
Malmö (South Sweden)	90 kWh/m², year	75	55
Stockholm (Central Sweden)	105	90	75
Luleå (Northern Sweden)	145	125	110

Energy savings in excess of these can also be achieved because the cold radiation from windows is reduced as a result of the improved U-value and the temperature on the inside of the windows is increased. When the cold radiation from the windows is reduced, the room temperature can be lowered without the room feeling colder.

6.1.3 Additional insulation of floor structures, external walls, etc.

The energy conservation effect in the form of reduced fabric losses which can be achieved by additional insulation can be calculated by the following relationship

$$\boxed{W = \Delta U \times Q \times A}$$

W = annual energy saving in kWh

ΔU = $U_{before} - U_{after}$, i.e. the difference in thermal transmittance before and after additional insulation, $W/m^2 \,°C$

Q = number of degree hours per year divided by 1000

A = the area provided with additional insulation in m^2 excluding windows, doors, etc.

The difference in thermal transmittance, ΔU, is an expression of the improvement in the thermal insulation of the wall as a result of additional insulation. Approximate thermal transmittances before additional insulation, U_{before}, can be extracted from tables 2.1, 3.2 and 4.1 for some common structures. The thermal transmittance after additional insulation, U_{after}, can be calculated from figure 6.2.

The number of degree hours depends on the outdoor and indoor temperatures and the duration of the heating season. By dividing Sweden into four zones, as shown in figure 6.1, (division in accordance with »Swedish Building Code 1975»), and assuming that the indoor temperature is 20 °C, it is possible to assume the following approximate values for the number of degree hours.

Zone	Q at an indoor temperature of 20 °C
I	163
II	130
III	110
IV	98

Figure 6.1. Degree hours (in thousands)/year for zones I–IV for an indoor temperature of 20°C.

More accurate Q values for different indoor temperatures and areas can be extracted from »Climatic Data Book for Sweden» (12) or »Building Services Handbook» (13).

U-values after additional insulation:

The U-value of the structure after additional insulation can be calculated from the following relationship:

$$\boxed{U_{after} = \frac{1}{M_{tot}}} \qquad \boxed{M_{tot} = \frac{1}{U_{before}} + m_t}$$

M_{tot} = total thermal resistance in $m^2\,°C/W$
m_t = thermal resistance of additional insulation in $m^2\,°C/W$

The thermal resistance of additional insulation varies according to standard of workmanship and insulation thickness.

For insulation covering the whole area, m_t is obtained from:

$$\boxed{m_t = \frac{d}{\lambda_n}}$$

d = thickness of additional insulation in metres
λ_n = practical thermal conductivity of material in $W/m\,°C$

For sheet metal bars, the following is used:

$$\boxed{U_{after} = \frac{1}{M_{tot}} + \Delta U} \qquad \boxed{M_{tot} = \frac{1}{U_{before}} + \frac{d}{\lambda_n}}$$

ΔU = allowance for the cold bridge caused by the metal bar in $W/m^2\,°C$

The following applies for mineral wool between wood studs:

$$\boxed{m_t = \frac{1}{\frac{P\alpha}{m\alpha} + \frac{P\beta}{m\beta}}}$$

$P\alpha$, $P\beta$ = percentage of insulation and percentage of timber studs respectively in relation to the whole area

$m\alpha$, $m\beta$ = thermal resistance (d/λ) in $m^2\,°C/W$ for insulation and timber studs respectively

The U-value of the structure depends on the thermal conductivity λ of the material used. The material's λ-value can vary quite considerably. The λ-values which can be used for calculations are indicated in »Swedish Building Code 1975», Chapter 33:5K.

