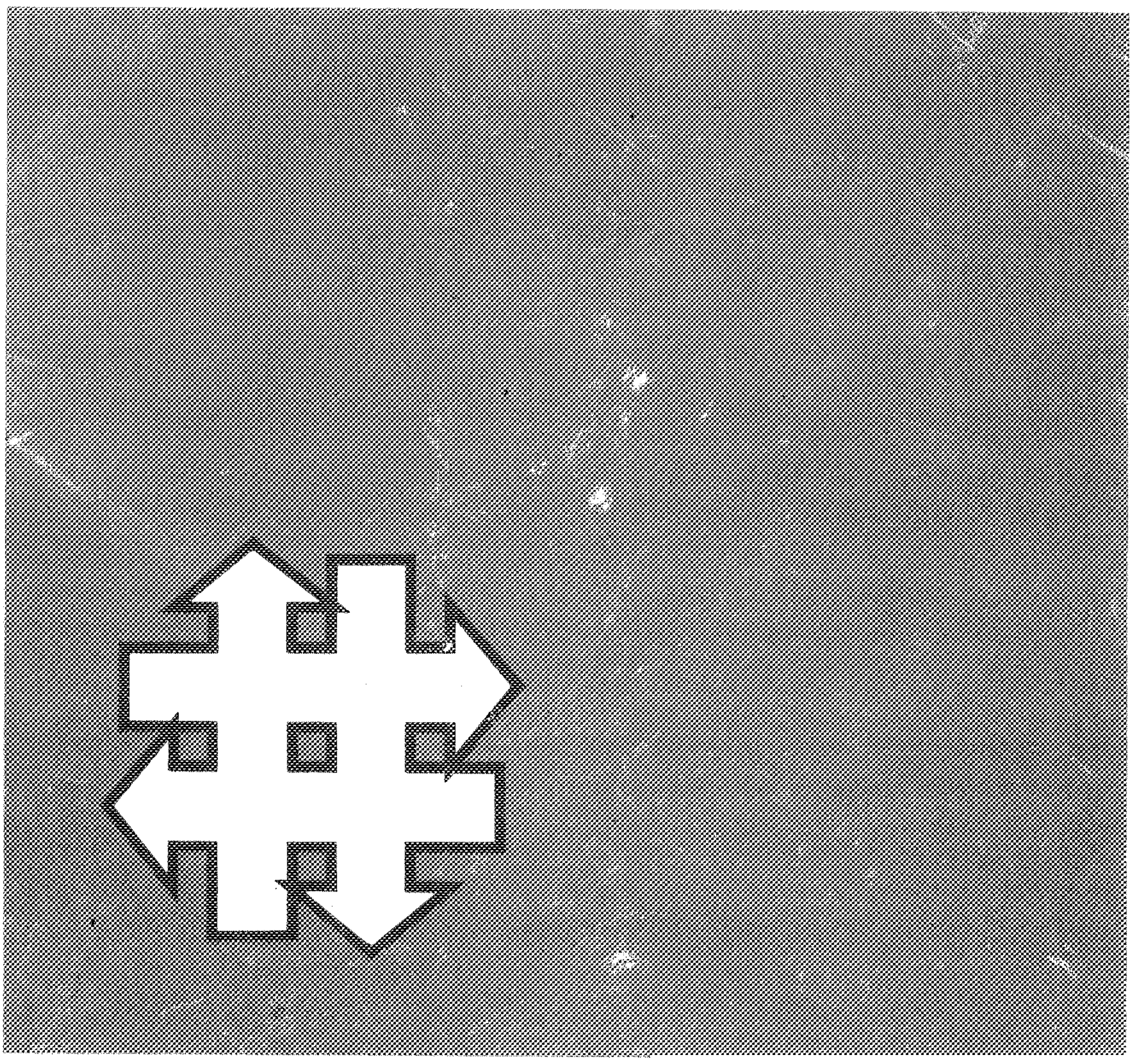
Airtightness and thermal insulation

building design solutions

Björn Carlsson Arne Elmroth Per-Åke Engvall



Byggforskningsrådet

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Editing and layout: Elisabeth Sedig,
Informationsprojekt AB

D37:1980

ISBN 91-540-3345-4
Swedish Council for Building Research, Stockholm, Sweden

Printing: Spångbergs Tryckerier AB, Stockholm 1980

Preface

Questions regarding the airtightness of buildings have been analysed by a special working group within the Swedish Council for Building Research. Several parallel research and development projects on airtightness have been carried out. The work described in this book covers building design solutions. Completely new designs for a building's outside shell have been necessary to fulfill the thermal insulation and airtightness requirements stipulated in Swedish Building Code 1975 (Svensk Byggnorm 1975).

The purpose of this work has been to take stock of designs used to date to fulfill the requirements for airtightness and those which are considered able to fulfill the airtightness requirements. A number of companies have made drawings available. The designs have been studied and carefully processed after study visits to different work sites and account has been taken of working methods and the potential for satisfactory and safe results in practice. Furthermore a number of airtightness tests have formed the basis for assessing how airtightness is achieved. The aim is to review the best design solutions possible but this does not rule out potential improvement and simplification as a result of greater experience of how these new designs function.

The project has been led by Arne Elmroth with Björn Carlsson and Per-Åke Engvall as investigators. A first class reference group has followed the work. This group was made up of the following people:

Lars Aldrin, Lättbetong AB, Bengt Axén, Svenska Riksbyggen, Bengt O. Englund, Svenska Träforskningsinstitutet, Christer Harrysson, AB Modulent-Konstruktioner, Alf Jergling, Chalmers University of Technology, Dage Kåberger, Gränges Aluminium, Arne Lindh, Tyréns Företagsgrupp AB, Sören Wiklund, Skånska Cementgjuteriet.

The reference group has helped with material, points of view and encouragement to a considerable degree. We should also like to thank a number of companies and individuals who have contributed material, time and knowledge in ways that have been most useful.

The work was financed with a grant from the Swedish Council for Building Research made to the Division of Building Technology, the Royal Institute of Technology, Stockholm.

Stockholm, March 1980

Arne Elmroth

Contents

Explanation of symbols

Particular symbols used in this report

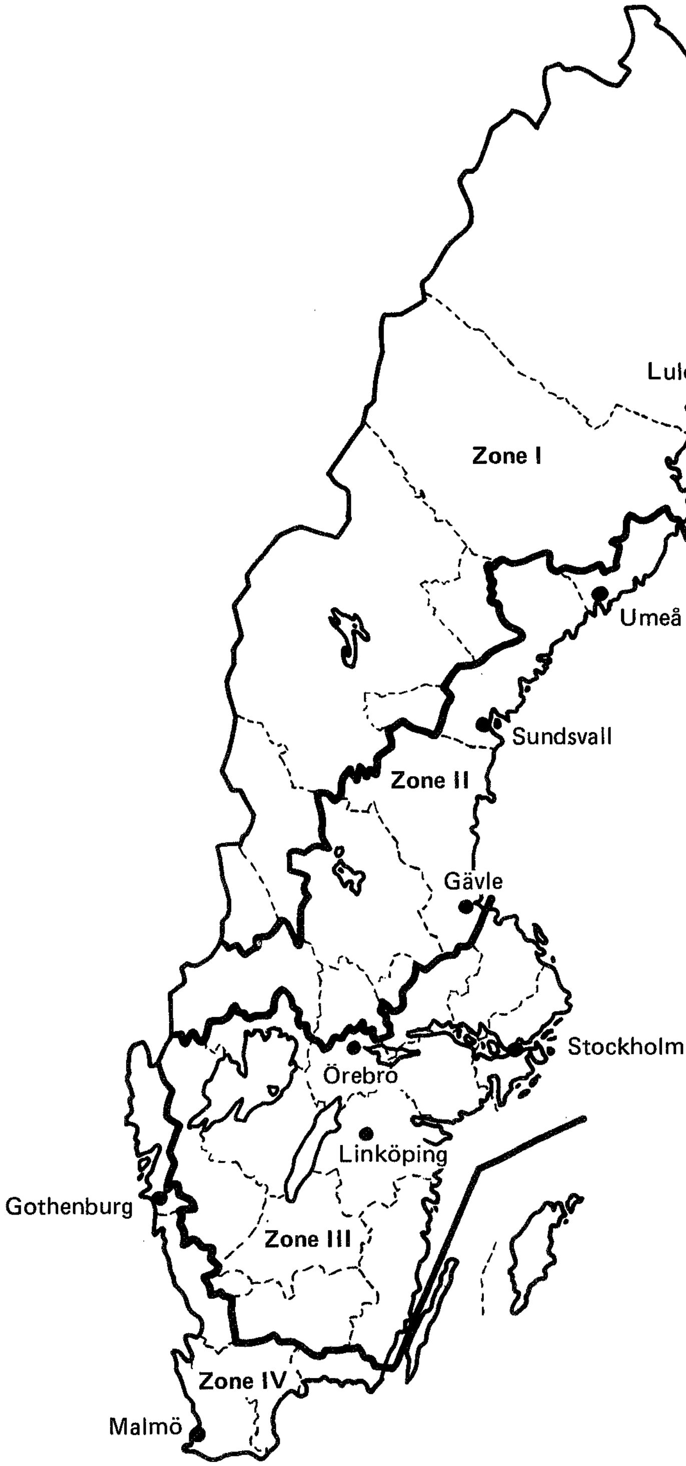
 Vapour barrier, usually plastic foil (plastic film), which also functions as an air seal.

 Jointed plastic foil, approx 200 mm overlapp, the joint being taped and/or clamped with battens or sheet material.

 Wind barrier which is a diffusive sheet or paper material with low air permeability.

 One of the following joint sealing systems: jointing foam of polyurethane, mineral wool strip covered with thin polyethylene foil inside and an uncoated mineral wool strip outside, special sealing strips of EPDM rubber.

 Arbitrary facade cladding.



Temperature zones.

Introduction and back-ground

Earlier code requirements for an outside shell's thermal insulation and airtightness have been dictated by hygiene or comfort. Thermal insulation requirements were enforced but there were no demands on a building's airtightness. In Swedish Building Code 1975 (SBN 1975) thermal insulation requirements for different building sections have been made considerably more stringent (table 1). Completely new requirements for a building's airtightness have been introduced and are stated in SBN 1975 as upper limit values for an outside shell's different sections. In addition there are recommendations for maximum perviousness measured at a pressure difference of 50 Pa for whole buildings.

With regard to airtightness of completed buildings, comments on the SBN 1975 recommendations on maximum air change rate in different types of buildings are given in table 2.

The requirements for thermal insulation mean, for example, that the insulation thickness fòr mineral wool insulated wooden walls must be approximately 190 mm and 150 mm respectively in zones I + II and III + IV. On attic joist structures approximately 260 mm mineral wool in zones I + II and approximately 220 mm in zones III + IV, is normally required. These are significant thicknesses which mean more complicated wall and joist floor constructions than was earlier the case. There is sufficient economic motivation to insulate to a greater extent than that stated in SBN 1975 bearing in mind the rapidly increasing price of energy.

Table 1. Maximum permitted heat transfer coefficients (k value) in W/m^2 °C for parts of buildings adjacent to rooms to be heated to more than +18°C. Temperature zone I+II includes northen Sweden, entailing somewhat more stringent requirements than those for zone III+IV covering southern Sweden.

Section of building	**Max. permissible k value allowed**	
	Zone I + II	**Zone III + IV**
Exposed outside wall	0.25	0.30
Roof and attic joist structure exposed to outside	0.17	0.20
Joist floor exposed to outside	0.17	0.20
Joist floor above crawl spaces and ground level floor constructions respectively	0.30	0.30

Table 2. Recommendations for the highest air change rate in different types of residential buildings.

Type of building	**Max. air change rate, changes/h**
Single-family houses	3.0
Other houses with 2 floors max.	2.0[a]
Residential buildings with 3 or more floors	1.0

[a] In the case of apartment-separating walls which are somewhat pervious, such as certain types of framework walls, and where correction for leakage through these is not made, there is a provisional allowance which deems it sufficient if the air leakage amounts to a maximum of 3.0 changes/h (Statens planverk aktuellt, number 4 1978, from the National Board of Physical Planning and Building).

The motives for airtightness in buildings

Energy savings

Energy consumption in houses built in the early 70's

The airtightness of the outside shell is of considerable importance to indoor climate and energy consumption. A building's airtightness primarily affects ventilation and thus heat losses. As a background for the following account, figure 1 shows an energy balance for a normal single family dwelling, with a living area of approximately 130 m^2, built before the energy crisis in the beginning of the 70's. The energy balance is shown in the form of a histogram for input and outgoing energy in the house. The balance is based on average values for houses in the Stockholm area as stated by Munther (1974) and Adamson/Källblad (1975). The sub-divisions are based on conditions in a normal household. The ventilation losses are based on the assumption that the house has a perviousness

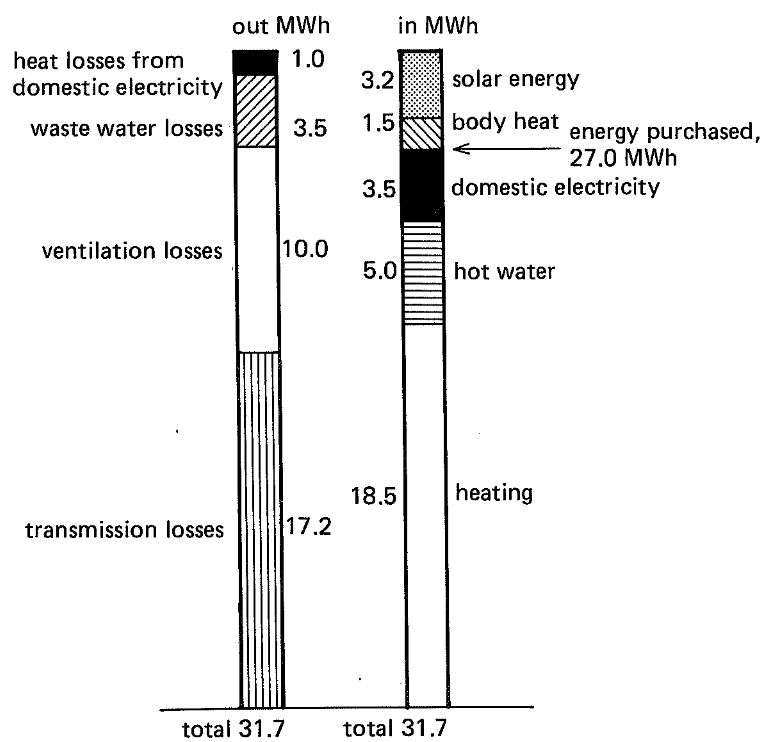


Figure 1. Energy balance for a dormer (1 1/2 storey) house of approx. 130 m^2, built in the early 70's, i.e. before the energy crisis. The required amount of purchased energy is on average 27 MWh in the Stockholm area.

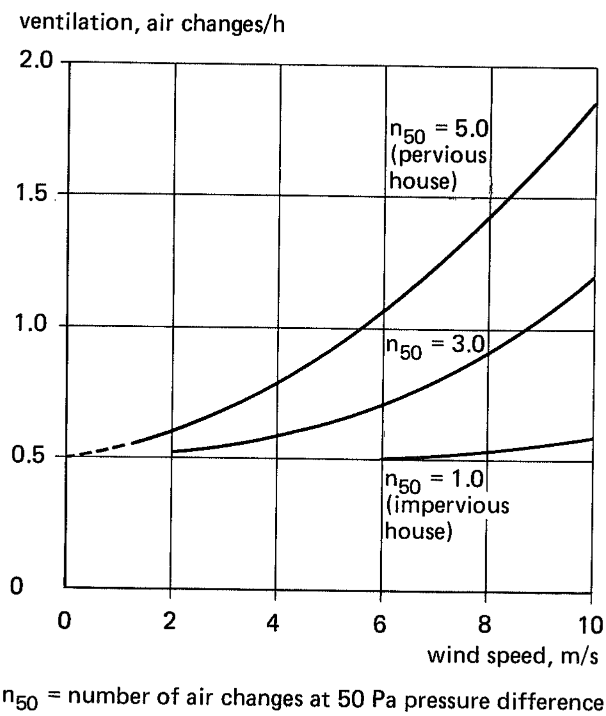


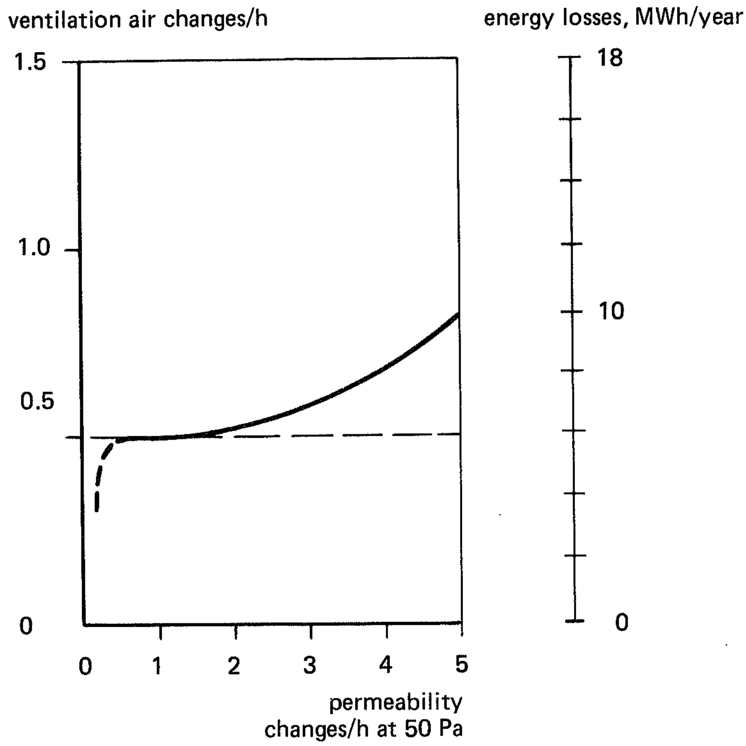
Figure 2. Theoretical calculation of air change rate for exhaust air ventilated, for single-family house with exhaust ventilation as a function of wind speed and the house's air change rate determined using the pressure test method. In impervious houses, n_{50} = 1.0, the ventilation is little affected by wind speed whereas the ventilation in pervious houses, n_{50} = 5.0, increases rapidly with wind speed.

normal for site-built houses of that period. This means an average air change rate of 0.7—0.8. From the »out» bar in figure 1 it can be seen that the ventilation losses, i.e. the sum of intentional and unintentional ventilation, is an important item in the energy balance. It should be possible therefore to reduce this through improved airtightness.

The relationship between airtightness, ventilation system and outdoor climate has been studied theoretically by Nylund (1979). Figure 2 gives an account of results calculated according to a proposed model of expected ventilation in a single-family house. It is assumed that the house is ventilated with an exhaust fan which is adjusted so that the ventilation rate is 0.5 changes/h in still air conditions. The example illustrates how ventilation is affected by wind speed. Three different levels for imperviousness of the houses are shown in the figure. The curves, designated n_{50}, illustrated in the figure, show the number of air changes when pressure testing at a pressure difference of 50 Pa. For impervious houses, e.g. n_{50} = 1.0 changes/h, the exhaust fan has a dominating effect on ventilation/air leakage. Air leakage does not increase until very high wind speeds are in force. In pervious houses, e.g. n_{50} = 5.0 changes/h, the air leakage increases rapidly with wind speed.

Using the same model, figure 3 shows the calculations of mean annual ventilation in single-family houses with different grades of perviousness. It has been assumed that the average wind speed is 4 m/s, the outdoor temperature is + 2°C during the heating season and that the house has an exhaust air system adjusted to 0.5 changes/h in still wind conditions and

Figure 3. Theoretical calculation of mean annual ventilation in a single-family dwelling as a function of the house's perviousness and from tests using the pressure test method. The scale on the right indicates energy losses in Stockholm's climate caused by ventilation. Considerable ventilation losses result in pervious houses. Based on a dormer house with approx. 130 m² living area.



identical indoor and outdoor temperatures. The same figure can be used to calculate energy losses through ventilation using the scale to the right. The result shows that in very impervious houses with exhaust air ventilation, the ventilation is entirely dependent on how the ventilation system is adjusted.

Energy consumption in well-insulated (SBN 1975) and airtight houses

Studies of energy consumption etc. have been carried out in a small group of houses outside Stockholm (known as the Åkersberga Project — discussed in more detail in a later chapter). The houses in this area have an insulation level which complies with the requirements in SBN 1975 and an airtightness which is below 1.0 changes/h at 50 Pa. This is very good airtightness. The calculations verified by short-term measurements indicate that with an indoor temperature of +20°C, annual energy consumption for transmission heat losses in the Stockholm area is approximately 13 MWh. With a ventilation rate of 0.5 changes/h the ventilation losses become approximately 6.4 MWh if this ventilation level is constant during the heating season.

Using half the fan capacity, the ventilation losses are 3.2 MWh. In order to save energy, ventilation will probably be reduced as much as possible. We can assume therefore that the ventilation will be set to a rate of 0.5 changes/h during half the day and 0.25 changes/h during the other half. This means that the ventilation losses will be 4.8 MWh. Since the houses are so impervious it will be possible to select the ventilation rate by adjusting the exhaust fan. The effect of the outdoor climate can be disregarded – as has been verified by measurements.

Ventilation losses also include a small item, »forced» ventilation – cooking, drying cupboard – approximately 0.3 MWh.

On the basis of Munther's calculations (1974) the waste water losses are assumed to be 3.5 MWh and other domestic electrical losses 1 MWh.

The energy balance is shown in figure 4. In order to arrive at a balance between energy supplied and consumed, we must add 9.4 MWh for heating. In this case the energy purchased is 17.9 MWh.

By comparing figures 1 and 4, i.e. the energy balance for an average house, built before the advent of the new code, with the energy balance for a house built according to the requirements in the new code related to improved thermal insulation and having an airtightness considerably better than that recommended in the code, it is seen that the reduction in additional energy required is in the region of 9 MWh. It should be possible therefore to make considerable savings where reduction of ventilation losses through improved imperviousness is a significant factor.

The example shows that, using mechanical exhaust ventilation, the ventilation in pervious houses can be set to the required level irrespective of the outdoor climate. The air supply in this case must be controllable so that air is supplied to all the rooms in a building. Air diffusers will be necessary since

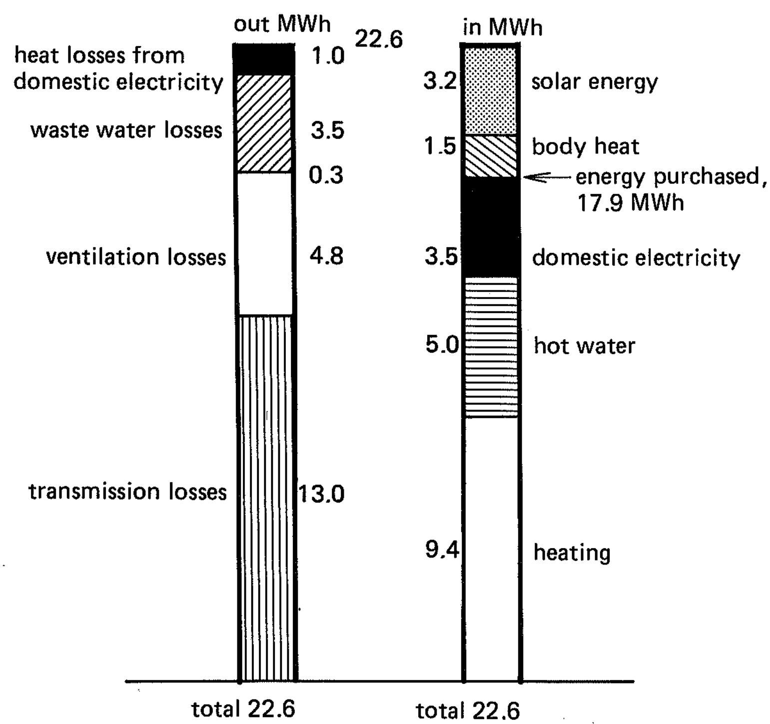


Figure 4. Energy balance for impervious and well insulated houses in Åkersberga. The average purchased energy requirement is approx. 18 MWh per year. This means approx. 9 MWh per year less than in corresponding houses built before the energy crisis (figure 1).

possible leaks in the building structure mean an evenly distributed air supply cannot be guaranteed. Building airtight houses does not imply inferior ventilation. On the contrary, it is evident that airtight houses are essential for controlled air flow to ensure the required air quality throughout the dwelling. Investigations have indicated that even in pervious houses there is a risk that certain areas will not be ventilated since leaks will not always occur where a supply of air is required.