An approximate U-value for walls with additional insulation can be obtained from figure 6.2 for mineral wool insulation covering the whole area and for min-

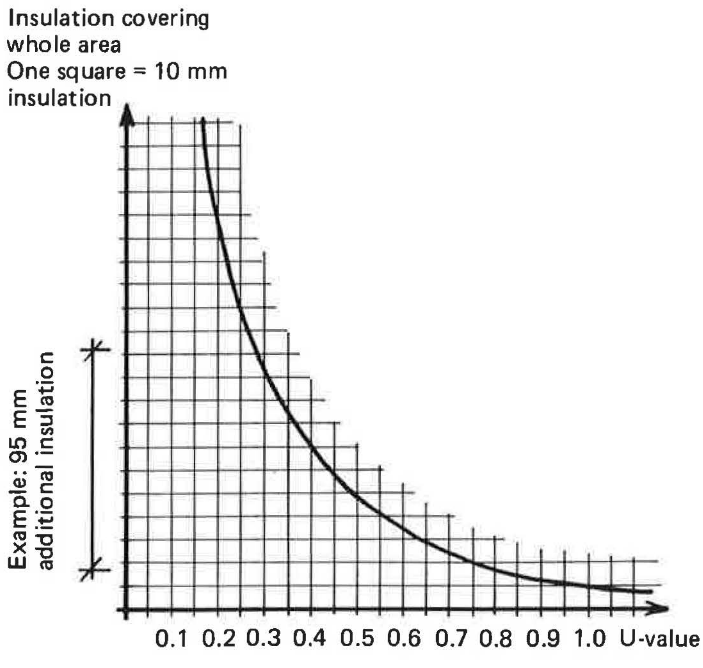
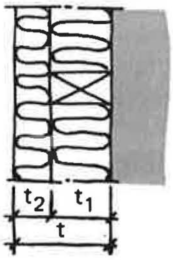


Figure 6.2. Diagram of U-values as a function of additional insulation thickness.

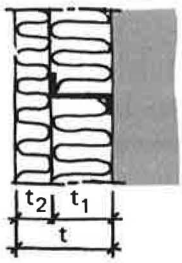
eral wool insulation between metal bars and timber studs respectively spaced at 600 and 1200 mm. Interpolation and extrapolation for other spacing is possible. In the case of normal metal bars it is assumed that the cold bridge between the bars and the cladding material is broken by a strip of wood fibre board or similar material. The diagram in figure 6.2 provides sufficient accuracy in most cases for practical calculations, bearing in mind the difficulty in obtaining a correct initial U-value.

The following applies for timber studs and steel bars:
$U_{after} = U_{whole\ area} + \Delta U$



ΔU_{timber}

Insulation thickness	C 600	C 1200
$t_2 = 0$	0.04	0.02
$t_2 = 0.5t$	0.02	0.01



ΔU_{steel}

Insulation thickness	C 600	C 1200
$t_2 = 0$	0.20	0.10
t_2 = 10–15 mm	0.16	0.08
$t_2 = 0.25t$	0.08	0.04
$t_2 = 0.5t$	0.04	0.02

Linear interpolation is applied for other stud spacings and insulation thicknesses.

□ Example. Additional insulation using 95 mm mineral wool between timber studs spaced at 1200 mm, $U_{before} = 0.8$ W/m² °C.

Enter the diagram at 0.8 on the horizontal axis. Draw a line up to the curve and then across to the vertical axis. Count 9.5 squares up on the vertical axis (= 95 mm supplementary insulation). Then go back to the curve and from the point of intersection go down to the horizontal axis.

Read off $U = 0.29 = U_{whole\ area}$.

Allowance for bars: ΔU according to table above = = 0.02

$U_{after} = 0.29 + 0.02 = 0.31$ W/m² °C.

6.2 Experience

Follow-up inspections of completed additional insulation projects have been reported on only to a limited extent. There are many difficulties in carrying out this type of evaluation. The problems include the difficulty in elucidating initial data, the U-value of the existing structure, energy consumption over a long period prior to the measure, etc. Furthermore, there are difficulties in carrying out measurements and uncertainties during the actual measurement. It is also very common for different energy conservation measures to be combined. For example a boiler may be adjusted in conjunction with additional insulation of an attic floor structure. This means that it may be difficult to ascertain the true effect of a specific conservation measure.

Results inferior to those expected as a result of different structural measures may be due to the fact that the heating system was not adjusted after the application of structural measures. This means that the room temperature has simply increased so that the expected savings have not been achieved. Other reasons may be badly carried out work, for example draughts between additional insulation and the old wall.

The Industrial Group for Light Construction Engineering (14) carried out a follow-up examination in 1977. This showed that the conservation effect, calculated in accordance with 6.1.3, was exceeded by 0–50%. Reasons for the variation were the state of the initial structure and the life styles of the occupants.

A technical explanation of these additional effects is given by the factors set out in 3.2:

- □ *Facade surfaces of increased airtightness*
- □ *Fewer cold bridges*
- □ *Dryer walls*
- □ *Warmer inner surfaces*
- □ *Reduced air temperature indoors (as a result of the above).*

A thesis presented to Chalmers University of Technology, Göteborg in 1978 – »Additional insulation of the facades of detached houses on the outside» (15) – gave evidence of the same tendency, i.e. the effects of additional insulation were often greater than expected. To quote an example, 20 detached houses achieved annual energy savings of 168,000 kWh instead of the expected 87,500.

Another thesis presented to the Royal Institute of Technology, Stockholm in 1978 – »The effects of energy conservation measures» (16) – noted certain additional savings as a result of additional insulation in residential buildings. Combinations of different measures were common in the buildings studied in this investigation.

Evaluations carried out on a more official basis indicate the same tendencies.

The calculated energy savings as a result of improved U-values constitute, with a few exceptions, the lower limit of the true effect.

Checks on the effects of energy conservation measures are made all the time as it is of great importance for Sweden's economy and energy supply position that future investments are primarily made in the most profitable energy conservation measures.

7. The energy conservation cost methods

Different methods can be used to determine the most economic additional insulation thickness.

The optimum economic insulation thickness can be determined according to the energy conservation cost method, originally proposed by Professor Bo Adamson, the University of Technology, Lund. The optimum economic insulation thickness is normally greater than the minimum stipulated in the Swedish Building Code. The energy conservation cost method is based on comparison of the investment cost and the present value of future maintenance costs with the total energy saved during the life of the building. Energy conservation cost is defined as:

$$\text{Energy conservation cost} = \frac{\text{investment cost}}{\text{total energy conservation}}$$

Energy conservation cost must be compared with the price of energy, i.e. the cost of consuming a unit of energy. Future rises in the cost of energy and rate of interest (net interest after tax) must be considered in this context. Rises in the cost of energy and net rate of interest determine a discount factor which is also dependent on the life of the building. This discount factor is tabulated in table 7.1. The energy cost to be used as the basis of comparison is today's energy cost multiplied by this discount factor.

An energy conservation measure is profitable as long as the energy conservation cost is lower than the corrected cost of energy, i.e.

$$\frac{\text{Investment cost + present value of maintenance costs}}{\text{Annual energy savings x life of building}} \leqslant$$

$$\leqslant \text{discount factor x current energy cost.}$$

If the remaining life of the building is 30 years, the net rate of interest 5% and the annual energy cost increase is assumed to be 7%, the relative value of a future energy saving is 1.358 x today's energy cost.

Using an energy cost of Skr. 0.15/kWh, the energy conservation cost must not exceed 0.15 x 1.358 = = Skr 0.2037/kWh.