In houses with natural ventilation it is often assumed that the building is pervious. Air infiltration through the building structure is determined in this case by pressure differences caused by wind and temperature changes. The ventilation is primarily determined by the outdoor climate and not by the fresh air requirement. The highest ventilation rate occurs during windy weather in winter. Thus a natural ventilation system creates uncontrolled and random ventilation. This means that if the minimum requirements for air quality are to be maintained for all outdoor climate conditions the ventilation during a greater part of the year is excessive.

Unintentional and uncontrolled excess ventilation increases the energy requirement for heating.

- ☐ Excess ventilation air must be heated to room temperature.
- ☐ Leaks can give rise to draughts which must be compensated for by an increase in room temperature which in turn causes increased energy losses.
- ☐ Air leakage can cool inner faces of parts of the outer structure. The room temperature must therefore be increased to compensate for radiation losses.
- ☐ Leaks can also give rise to blow through in mineral-insulated constructions for example, significantly reducing the insulating effect.

Hygiene consequences

Apart from the effects on energy requirements, uncontrolled air leakage also causes discomfort. A number of our own investigations agree with Axén and Pettersson's findings (1979) that significant deficiencies in insulation and airtightness techniques are evident even in new-built houses, resulting in loud and widespread complaints of uncomfortable draughts. The deficiencies often have a systematic character and reappear with considerable regularity in certain types of constructions, materials and working methods. Figure 5 shows a sketch of where sensitive components often occur from a thermal insulation and airtightness aspect. The causes of air leakage can be summarized as follows:

- ☐ Deficiencies in the building construction methods, incomplete drawings or drawing documentation not thought out.
- ☐ Unsuitable positioning and layout of installation.
- ☐ Unsuitable choice of material.
- ☐ Unsuitable working methods and procedures.

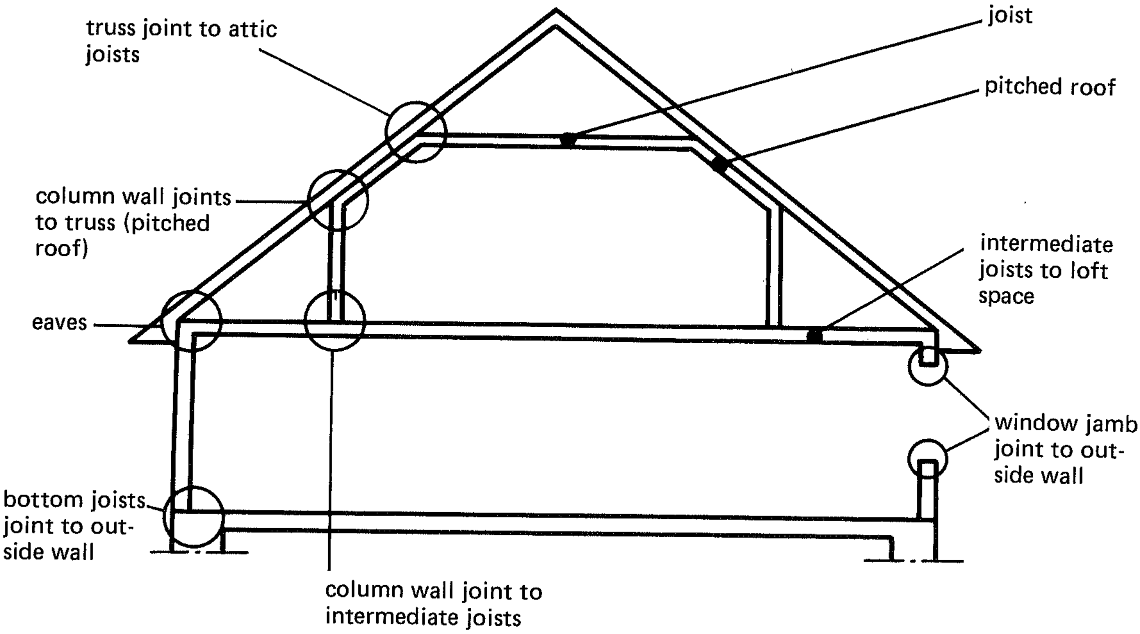
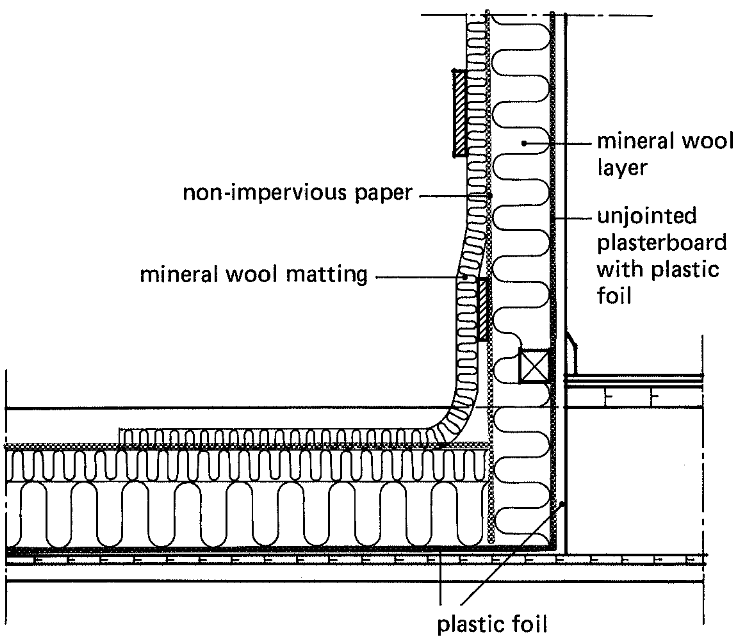


Figure 5. The figure shows the structural sections which often give rise to complaints about draughts. The ways in which airtightness is achieved at joints between different building elements are seldom shown in building documentation.

A particularly difficult item of construction in a dormer single-family dwelling is where the column wall is joined to the intermediate joists. Figure 6 shows drawing documentation of this common type of joint. The figure also shows a reconstruction of the normal method of connection in a group of buildings. Figure 7 shows a thermogram from floor level inside the column wall in the construction shown in figure 6. These figures show that there is both a considerable amount of air leakage, at the joint in the upper floor, which in itself is uncomfortable, and that the temperature at the joint and at the floor is very low during winter. The main reason for the deficiencies is that the planning documentation does not give simple and clear indications of how airtightness is to be achieved at the intermediate joists. The result is a significant leakage of air and considerable discomfort for the occupants.

Figure 6.
a. An example of quite common drawing documentation showing how the joint between support wall and intermediate joists is to be carried out in a dormer house. Bearing in mind the fact that the load bearing beams pass through both the air sealing and thermal insulating layers, there is little chance of producing a good result, in practice.
b. This is the way the construction was carried out in practice. The internal plasterboard has naturally been joined between the beams and airtightness has not been achieved. The external wind shield made of particle board has been joined above the beams and again airtightness has not been achieved. The mineral wool has not completely filled the lower section of the column wall.



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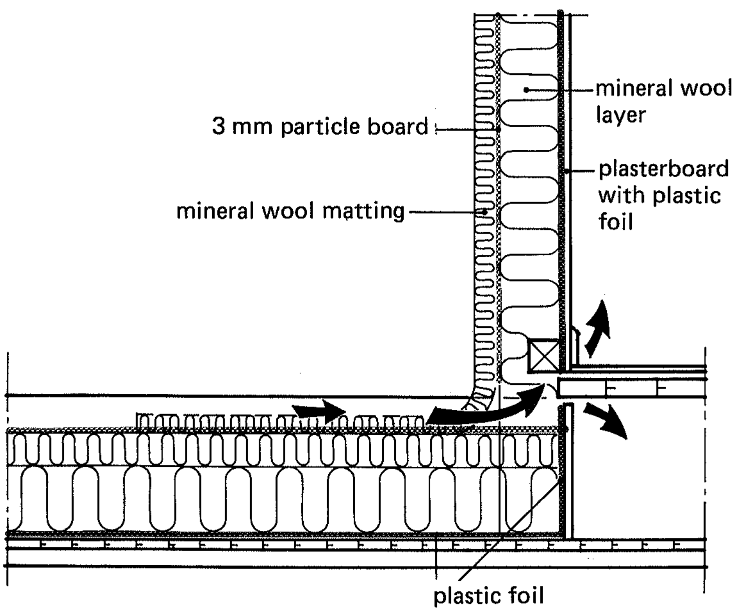


b

possible air leakage routes

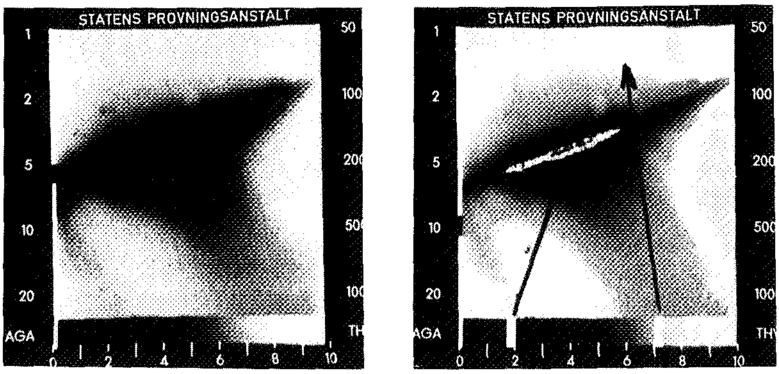


Figure 7. Thermogram from the floor level inside the column wall in the construction in figure 6. The figure to the left is a grey tone photograph and the one to the right an isotherm photograph. When the thermophotography was carried out the outdoor temperature was -0.5°C and the room temperature +22.5°C. The thermogram shows that the temperature difference between the coldest and warmest areas at the joint is 7.4°C, and is an entirely unacceptable temperature drop. Measurements show that the air speed at the actual floor angle amounted to 6–7 m/s when the internal pressure difference was 5 Pa. Deficiencies in airtightness and in filling with thermal insulation have therefore caused discomfort. Discomfort is increased by »unrestricted blow through» in the intermediate joists.

Consequences for building design

Another inconvenience caused by leaks in the inner layer is the fact that they can cause moisture damage. There have been frequent examples of such damage when covering the ceiling with wood on the upper floor of dormer houses. The reason for this is that moisture is transported by warm air convection out into the loft area (figure 8). In dormer houses an excess difference pressure in the upper floor is often caused by natural ventilation. If the airtightness is defective at the joints in the upper floor, particularly at the truss joints, moisture can pass through to the cold roof and condense. Mould and, in particularly bad cases, rot has occurred. Figure 9 shows damage caused by moisture on an external panel. Even relatively good ventilation of the loft and the pitched roof have not been able to prevent condensation damage. This is another reason why it is important to build airtight houses. All parts should be designed with good airtightness in mind.