Life of building 30 years

Annual rise in energy cost in %	*Interest %* 3	4	5	7	10	15
3	1.000	0.864	0.752	0.585	0.422	0.276
4	1.166	1.000	0.865	0.663	0.470	0.300
5	1.366	1.164	1.000	0.758	0.527	0.327
7	1.905	1.601	1.358	1.000	0.670	0.395
10	3.242	2.677	2.227	1.579	1.000	0.540
15	8.394	6.766	5.489	3.687	2.142	1.000

Life of building 20 years

Annual rise in energy cost in %	*Interest %* 3	4	5	7	10	15
3	1.000	0.905	0.822	0.687	0.538	0.382
4	1.108	1.000	0.906	0.752	0.584	0.409
5	1.231	1.107	1.000	0.825	0.638	0.440
7	1.526	1.386	1.226	1.000	0.758	0.511
10	2.141	1.898	1.689	1.354	1.000	0.548
15	3.862	3.381	2.972	2.321	1.548	1.000

Table 7.1. Discount factor for building life of 20 and 30 years for varying net interest rates and rises in energy cost.

Average and marginal energy conservation cost

The effect of each centimetre of insulation decreases with thickness. From the point of view of energy economy, it is profitable to increase the insulation thickness by just so much that the last cm exactly achieves the required return on capital.

The marginal energy conservation cost can be obtained by calculating the energy conservation cost stage by stage. From a practical point of view it is best if 20–30 mm insulation is added for each stage. For maximum profit, the marginal energy conservation cost must be the same as the current energy price.

This determines the thickness which is the optimum from the point of view of energy economy.

When the optimum insulation thickness has been determined, the overall profitability of the measure is checked by calculating the average energy conservation cost. In the case of profitable insulation measures, this is always lower than the marginal energy conservation cost. The following thus applies in general:

- □ *The marginal energy conservation cost determines the insulation thickness.*
- □ *The average energy conservation cost determines the profitability.*

8. Worked examples

8.1 Description of the building

The building being considered is a three storey block of flats built in the 1950's. The building is situated in zone III. The dimensions of the building are length = = 34.5 m, width = 9.0 m, height = 8.0 m. It comprises 12 flats.

The walls consist of 250 mm lightweight concrete + plaster with a calculated U-value of 0.8 $W/m^2\,°C$. The total external wall area provided with additional insulation is 530 m^2.

The attic floor structure consists of 200 mm lightweight concrete and 30 mm mineral wool. The U-value of the structure is calculated as 0.5 $W/m^2\,°C$. The total area accessible from the outside is 280 m^2.

The windows comprise 84 inward-opening double windows. The overall window area is 130 m^2, the glazed area is 105 m^2. The U-value is calculated as 3.0 $W/m^2\,°C$. Weatherstripping is made up of textile strips. 12 doors have glazed panels.

8.2 Airtightness of windows and doors

Weatherstripping comprises older textile strips of inferior sealing properties. Replacement of weatherstripping and adjustment of all windows and glazed doors is expected to reduce the air change rate by 0.2 changes/h. According to 6.1.1 this gives an annual energy conservation effect of

$$0.2 \times 34.0 \times 8.5 \times 2.4 \times 3 \times 0.36 \times 110 =$$
$$= 16{,}480 \text{ kWh/year.}$$

Based on an energy cost of Skr. 0.15/kWh, this gives a saving of Skr. 2470/year. The cost per flat is assessed as Skr. 450 or Skr. 5400 in all. The Government energy conservation grant amounts to Skr. 150/flat, or Skr. 1800. The service life of the measures is assessed as 10 years.

8.3 Additional insulation of windows

Windows not only constitute a source of energy losses but also require a considerable amount of maintenance. External maintenance painting of a window currently costs approximately Skr. 275 and must be repeated every 5–10 years.

In the building in question, the external casements of the double windows were replaced by a double-glazed sealed unit as described in 1.4.4 and at the same time the external wooden frame was clad with a factory-painted sheet metal profile. According to 6.1.2, the annual energy gain is

(3.0 - 2.0) x 105 x 110 = 11,550 kWh/year.

Applying an energy cost of Skr. 0.15, this corresponds to Skr. 1,730/year. The cost is Skr. 350/m² or Skr. 45,500. The energy conservation grant (approved cost) amounts to Skr. 250/m² or Skr. 32,500. The reduced cost of painting is Skr. 275/window after 0,7, 15 and 22 years if we assume a 30 year period. This amounts to Skr. 23,100 each time or a total of Skr. 92,400 over a 30 year period.

8.4 Additional facade insulation

The building was provided with additional insulation on the outside and was clad with metal sheeting on timber studs at a spacing of 1200 mm (framework approximately 5% of area).

In order to arrive at an optimum insulation thickness, thicknesses of 45, 95, 145 and 195 mm were studied (95 mm is currently the minimum approved thickness for Government loan and grant). In the case of 145 and 195 mm, the insulation was applied in two thicknesses with an external layer of 50 and 100 mm respectively covering the whole area.

The remaining life of the building was assumed to be 30 years. Q = 110 (see figure 6.1). The total building cost is assumed to be Skr. 220, 240, 260 and 290/m² for the insulation thicknesses studied (the approximate cost of additional insulation including facade cladding).

The U-values after the measures are carried out are extracted from figure 6.2. The U-value for 95 mm insulation is already described in the diagram, the others are given in table 8.1. The table also shows the energy consumption for the different thicknesses. In the case of 95 mm insulation this is:

$$\boxed{W = U \times Q \times A \text{ kWh/year}}$$

$$W = 0.31 \times 110 \times 530 = 18{,}000 \text{ kWh/year}$$

		Additional insulation, mm				
		0	*45*	*95*	*145*	*195*
U-value	$W/m^2\,°C$	0.80	0.45	0.31	0.22	0.19
m_t	$m^2\,°C/W$	0	0.98	1.98	3.30	4.00
Construction cost	$Skr./m^2$	0	220	240	260	290
Energy consumption	kWh/year	46,600	26,200	18,000	12,800	11,100

Table 8.1.

The energy conservation cost (see Chapter 7) is calculated for 95 mm insulation as:

$$\frac{\text{Investment}}{\text{Savings}} = (\text{Skr./kWh})$$

$$\frac{240 \times 530}{(46{,}600 - 18{,}000) \times 30} = \frac{1272 \times 10^2}{85.8 \times 10^4} = \text{Skr. } 0.15/\text{kWh}$$

The marginal energy conservation cost for the step between 95 and 145 mm is:

$$\frac{(260 - 240) \times 530}{(18{,}000 - 12{,}800) \times 30} = \frac{106 \times 10^2}{15.6 \times 10^4} = \text{Skr. } 0{,}07/\text{kWh}$$

The average and marginal energy conservation costs are given in table 8.2.

Energy conservation cost, Skr./kWh	*Additional insulation, mm* *0*		*45*		*95*		*145*		*195*
Average			0.19		0.15		0.14		0.14
Marginal		0.19		0.04		0.07		0.31	

Table 8.2.

The current energy price can be assumed to be Skr. 0.15/kWh, the rate of interest 8% and the increase in energy cost 8%. Then, from table 7.1 in Chapter 7, the relative value of future energy savings is 1.0 greater than the current cost of energy. Therefore the energy conservation cost must be compared with:

0.15 x 1.0 = Skr. 0.15/kWh

145 mm insulation is therefore the optimum thickness in this case since the step between 95 and 145 is the »last one which is profitable», i.e. is less than the comparison price of Skr. 0.15/kWh.

The average energy conservation cost is of the same magnitude as the »comparison price», despite the fact that the whole of the construction cost is borne by the insulation. This is not always correct since the effect due to new cladding, better acoustic insulation, etc., should also be included in the calculation. If facade renovation is necessary, irrespective of additional insulation, only the cost of insulation should be included when the energy conservation cost is calculated. This will then be considerably less than calculated above.