Air penetration in insulation layers can drastically reduce a wall's insulation performance. Figure 10 illustrates the effect of air penetration in a 1 mm gap for different pressure drops according to Bankvall (1977). A comparatively insignificant amount of air penetration can almost nullify the effect of an increase in insulation thickness.

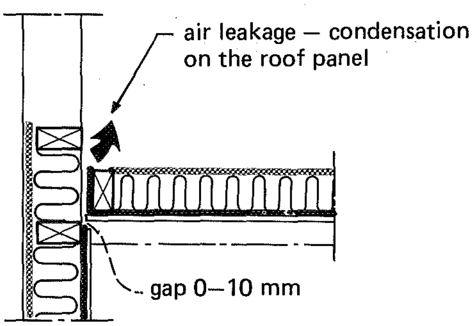
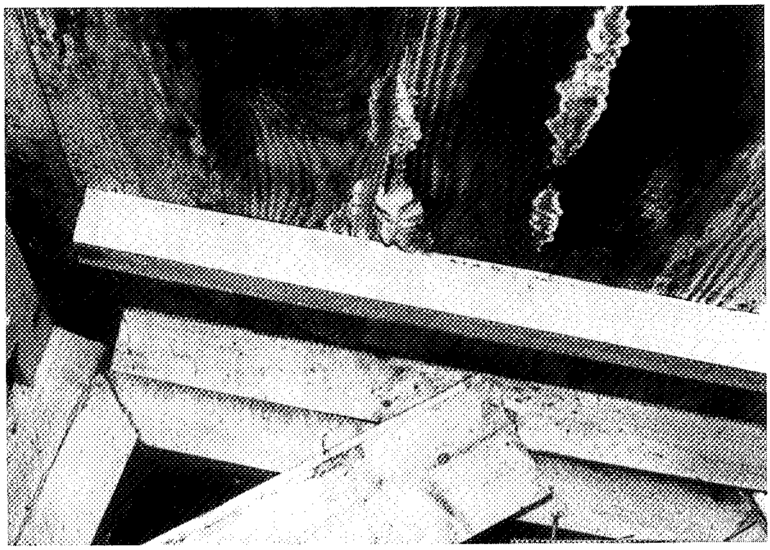


Figure 8. A common method of jointing between an outside wall and a truss in a dormer house. As a result of tolerances applied during building work, smaller gaps in the actual joint are not uncommon. Under certain conditions and internal pressure difference sometimes occurs at the roof in upper floors of dormer houses. When there are gaps, air can leak through and cause moisture damage. It has been shown that gaps with a width of 1 mm are quite sufficient to cause damage.

Figure 9. Blueing and initial rot damage on the roof panel. It can be seen that the main cause is the air leakage which can occur as shown in figure 8. Experience has shown that it is not possible to avoid damage by improving ventilation. Only by making joints airtight is it possible to eliminate moisture accumulation and the consequent risk of mould and rot damage.



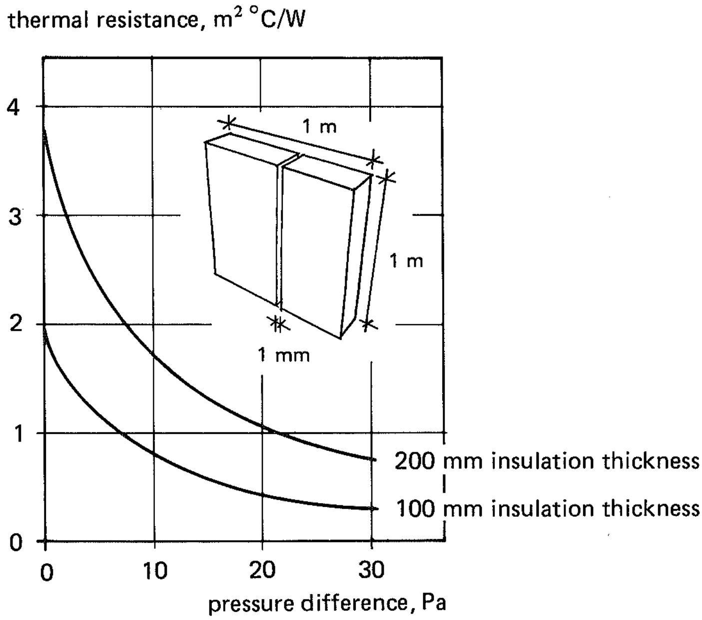


Figure 10. A pressure difference across a wall can cause air penetration in the construction, thus affecting its thermal insulation characteristics. The figure illustrates how the thermal resistance deteriorates with an increased pressure drop in the case of a mineral wool insulated wall with a complete gap in the insulation.

Planning for airtightness

The principles for achieving airtightness

The problems of airtightness must be carefully considered in order to build airtight houses. A thorough system for how airtightness is to be achieved facilitates practical work. Great importance must be attached to the design of the different construction parts illustrated in figure 5, and, just as important, how the penetrations for services — electricity, water, heat and ventilation — are designed.

A few examples show the requirements for achieving satisfactory airtightness. Figure 11 shows results of laboratory tests of air leakage measured as a function of air pressure at different joint designs between sheets mounted on beams. The sheets themselves are airtight for all practical purposes. The results show that with a pressure difference of 50 Pa the air leakage rate is often of the order of 1—4 m^3/m^2 h if the joint length is 1 m/m^2. This is a considerable amount of air leakage and cannot be accepted in airtight houses. In order to achieve good airtightness, sheet joints must be carefully sealed. This can be done internally using strips and filler or tape. Certain types of tape or paper strips have been used externally. Experience shows such seals have a limited value.

Similarly, figure 12 shows results of air leakage measured at an electrical junction box fitted in plasterboard. In this case the air leakage amounted to 2—4 m^3/h for each connection box. It should be noted that the electrical connection was very carefully mounted and such accuracy can hardly be expected in practice. This result evidently shows that penetrations in sealing layers in installations etc. can have a detrimental effect on airtightness in a building. Field investigations also indicate that electrical connections mounted without special surrounding sealing also cause an increase in air change in the order of 0.5 changes/h measured at a pressure difference of 50 Pa. If the fitting of electrical installations is unavoidable in external walls and routes through sealing layers, careful sealing is essential. Air movement caused by pervious services routes can, at worst, also lead to a reduction in thermal insulation properties and can also cause draughts as was shown previously.

Depending on material and design there are a number of available alternatives to ensure airtightness. Table 3 indicates suggested principles. The air sealing principle selected should be carried out as consistently as possible over the whole of the external structure of the building. This means that not only walls and ceilings follow the principle but this must be

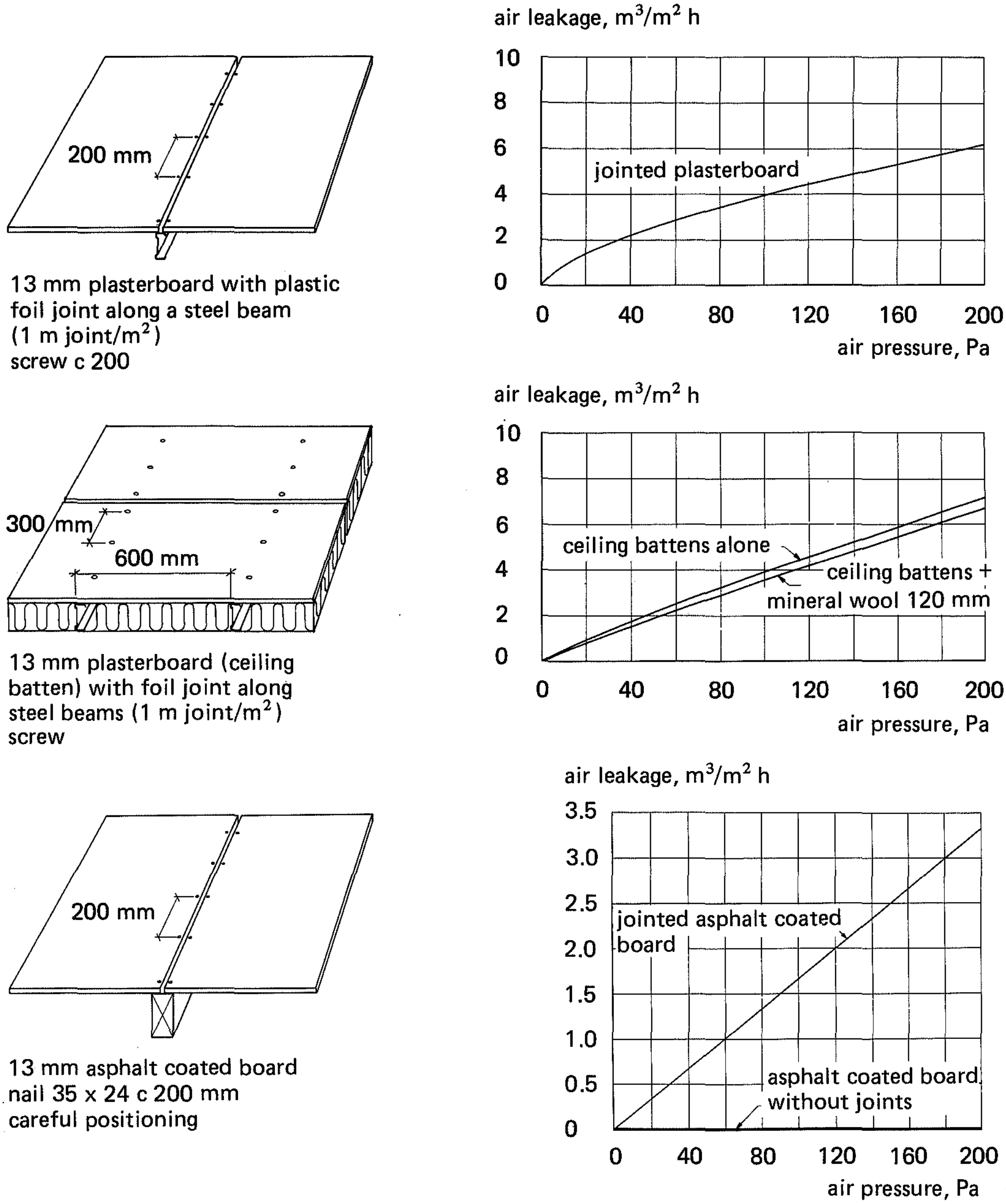


Figure 11. The top diagram shows air leakage measured through a plasterboard joint. Despite careful fitting, a considerable amount of air leakage was measured through the joint. Airtightness can only be achieved by laying foil completely across the joint or by using sealing strips (or tape) and filler.
The middle diagram shows air leakage measured through a joint between two plasterboard ceiling panels. Such boards are normally mounted on thin panels and the result can be considered representative of normal practice. Mineral wool insulation has, as expected, no particular effect on airtightness. There is considerable air leakage through the joint.
The bottom diagram shows air leakage measured through a joint between asphaboard sheets carefully nailed to a wooden beam. Despite the sheet being almost impervious, a leakage of almost 1 m^3/m^2 h (with 1 m joint/m^2) was measured with a pressure difference of 50 Pa. Bearing in mind normal movements in sheets material and nails, airtightness cannot be achieved without the further sealing of joints.