Additional insulation of 145 mm saves 33,800 kWh/year. This corresponds to 4.8 m^3 oil (1 m^3 oil is equivalent to approximately 10,000 kWh) if efficiency is assumed to be 70%.

The construction cost in the example is:

260 x 530 = Skr. 137,800

Additional insulation qualifies for a Government loan and grant. According to rules applicable in July 1979, we have the following:

Using 145 mm additional insulation, the approved cost for a Government energy conservation loan and grant is:

Insulation:	m_t x 20 + 70	Skr. 136/m^2 *
Cladding, sheet metal:	Skr. 80/m^2	Skr. 80/m^2 **
	Total	Skr. 216/m^2

Total approved cost 530 x 216 = = Skr. 114,480

8.5 Additional insulation of attic floor structures

Attic floor structures are accessible from above. The optimum thickness is calculated in the same way as for external walls. Here we have chosen to study 100, 200, 300 and 400 mm at costs of Skr. 30, 45, 60 and 75/m^2 respectively.

* Qualifies for grant.

** Does not qualify for grant.

The U-values for the different alternatives are given in table 8.3. The average and marginal energy conservation costs are given in table 8.4.

		Additional insulation, mm				
		0	*100*	*200*	*300*	*400*
U-value	W/m² °C	0.50	0.24	0.15	0.11	0.19
m_t	m² °C/W		2.20	4.70	7.10	9.10
Construction cost	Skr./m²		30	45	60	75
Energy consumption	kWh/year	16,520	7,930	4,960	3,640	2,975

Table 8.3.

Energy conservation cost Skr./kWh	*Additional insulation, mm 0*	*100*	*200*	*300*	*400*
Average		0.03	0.04	0.04	0.05
Marginal	0.03	0.05	0.11	0.21	

Table 8.4.

Skr. 0.15/kWh is the comparison cost as in the case of the walls, which means that 300 mm is the optimum insulation thickness.

The energy savings are (16,520 - 3,640) = = 12,880 kWh/year.

The construction cost is 60 x 280 = Skr. 16,800.

For 300 mm additional insulation the approved cost for Government energy conservation loan and grant is:

m_t x 10 + 20 = Skr. 91/m².

Total approved cost: 280 x 91 = Skr. 25,480.

8.6 Finance

Alternative 1

We will assume that the facade is in very good condition and that the windows are not in direct need of renovation. The building owner chooses to insulate the attic floor structure and carry out »general sealing» of windows and doors.

Measure	*Cost* *Skr.*	*Approved cost* *Skr.*	*Savings* *kWh/year*	*Savings* *Skr./year**
Sealing of windows, doors	5,400	1,800	16,480	2,470
Attic floor structure	16,800	25,480	12,880	1,930
Total	22,200	27,280	29,360	4,400

Government grant: 35% of approved cost = Skr. 9,550 (Maximum Skr. 3,000/flat.)
Government loan: Approved cost – grant = = Skr. 17,730.

* Energy cost of Skr. 0.15/kWh.

Table 8.5.

Alternative 2

We will assume that the facade is in immediate need of renovation and that the windows need repairing. The building owner has decided to carry out additional insulation of the facade and windows and to clad the outside of window frames with sheet metal in addition to the measures for attic floor structures, windows and doors proposed in alternative 1.

Measure	*Cost* *Skr.*	*Approved cost* *Skr.*	*Savings* *kWh/year*	*Savings* *Skr./year*[1)]
Sealing of windows, doors	5,400	1,800	16,480	2,470
Attic floor structure	16,800	25,480	12,880	1,930
Additional insulation of windows	45,500	32,500	11,550	1,730[2)]
Additional insulation of facade[3)]	137,800	114,480	33,800	5,070
Total	205,500	174,260	74,710	11,200

1) Energy cost of Skr. 0.15/kWh.

2) Savings due to reduced maintenance painting of windows resulting from the cladding of external timber frames, is assumed to be Skr. 3,000/year.

3) Including new facade cladding.