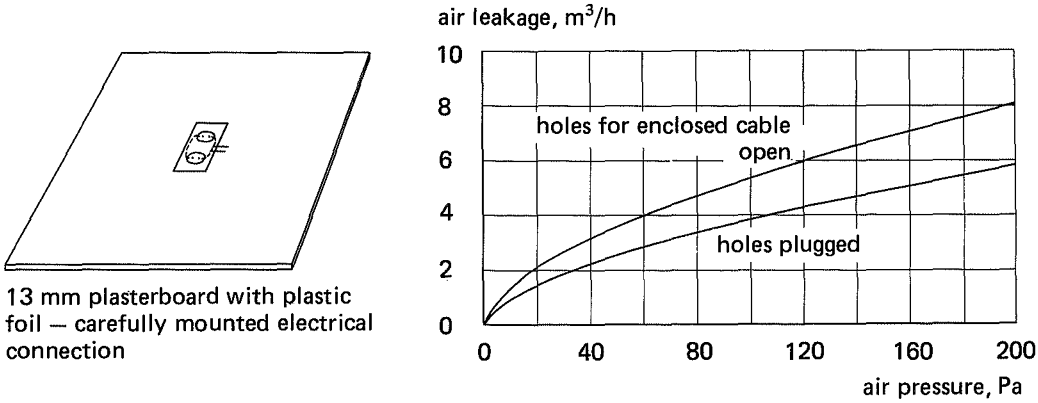


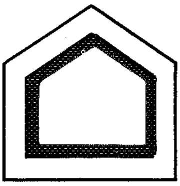
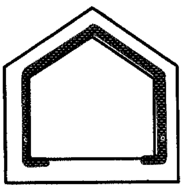
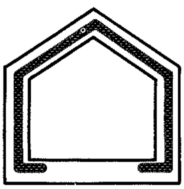
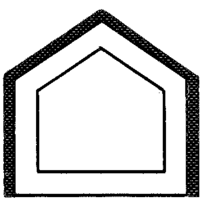
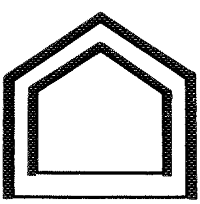
Figure 12. Air leakage measured when an electrical connection was very carefully mounted in a plasterboard. The result shows that air leakage is considerable and for this reason penetration of a sealing layer must be avoided as far as possible. Electrical installations should be positioned so that the sealing layer is not punctured.

carried out consistently even at joints, connections etc. *One should also try to lay the air sealing layer in the same plane everywhere.*

Table 3 indicates the advantages and disadvantages of the different principles. Further comments are necessary. The table talks about *airtightness and windtightness. By airtightness we mean the property of preventing air from penetrating through the shell. By windtightness we mean that air is prevented from penetrating the shell so that the thermal insulation property of the immediately adjacent insulation material is not reduced.* Using these definitions there is therefore a clearly defined difference between requirements for windtightness and airtightness. The requirement for windtightness can therefore be fulfilled without the requirements for airtightness being achieved. This means that a material which can function as a wind protection, for example rigid mineral wool slabs in a certain way, cannot be used to fulfill airtightness requirements. As has already been shown, airtightness requires very careful sealing of joints between slabs. Such sealing is not normally necessary in order to attain full wind protection in a construction. Special measures are therefore required if the wind protection is to be changed and improved so that it can also constitute an air sealing layer.

Using homogenous constructions of porous concrete, for example, problems often arise in achieving airtightness where there is a change in material; for example if a wooden roof is mounted onto a porous concrete house. Work is in progress however to find suitable methods to provide good airtightness at such transitions.

The new requirements for airtightness demand therefore new, more stringent planning requirements. It is very important that the complete sealing function is carefully stated in design documentation. It is also important, during planning work, to indicate an acceptable work sequence on site. Supervisory staff and the workforce should be adequately informed about the problems of airtightness and the significance of carrying out sealing work in the correct manner. To produce a well-insulated and airtight house, careful choice of correct materials and proper material handling are necessary.

Construction principle	Advantages	Disadvantages
Internal airtight cladding, e.g. plasterboard 	Uses common sheet material properties Can be checked relatively easily and rectified where necessary	The sheet lies unprotected Risk of puncturing The joints must be sealed carefully even against floors and roofs e.g. sensitive to movement and subsequent crack formation
Internal sealing layers, foil 	Vapour barrier can naturally be used for air sealing as well Large size foil sheets can be used, with few joints as a result	Certain difficult constructional problems Accuracy required at joints Services installation penetrations cause problems
»Drawn under» sealing layer, e.g. paper, plastic foil 	The sealing layer is protected against damage Electrical installations possible without the sealing strip being damaged Good prospects of achieving a high level of airtightness	Moisture damage risks not known The effects of »supplementary insulation» from carpentry and furnishing, e.g. on moisture conditions in the sealing strip, in particular at outside corners, are unknown Requires a double wooden frame
External air sealing – »wind protection» 	Easy to apply The wind protection's air sealing properties can be used	Significant risk that airtightness is so good that moisture can condense inside the construction The layer is affected by outdoor climate which can lead to higher demands on material properties Risk of damage during the building period Stringent requirements for weather resistence of the material Stringent airtightness requirements in internal vapour barriers
Combination of internal and external air sealing 	Double safety	Use of double sealing layers uneconomic An airtight wind protection can cause moisture damage

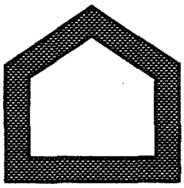
Construction principle	Advantages	Disadvantages
Homogenous constructions, e.g. cellular concrete 	Simple design Electrical cables can be positioned in the material without jeopardizing airtightness	Limited choice of material Connection details to other building must be solved separately All building sections should be able to be carried out applying the same system which limits the method and choice of material

Table 3. The main principles for the design and positioning of air sealing layers in constructions.

Vapour barrier – air sealing

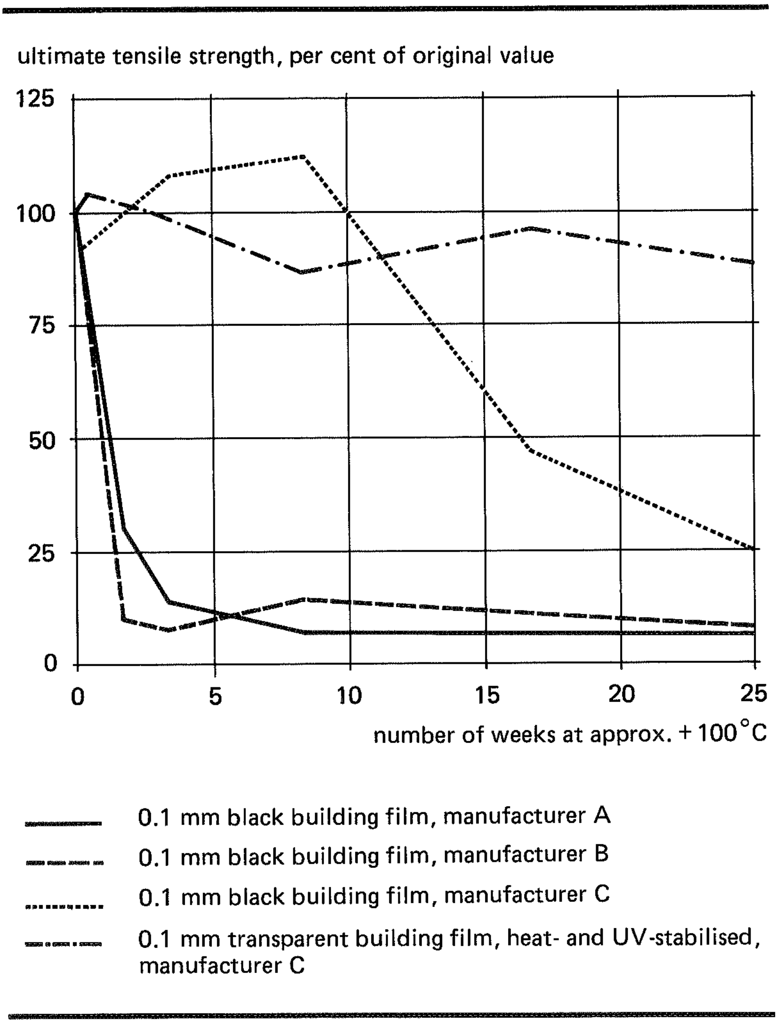
Plastic film can be both a vapour barrier and an air seal. It should be approximately 0.2 mm thick and transparent in order to facilitate both inspection of the thermal insulation work and subsequent board erection. The foil shall also be resistant to UV light and heat so that ageing characteristics can be guaranteed to a certain degree. Quality requirements for plastic film are given in Verksnorm 2000 (see page 24). This is the basis for the requirements for type-approved films for fitting in dwellings. The age-resistance of building film is determined by measuring the change in ultimate tensile strength after ageing the film at an elevated temperature according to the method given in Verksnorm 2000. An example of a test result is shown in figure 13. It can be seen that degradation is accelerated at higher temperatures and for this reason, the risk of degradation in buildings can be expected to be greatest behind radiators. Verksnorm 2000 recommends therefore that heat reflecting foil be used behind radiators in order to reduce the temperature where plastic film is fitted.

It should also be noted that mounting plastic film with copper clamps or non-rust protected steel clamps should not be practised since both copper and steel accelerate degradation of the film. Rust-protected steel clamps should be used.

Different width of plastic films should be used. For mounting in room high elements or walls, a width of 2.8 m is considered suitable. For mounting in pitched roofs, a width of 1.4 m fits better bearing in mind normal rafter spacing distance of approx. 1200 mm. Furthermore, strips of varying widths are needed for special tasks, e.g. at joints. The size should be selected to minimize the number of joints, since each joint constitutes a weak point and a risk of reduced airtightness.

When making joints with plastic film, an overlap of at least 200 mm should be used. Furthermore the joint should be taped and/or clamped using battens, sheets, etc. Welding trials on plastic foil have been successfully applied on a few sites. Using tape materials currently available, it is inadvisable to tape plastic films during humid or cold conditions. If taping has to be carried out, the buildings must be covered and heated. Compare with the requirements for heating when

Figure 13. An example of a test result on the age resistance of a plastic film. 23 week test at approx. +100°C is assumed to correspond to 40 years at +35°C. The result shows that the plastic film must be heat and UV stabilized. A black building film gives no guarantee of good age resisting properties.



using polyurethane foam or when laying concrete etc. during the winter.

As yet, insufficient documented experience on joint taping is available. The service life of a joint cannot be determined with any confidence. It would appear therefore that, wherever possible, an overlap and clamped joints should be used in order to achieve airtightness. Taping should only be used as an aid to mounting. Experience has shown that taped joints do not provide permanent airtightness even if the work was well done from the beginning. Bearing in mind the difficulties in making joints tight, plastic film work should be planned very carefully and all joints should be indicated on drawings.

Wind protection

The main purpose of a wind protection is to prevent air movements which can impair insulation efficiency in walls and floor structures. Paper or sheet materials are used as a wind protection in wooden constructions. Both paper alone and paper stuck to different types of mineral wool, such as rigid mineral wool slabs and mineral wool matting are used.

Wind protection in the form of paper should be applied so that the joints overlap. The paper should be securely fixed so that it is not disturbed by air movement. Paper covering sloping or vertical surfaces should be securely clamped to the surface with all the joints clamped to solid materials. During asessment it was found that paper exposed to the outside for a long period is easily damaged. It was also discovered that the joints had often not been clamped tight. In such cases the risk of deterioration of the function of the wind protection is very great.

Paper glued to slabs of mineral wool intended for use on walls, is positioned so that the mineral wool protects the paper. In these cases the paper is stapled to wooden frames. With this method the paper is subject to less risk of damage than where loose paper is used. In this way the function of the wind protection is improved.

In the case of attic joist systems, mineral wool matting with glued-on paper is used. If such matting is laid carefully side-by-side and if the insulation fills the space to be insulated in all other respects, this method provides a satisfactory wind protection. The joints must be formed correctly for the wind protection to function satisfactorily at the junction of walls and joist systems. Continuity between the wall's and the joist system's wind protection is of considerable importance.

The different types of sheet materials which can be used for wind protection are wood fibre sheets, both asphalt impregnated particle boards and oil-tempered hardboard sheets. Furthermore a special plasterboard quality can be used. In order to achieve a satisfactory wind protection function the building instructions supplied by the respective manufacturers must be followed. It is important to join the sheets in the middle of wooden framework members and the distance between nails must be that recommended. When nailing sheets outdoors, hot-galvanized wire nails with large heads should be used.