Table 8.6.

Government grant:	35% of approved cost Maximum Skr. 3,000/flat = = Skr. 36,000.
Government loan:	Approved cost – grant = = Skr. 138,260.

All the measures are individually profitable. The conservation effects of the measures illustrated here *can* be added. Despite this, the example in alternative 2 indicates that the Government loan and grant regulations do *not* cover the whole of the cost although this was the intention of the energy conservation grant.

It should however be pointed out that the costs in the example are very approximate and refer to work *and* materials. Some of the costs could be kept down by »do-it-yourself» work.

Appendix

Energy conservation, loans and grants

Information booklet of the Swedish Housing Board regarding energy construction loans and grants for houses and certain residential premises. Valid from 1980-01-01

You can get a grant of up to Skr. 3,000/flat if you improve the thermal economy of your house. You can also apply for a Government loan. In order to qualify for a loan and a grant, the approved cost must be at least Skr. 1,500.

Information and application forms are available from the Local Authority. Applications are to be made to the Local Authority.

Holiday homes excluded

Loans and grants are available for detached houses and blocks of flats. In certain cases it is also possible to get assistance for non-residential premises associated with dwellings. Non-residential premises which do not need an appreciable amount of heating are not eligible for assistance. A housing association can, in certain cases, get assistance for a communal amenity. You can get assistance for permanent dwellings but not for holiday homes.

Real energy savings

Another condition is that the measures must result in real energy savings. Additional insulation on the outside of external walls and attic floors must correspond to at least 10 cm Quality A mineral wool or 10 cm expanded plastics.

Additional insulation of floors and internal insulation of walls and attic floors must correspond to at least 5 cm Quality A mineral wool or 5 cm expanded plastics.

Houses which already have acceptable insulation are not eligible for grants or loans for further additional insulation and improvements.

Apply in good time!

Work must not be commenced before the County Housing Board has reached a decision or given dispensation to commence the work. It is therefore necessary to apply in good time.

Approved cost

Loans and grants are calculated on the cost approved by the County Housing Board. Standard costs have already been calculated for most measures. This means that you only get assistance according to the standard costs even if the work costs more. If there is no standard cost calculated, the County Housing Board will calculate the approved cost.

An example for a detached house

These are the approved amounts which are applicable on 1/1 1980. If you apply later, they may be different.

District heating

Connection to district heating	maximum Skr. 15,000

Electric heating

Control equipment for direct electric heating	Skr. 1,000
Night storage of hot water	Skr. 500

Heating controls, etc.

Motorized mixer valve with external sensors and time control	Skr. 2,500
Type-approved thermostatic radiator valves	Skr. 125
Circulation pump (in conjunction with heat control)	Skr. 500

Wood-fired heating

In order to get assistance it is normally necessary for free fuel to be available.

A boiler which needs recharging not more than 2 – 3 times/day	maximum Skr. 10,000

Heat pump, type-approved/or similar

Heat pump for entire annual requirement	maximum Skr. 24,000
Heat pump for at least half the annual requirement	maximum Skr. 14,000

Solar heating

Hot water system	maximum Skr. 8,000

Heat recovery

For example ventilation heat exchanger	Skr. 7,000

Wood chip firing

Stoking device with automatic thermostatic controls	maximum Skr. 8,500
Pre-heater with a reservoir of at least 300 litres	maximum Skr. 4,000

Additional insulation

The amount depends on the amount of additional insulation, for example:	10 cm mineral wool (Quality A)
Attic floor structure	Skr. $40/m^2$
Ground floor structure	Skr. $75/m^2$
External walls	Skr. $110/m^2$

Facade cladding

Facade cladding is eligible only for loans and not for grants. Facade cladding is normally eligible only if the additional insulation satisfies the conversion requirements in Swedish Building Code 1975.