If the wind-protective layer is intended as an airtight layer, additional sealing must be carried out at the joints between each sheet. Tape can be used in such cases. As mentioned earlier, it is pointless to use tape outside. For this reason it is uncertain whether airtightness can be achieved.

A new method of sealing wind-protecting paper has been developed. A special type of paper is used together with jointing strips which have an adhesive coating. The strips are applied across the joints with heat from an iron etc. This method has also been applied to seal joints between sheets of plasterboard. It would appear that very good airtightness can be achieved using this method.

Sheet material with a wind-protecting function would appear to be less sensitive than paper to climatic loads during the building period. Damage from careless handling during building is minimal and is often repaired on the spot. It is however very important to use sheet material which is sufficiently moisture and temperature resistant. A considerable period of time can elapse before facade cladding is applied to a building and during this period, extensive deformation can occur in certain types of sheet material. Unsuitable or incorrect application of sheets can also contribute to an inferior result.

Thermal insulation

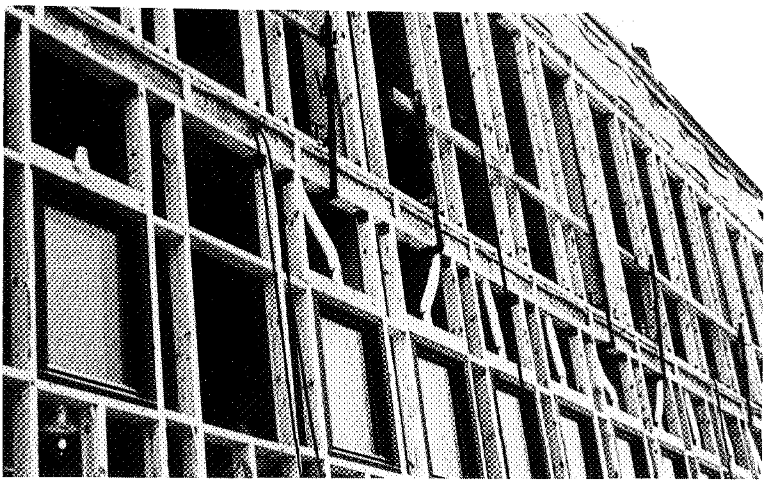
Today, mineral wool is the most common thermal insulation material. It is however necessary to select the correct mineral wool product for the particular application. Material manufacturers have a wide range of products whose areas of application are very specific. In general, manufacturers supply adequate instructions on how and where a respective product is to be used. In wooden frame walls, a relatively pervious mineral wool product is used which, in order to function correctly, must completely fill the space between the containing surfaces. Gaps and cracks cannot be tolerated since the insulation effect can be severaly jeopardized through convection and air movement. Furthermore, mineral wool products of this type require an adequate wind protection on external surfaces and an air-sealing layer on the internal surface in order to function as intended.

In certain types of wood-framed walls, more rigid mineral wool slabs with low perviousness are used and are applied directly to the outside of the framework. Sufficient wind protection is achieved for these walls with glued-on paper, placed on the inside of the walls for example. Special wind protection on rigid mineral wool slabs is not needed on the outside. This type of insulation — rigid slabs — can also be used against a concrete wall for example and no special wind protection is necessary apart from normal external cladding. In all these design alternatives it is assumed that there is an air-sealing layer on the warm side of the insulation.

In the case of attic joist systems there are several products apart from mineral wool slabs to choose from, both in the form of lengths of material whose dimensions are adapted to roof truss spacing of 1200 mm and joist structure matting with paper glued on as wind protection. There are also products which are particularly suitable for application to the inside of roofs which make it possible to carry out the insulation work when the external roof has been erected.

Mineral wool products can be easily adapted to the construction in which they are to be used. However this often means that insufficient consideration is paid to the dimensions of mineral wool products supplied. An unnecessarily large number of wooden frames is often used in walls bearing in mind the dimensions of cladding sheets and mineral wool slabs and unsuitable spacing often results (figure 14). Since mineral wool slabs are so easy to cut and adapt, this work is quite often carried out haphazardly. Spaces and gaps result which reduce insulation efficiency (figure 15).

Figure 14. The proportion of wooden framework in walls should be kept as low as possible. Unnecessary frames, as shown in the photograph, cost money, make good thermal insulation difficult and reduce the quality of the thermal insulation.



It is of fundamental importance that mineral wool used for insulation completely fills the space between frameworks and between the internal air-sealing layer and the external wind protection. Increased thicknesses of insulation have to a great extent brought this to notice. Bankvall (1977) shows how the thermal resistance varies for different insulation thicknesses different widths of vertical gaps (figure 16). The thermal conductivity of the material in the figure is assumed to be $\lambda = 0.035$ W/m^2 °C.

The diagram shows that the framework section with thick insulation is affected more than thinner sections as a result of an air gap. An air gap of 10 mm reduces the thermal resistance for a 300 mm insulation thickness by approx. 0.7 m^2 °C/W (approx. 10%). In the case of 100 mm thick insulation, the thermal resistance for a similar case is reduced by approx. 0.1 m^2 °C/W (4%). Where the air gap is 50 mm, i.e. constitutes less than 1/10 of the insulation space, a construction with 300 mm insulation has its thermal resistance reduced by 50% from 6.9 to 3.5 m^2 °C/W. The corresponding reduction with an insulation thickness of 100 mm is 35%, i.e. from 2.4 to 1.6 m^2 °C/W. Bankvall's results show therefore that good workmanship is even more important in the case of greater insulation thicknesses.

The most common faults which occur during the fitting of mineral wool in wooden framed walls (which can be easily avoided by using carefully considered methods) are:

- ☐ *Faults adjacent to framework members.* This is the result of cutting mineral wool slab (primarily glass fibre) too generously.
- ☐ *Gaps adjacent to framework members, adjacent to cross ties, breast timbers, or other slabs of mineral wool.* The reasons are that the distance between framework members is irregular, often for no reason, that guides are seldom used in cutting slabs of mineral wool and through simple neglect when constructing the framework (figure 17).
- ☐ *Gaps at the end faces of slabs of insulating material.* These are caused when the slabs catch on the rough surfaces of wooden framework members. Since mineral wool is rela-

Figure 15. Insufficient regard paid to frame spacing of approx. 600 mm causes inadequate fitting of the mineral wool slabs with reduced insulation as a result.

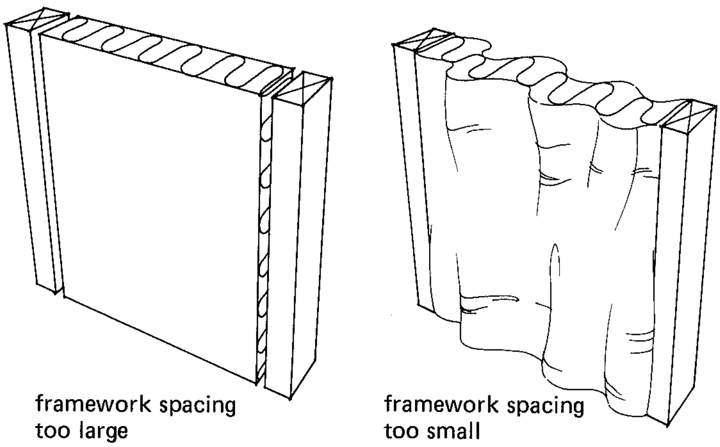
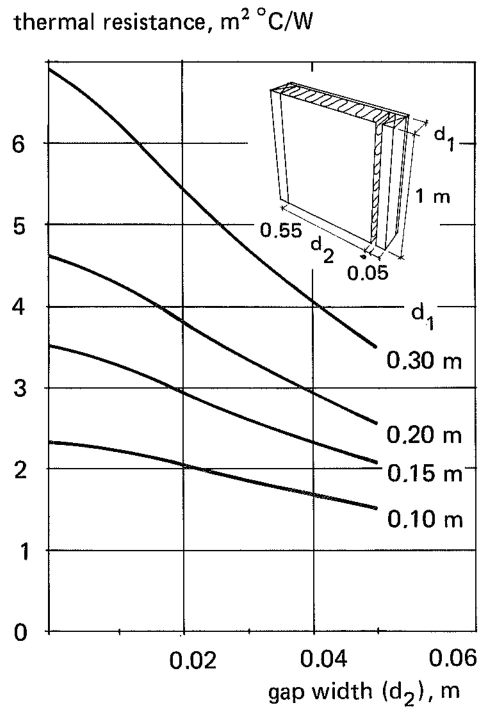


Figure 16. The reduction in thermal resistance in a framework section in the figure where there is a consistent vertical air gap in the insulation (Bankvall 1977).



tively rigid, if the slabs are cut too large, gaps can occur when a slab is bent to press it in between framework members.

☐ *Pressing in position.* When insulating sections with a small distance between framework members, less than approx. 600 mm, the work is often inferior (figure 17). A new slab is not used and instead, pieces of insulation material with »good enough dimensions» are used. When a piece is somewhat too large, it is merely forced in between the framework members. These make-up bits are, furthermore, dis-

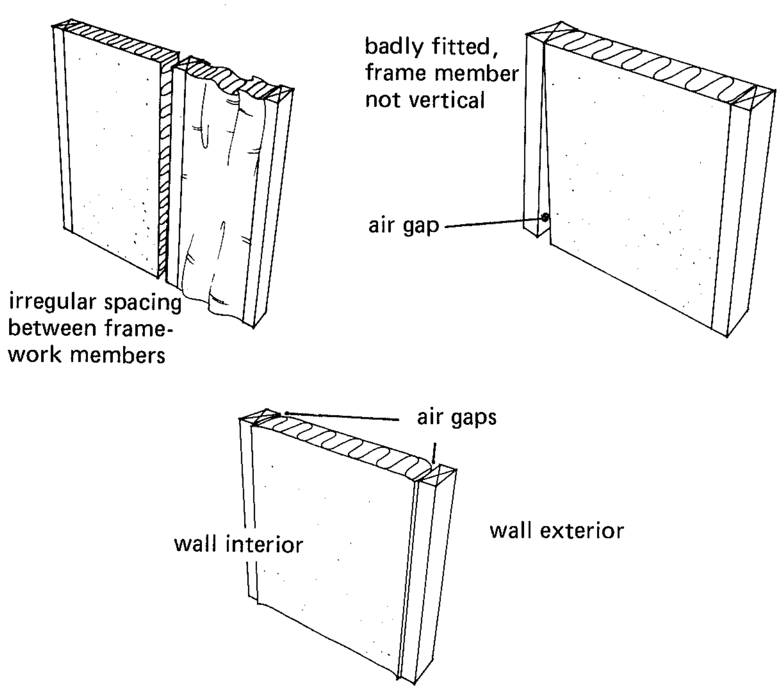


Figure 17. Satisfactory insulation in framework walls is facilitated if the wooden frame spacing matches the widths of the mineral wool and cladding slabs. Exact positioning is ensured by use of a measuring rod. The framework sections must obviously be fitted vertically. Friction between framework members and insulation slabs gives rise to air gaps. If the insulation work is carried out from the inside, these gaps are formed on the outside where they are less significant than if the gaps were on the warm inner surface of the wall.

carded pieces from earlier cutting work and are often damaged. Another example of insulation forced into position is when electricians affix junction boxes and nail wooden blocks in position for attaching the junction boxes (figure 18).

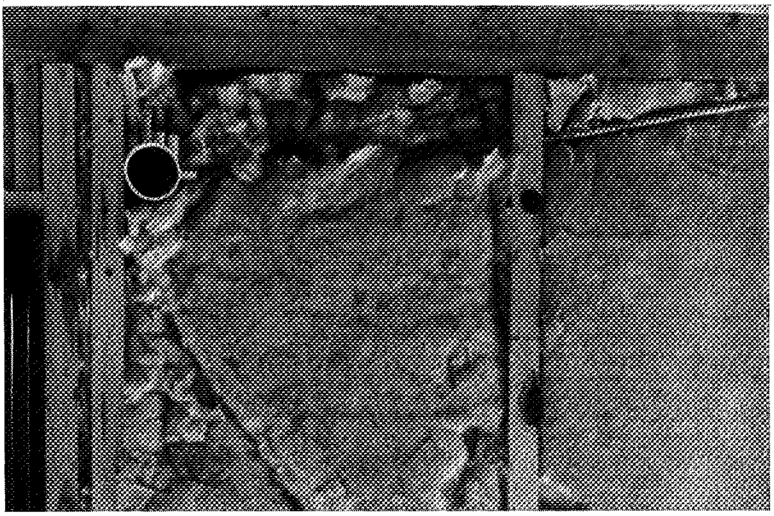
☐ *Cut outs.* An alternative to drawing electric cables across the outside of insulation is to make channels in the insulation layer. This is seldom carried out satisfactorily. Often the result is quite inferior.

When insulating joist structures there are also several important rules to follow. The spacing between the joists should be very carefully measured to exclude unnecessary gaps and spaces between roof trusses and slabs of insulation. The insulation products used are normally suited to a distance between roof trusses of 1200 mm. In order to avoid gaps adjacent to roof trusses, they should be jointed with nail plates. Making joints with laths and nails invariably leads to gaps and spaces with inferior insulation as a result (figure 19). Roof joist structures are often insulated using several layers where the uppermost layer is usually insulated with papercovered insulation matting. In such cases it is important that the bottom layer of mineral wool slabs is sufficiently thick, so that they reach at least to the upper edge of the roof truss beams (figure 20).

Matting is often laid at right angles to the sub-frames of the roof trusses, – an acceptable practice; but the insulation must be carried out so that no air channels are produced between the matting and the underlying slabs of mineral wool.

It is also important to plan the insulation work so that the insulation is not walked or trampled upon unnecessarily. This

Figure 18. An example of the difficulty in fitting insulation adjacent to electric cables.

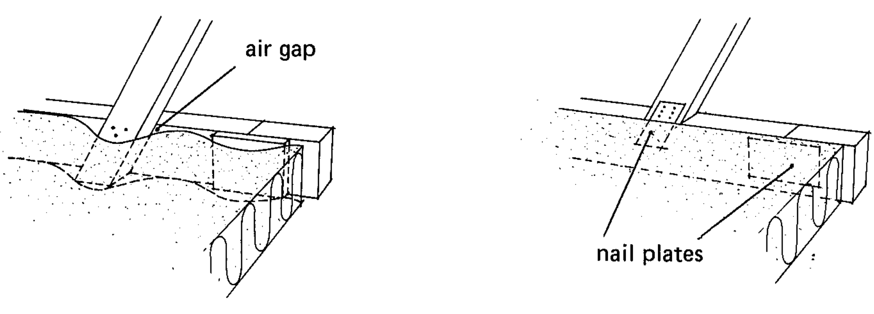


often causes damage to the insulation material and inadequate filling of the space. Likewise, in the case of roof joist structures, it is important to avoid routing electrical installations in the insulation layer. Such installations often give rise to a number of unintentional air channels in which air can flow so that the thermal conductivity is seriously jeopardized (figure 21).

Summarizing, the conditions for attaining good thermal insulation in a construction are:

- ☐ *A carefully considered constructional design with comprehensive drawings* (figure 22).
- ☐ *Suitable positioning of services*, preferably outside the insulation layer.
- ☐ *Suitable choice of materials.* Nowadays there are insulation products which are tailor-made for practically every purpose and which facilitate satisfactory work on site.
- ☐ *Suitable method of working.* The work procedure should be considered and indicated, as should the method for insulation work, at the drawing and planning stages.
- ☐ *Training and information.* Only proper knowledge of how insulation functions can create the right conditions for satisfactory work in practice.

Figure 19. The left hand figure shows a construction where the support column for the roof truss is nailed to the outside of the joist. Furthermore the roof joist is jointed. Such measures often lead to gaps and spaces in the insulation. Joints made with nail plates, as illustrated in the right hand figure, often provide a better insulated joist structure.



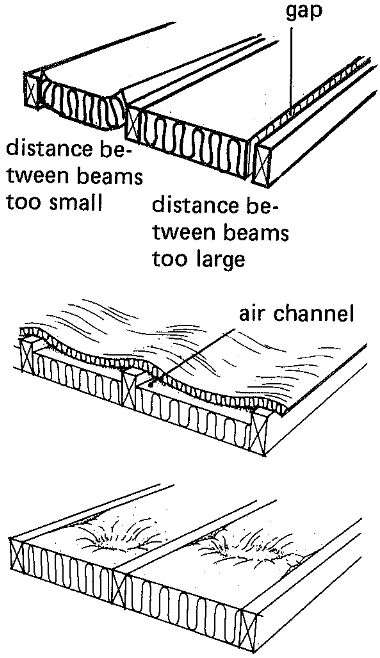


Figure 20. Insulation work must be planned to prevent gaps and air spaces in the insulation and the insulation must not be walked upon during the course of the work.

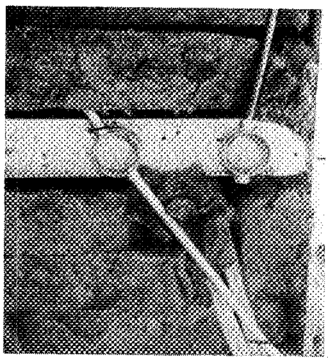


Figure 21. Electrical installations in joist structures and external walls often create air channels. For this reason cables should not be laid in the insulation layer.

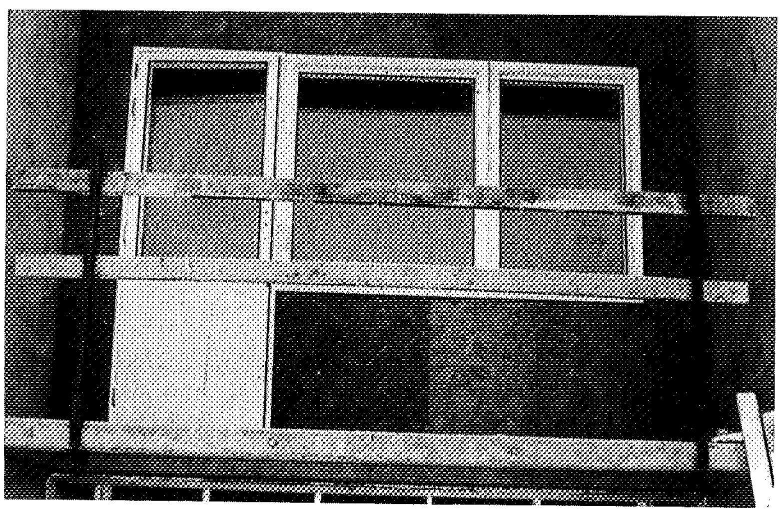


Figure 22. An example of well planned and executed insulation work.

Joints – materials and construction

Materials for sealing joints

EPDM

Ethylenepropene rubber is built up of a copolymer with 60–70% ethylene, 30–40% propene (EPM) and usually a third monomer, e.g. 1.4 hexadiene (EPDM) which provides double linkage for vulcanization. Thanks to good resistance to weather, wind, ozone, hot water, fumes, acids and alkalis, the material is now used instead of chloroprene for jointing and glazing strips in facades.

The type of polymers used in rubber are called elastomers. After cross linkage between the molecular chains, a process called vulcanization, these substances produce rubber, a material capable of being deformed to a considerable degree and after unloading being able to resume its original form almost completely. Apart from the polymer, rubber comprises fillers, usually carbon black, a vulcanizing medium, as well as other additives. Sulphur or one of the organic sulphur compounds is usually used as a vulcanizing medium. When the vulcanizing medium is heated during the final production process (vulcanization), the elastomer converts from a thermoplastic mass to an elastic rubber. In physical terms this means the formation of a limited number of strong cross-linkages, which prevent the general movement of the molecules but allows local segments of molecules to change form (e.g. stretch) and move. A number of profiles for sealing strips are made of this material.

The most common EPDM sealing strips which are used today for air and vapour sealing are:

- □ *S strip* – e.g. when jointing between a ground plate and foundation plate (foundation wall) and when jointing construction elements.
- □ *T strip* – when jointing between walls and frames.
- □ *Tubular strip* – when jointing between window frames and surrounds.
- □ *V strip* – when jointing between window frames and surrounds.

Sealing strips and sealing problems between window frames and surrounds as well as between doors and door stiles are treated by Höglund and Wånggren (1979).

Mineral wool

For a long time mineral wool has been used as a »sealing material» in joints. However its primary function is thermal insulation. During the last few years, several ready-made mineral wool products have been developed for improving airtightness. This has been achieved by containing the mineral wool inside different types of plastic film. Sealing systems have been developed for different purposes. The most common products and systems are:

- ☐ *»Sealing fibre»* — used between ground plate and foundations as well as between construction elements. The system comprises mineral wool strips packed in plastic film.
- ☐ *»Jointing fibre»* — used between walls and frames. This system comprises one strip with an external plastic film coating and one without.
- ☐ *Mineral wool packing* — is quite often used for sealing joints but its primary function is thermal insulation and it should be supplemented with a T strip (made of EPDM) or jointing compound on the inside in order to achieve good airtightness.

Polyurethane foam (PU foam)

Polyurethanes are a group of polymers which are produced when isocyanates react with polyalcohols. There are a number of variations. By differing the manufacturing process, expanding polyurethanes with different properties can be produced. The product can be made rigid or soft. The cells can be made open or closed. The material's natural colour is a weak yellow-grey, but a number of dyes are used.

Rigid expanded polyurethanes can be used as thermal insulation material. Excellent thermal insulation can be achieved when the closed cells are filled with a high molecular gas (e.g. freon). The material has a further advantage in that the use of transportable machines and tubes can expand the material on the actual building site. Self expanding polyurethanes can be produced with open cells. Such materials have very good acoustic absorption.

The most common PU foams available today, which are used for air and vapour sealing, are of a single component type.

The main area of application for jointing foam, seen from a sealing aspect, is for jointing around curtain wall sections, adjoining the structure of the building and for sealing joints around windows, doors, etc. PU foam also has a thermal insulating function in the joint.

During application on the building site the foam leaves the spray nozzle with a creamy consistency, rapidly expands up to approx. 15 times its volume and hardens during contact with moisture in the air or in water. (Polyurethane is a thermosetting plastic.) The hardening of the foam is initiated by the surrounding moisture. The material is almost completely cured after one day.

When the foam is correctly used, it is sufficiently elastic to tolerate a movement of ±10% of the gap width, and this must naturally be considered when forming joints.

As of 1979-07-01, freon may not be used as a propellent for polyurethane foam by order of the Swedish Products Control Board. Dispensation has been granted for foam which is used for joint sealing in buildings.

Jointing compounds

Jointing compounds or joint sealing compounds refer to products whose main function is to produce a sealant and, in certain cases, an adhesive between construction elements. The purpose is to prevent water, air and impurities from penetrating and passing through the joint. Sealing compounds are usually viscous, paste-like compounds which contain polymer binders, fillers, solvents and, in certain cases, pigment. The binder may be based on polymers of the same type used in certain thermosetting resins, thermoplastics and rubber or can comprise special polymers.

When jointing compounds are used for air and vapour sealing they shall be applied inside the joint, as near to the warm side as possible. From the point of view of water vapour transport it is particularly important that the joint is not vapour-tight on the outside towards the cold side. Jointing compounds for air sealing are used between frames and walls, where veranda sections pass through walls and under door thresholds. These materials can also provide a suitable substitute for other sealing materials where the latter are difficult to apply.

It should be noted that it may be difficult to paint and wallpaper on top of certain types of jointing compound.

Other sealing applications require jointing compounds with different characteristics with regard to forming properties, i.e. greater or lesser elasticity (rubber-like characteristics) or plasticity (with residual deformation after loading). The manufacturers of elastic jointing compound products usually set the limit for elongation allowed after compression, without residual deformation, to at least 25%. This is of particular importance for the construction and forming of the joint.