Sheet metal cladding	Skr. 80/m²
Timber panels	Skr. 100/m²
Thick plaster	Skr. 120/m²
Facing bricks	Skr. 140/m²

Insulation with injected expanded plastics

Edge of floor construction	Skr. 25/meter
Floor constructions above crawling spaces or external walls	Skr. 30/m²

Triple glazing

or similar improvements (m² = overall window area)	Skr. 250/m²

Energy conservation grants

Energy conservation grants amount to 35% of the approved cost. The maximum grant is Skr. 3,000/flat. You can get either grants only or grants together with energy conservation loans.

Those who get improvement loans for energy conservation instead of energy conservation grants can get a larger proportion of the loan free of interest and capital repayment. See under Home improvement loans.

Energy conservation loans

Energy conservation loans can be given for that part of the approved cost which is not covered by an energy conservation grant. No collateral is required for loans up to Skr. 20,000. A local authority guarantee or a mortgage is required for higher loans.

The maximum period of repayment for loans is 20 years. The loan is a fixed instalment one, i.e. the sum of the interest and capital payments is approximately the same each year over the period of the loan. In this way the annual capital repayment is small in the beginning and increases over the years. If the energy conservation loan is combined with a government housing loan for any other type of rebuilding, the energy conservation loan has the same repayment period as the housing loan.

The rate of interest is determined each year (11% in 1980).

In the case of blocks of flats, an interest subsidy is given if the cost exceeds Skr. 25,000 or if the total cost is over Skr. 25,000 for the energy conservation loan in combination with the Government housing loan.

Interest subsidy is not given for energy conservation loans applicable to detached houses, but it is given for Government loans for new construction or rebuilding (see Government housing loans).

In certain cases it is possible to get an advance on a loan.

Government housing loans

Government housing loans are given for new construction and rebuilding. If you are planning to extend the building and also to improve its heating economy, you can combine the energy conservation loan with the housing loan for rebuilding.

A mortgage is required as collateral for a Government housing loan. In certain cases a guarantee from the local authority is acceptable. The approved rebuilding cost must be at least Skr. 10,000 in the case of detached houses and Skr. 25,000 for blocks of flats.

The housing loan plus first mortgage, or in certain cases only the housing loan, can cover up to 100% of the approved cost of rebuilding.* If the first mortgage is insufficient the Government loan can be increased/extended. The approved cost is determined by the County Housing Board.

The maximum repayment period for the housing loan is 30 years (a maximum of 20 years for detached houses in certain cases). The loan is a fixed instalment one (see explanation under Energy conservation loans). The rate of interest is determined each year (11% in 1980). If the approved rebuilding cost is more than Skr. 25,000, an interest subsidy is given which covers part of the interest costs (applies also to the part below Skr. 25,000). The housing loan is paid when the work is finished. It is however possible to get an advance on the loan in certain cases.

*In certain cases, the housing loan plus first mortgage can cover more than the rebuilding cost in blocks of flats. More information is given in »Loans and grants for rebuilding of homes» available from the local authority or the County Housing Board.

Home improvement loans

Government improvement loans are granted after a means test to people who have reached the age of 60 years, those on early retirement pensions, handicapped people etc. The loan can be used to improve the dwelling and for energy conservation measures. Only those with low incomes are eligible for home improvement loans. The net assets of the person concerned must not exceed Skr. 100,000.

Interest and capital repayments are low or non-existent. A person granted a home improvement loan is not eligible for an energy conservation grant. Instead the proportion of the loan which is not subject to interest or capital repayment amounts to a maximum of Skr. 6,000. More information regarding home improvement loans can be obtained in the National Housing Board publication »Improvement loans for detached houses», available from the local authority or the County Housing Board.

It is also possible to get assistance for energy conservation measures in

Public assembly halls (application is to be made to the Assembly Hall Delegation of the National Housing Board).

Local and County Council Buildings (application is to be made to the National Housing Board).

NB. Different regulations apply to these premises and buildings.

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