Ageing in materials

For airtightness requirements to be satisfactory during the life of buildings, there must be good resistance to ageing in the joint sealing materials used, or the design of the joints must be such that they can be maintained easily.

Materials whose resistance to ageing is of primary importance from the point of view of sealing are polyurethane foam, EPDM rubber and jointing compounds. Furthermore the ageing properties of the plastic films used for covering mineral wool are of great importance. Another group of materials is tapes and tape adhesives whose ageing properties can hardly be called well documented. However these are not of lesser importance.

When compared with the expected life of a house, all these materials have been used during a relatively short period. Products are developed continually and compositions change. The experience gained from the long term use of material, in what can be called natural climates, is thus very limited. Test methods for accelerated ageing are inadequately developed. Often only one or a few properties are studied in accelerated laboratory tests. Knowledge about newer materials' resistance to ageing is therefore very limited and considerable research efforts are necessary. It is also important that material manufacturers provide their materials with correct merchandise descriptions. Far too many sealing products are sold under anonymous advertising names.

Field trials carried out so far on polyurethane foam refer to 2-component foam since single-component foam has not been commercially available for a sufficient length of time. One of the best documented investigations has been carried out in Germany by Dr. Grunau and indicates a service life of approx. 10 years for 2-component polyurethane (Swedish trade journal, Byggmästaren Nos. 7–8 1976). If these investigations are correct, then the result indicates the importance of constructing polyurethane-insulated joints so that the joint can be resealed without too much work on the building. The main purpose of the German research project has been to assess the average service life of sealing materials used in older buildings. *Sealing material is a material used for sealing joints* according to the definition in German Standard DIN 18540. Investigations have also been carried out to see how the environment affects the life of sealing materials.

Table 4 shows the service life of different materials. Polysulphide materials have been tested the longest. In this case it is possible to expect a service life of more than 20 years assuming that the necessary planning, composition and processing has been complied with. This does not exclude the possibility that the sealing material can have an even longer service life under these conditions than the extrapolated value of 22 years based on experience in USA and Canada.

Many years' experience of other putty-like sealing materials and other experience during the last decades indicates that the service lives of these materials are short. The investigations referred to relate primarily to sealing materials around windows and in joints between outer wall elements where the joint sealing material is applied near to the outside and which can thus be affected by the outdoor climate. Jointing (air-tightening) is often best carried out on the structure's inner surfaces where the joint sealing material is better protected. In such cases, the service life of the joint sealing material can be longer than that indicated in table 4.

Table 4. The expected service life of different sealing materials. This is assuming that the material is correctly produced, is fully processed and is not subjected to excess loading within its area of application. The figures given for the calculated service lives can be considered the minimum service life based on values from practical experience.

Type of sealing material	Documented test period, years	Calculated service life, years	Continual loading, per cent of joint width
Polysulphide	16	22	20
Silicone rubber	8	15	20
Polyurethane	7	10	5–10
Butyl rubber	13	15	3
Acrylic plastic	13	15	5
Acrylic polymer	7	15	10

»Durability and ageing in Sealing compounds» has also been studied by Burström (1977). He treats the fundamental ageing factors' effect on the deformation characteristics of jointing compounds. The ageing factors investigated are temperature, moisture, alkalis, UV light and ozone. Furthermore the effect of natural ageing, i.e. the effect of a natural climate, in combination with forced joint width variations has been studied.

The ageing factor which has been found to have the most significant effect on the deformation properties of jointing compounds is temperature. At the same time it can be deduced that the effects of heat storage differ from material to material. It is therefore impossible to give a general relationship between accelerated ageing in heat and natural ageing for different types of jointing compounds. However the relationship has been outlined in the report for two types of jointing compound.

Burström states quite clearly that knowledge of the ageing properties of jointing compounds is very limited. *Bearing this in mind, consideration during the planning stage will facilitate future jointing work.* The advice refers primarily to external joints but is equally relevant for internal joints which primarily have an air sealing function.

The ageing effects on EPDM rubber strips have also been studied by A Jergling at the Chalmers University of Technology. Preliminary results indicate that ageing effects after approx. 30 years are more evident in chloroprene strips than in EPDM strips.

Air leakage in joints – test results

The following illustrates some of the results from field trials on the airtightness of joints.

When constructing a new bank house in Stockholm, stringent requirements for airtightness in joints around window sections were demanded. »Jointing foam» was used as a sealant for the joints. The airtightness of the joints was tested according to a prescribed method.

No leaks were discovered when testing at a partial vacuum of 800 Pa. Neither was any leakage discovered in a 4 year-old joint when subjected to a similar test.

Joints around windows, sealed with sealing strips and »jointing fibre» were also tested. Measurements were carried out on the inside of the joints which were subjected to partial vacuum. In both cases, air leakage was discovered at an early stage along the joints around the windows. A significant partial vacuum was used during the test. This was motivated by stringent airtightness requirements.

Comparable investigations of joint sealing systems at ground plates

The following alternative procedures for ground plate sealing have been tested using an IR camera (Axén and Pettersson, 1977):

Alternative 1 Ground plate sealing with mineral wool strips.

Alternative 2 Ground plate sealing with the joint sealing system »jointing fibre».

Alternative 3 Ground plate sealing with single-component polyurethane foam.

Alternative 4 Ground plate sealing with EPDM rubber strips.

Sealing alternatives 1, 2 and 3 were fitted and tested in three storey multi-family houses of similar construction built in the same area in the town of Skellefteå in Sweden.

Thermography was carried out at the following times:

- During the final inspection.
- Approx. 12 months after the final inspection.

Tests have been carried out on two different projects with regard to alternative 4, EPDM rubber ground plate sealing.

Constructional and procedural aspects:

Different joint sealing systems demand different working methods. When sealing ground plates with mineral wool strips and EPDM rubber strips respectively, it is assumed that the ground plates press on the strips along the whole of their length. For this a carefully smoothed surface and small tolerances when setting concrete slabs are required.

Sealing ground plates with »jointing fibre» and polyurethane foam respectively requires that the ground plate be blocked up since a space for the joint is required. When using the »jointing fibre» system, exact jointing dimensions are required if a satisfactory result is to be achieved but significantly larger tolerances can be accepted when using polyurethane foam.

Results and comments:

Alternative 1 Ground plate insulation strips of mineral wool placed straight under the ground plate often give rise to considerable recurrent air leakage at the floor foundation, particularly if the edge of the joist structure is uneven. The air movements measured varied considerably depending on the pressure difference across the construction. When carrying out control measurements 12 months after the final inspection, it was observed that air leakage had increased. All the houses investigated gave this result (figure 23a).

Alternative 2 The jointing fibre system generally provided satisfactory results. In isolated cases a certain amount of air leakage was observed. When measured 12 months after the final inspection, the result was usually unchanged. However, it is possible to assume, with good reason, that sealing adjacent to distance blocks is less satisfactory using this method (figure 23b).

Alternative 3 Investigations showed that polyurethane foam-filled joints generally provided satisfactory results. Both sealing and insulating values were satisfactory. In a few isolated places, a blister had developed in the material which gave rise to a small amount of air leakage. The result of measurements carried out 12 months later remained satisfactory (figure 23c).

Alternative 4 Joint sealing with ground plate insulation of EPDM rubber gave satisfactory results during tests. It can be seen that the results are comparable with those of alternative 2. When inspected 12 months after the first inspection, no significant change in the function was observed (figure 23d).

Comparable inspections of joint sealing system around window and door sections (joints between frames and walls)

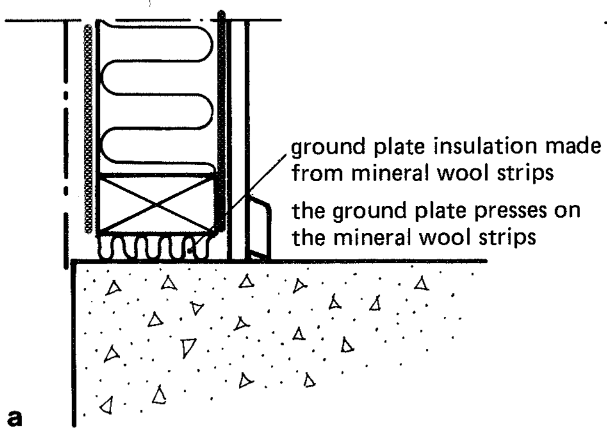
The following alternative methods (figure 24) of joint sealing around window and door sections were tested with the aid of an IR camera:

Alternative 1 Packing strip (50 mm wide), single, unfolded.

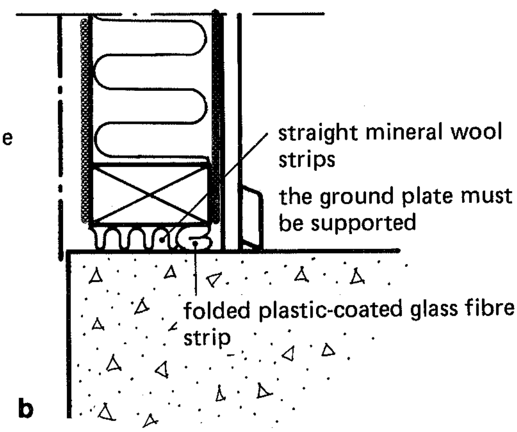
Alternative 2 The »jointing fibre» system.

Alternative 3 Joint insulation with single-component polyurethane foam.

In all cases the joint thicknesses were 15 ± 5 mm. Furthermore the joints were »open» outwards. Only a bevelled strip has covered the joint on the outside. Joint sealing systems 1–3 were fitted and tested both in certain sections of similar 3-storey multi-family houses in the same area in Skellefteå,

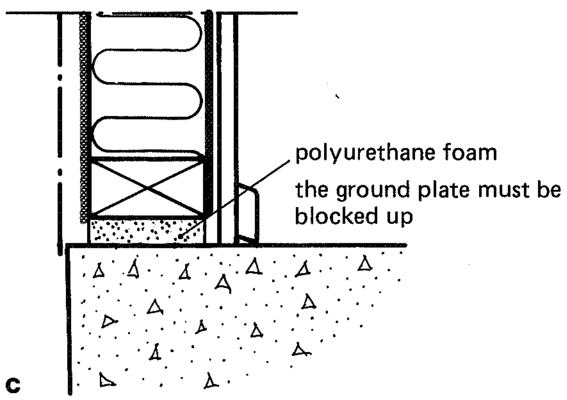


significant risk of air leakage

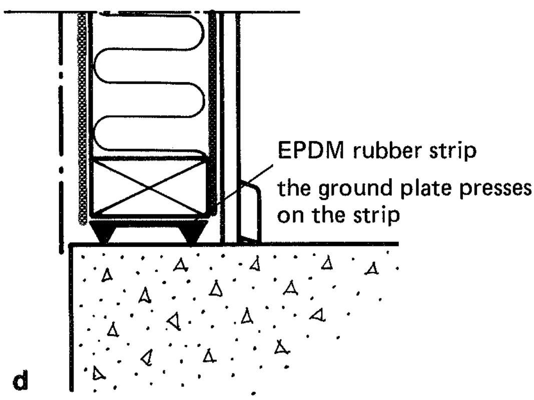


risk of leakage points around blocks

exact joint dimensions are necessary for satisfactory function



airtightness is usually good



airtightness is good if the concrete surface is carefully smoothed

Figure 23. Ground plate sealing.
a. Sealing with ground plate insulation strips of mineral wool.
b. Sealing with »jointing fibre».
c. Sealing with polyurethane foam.
d. Sealing with EPDM rubber strips.

and in two 3-storey, similar multi-family houses all in the same area in Lysekil, another town in Sweden.

With the exception of alternative 3, the investigations were all carried out at the following times:

- ☐ During the final inspection.
- ☐ Approx. 2 months after the final inspection.
- ☐ Approx. 12 months after the final inspection.

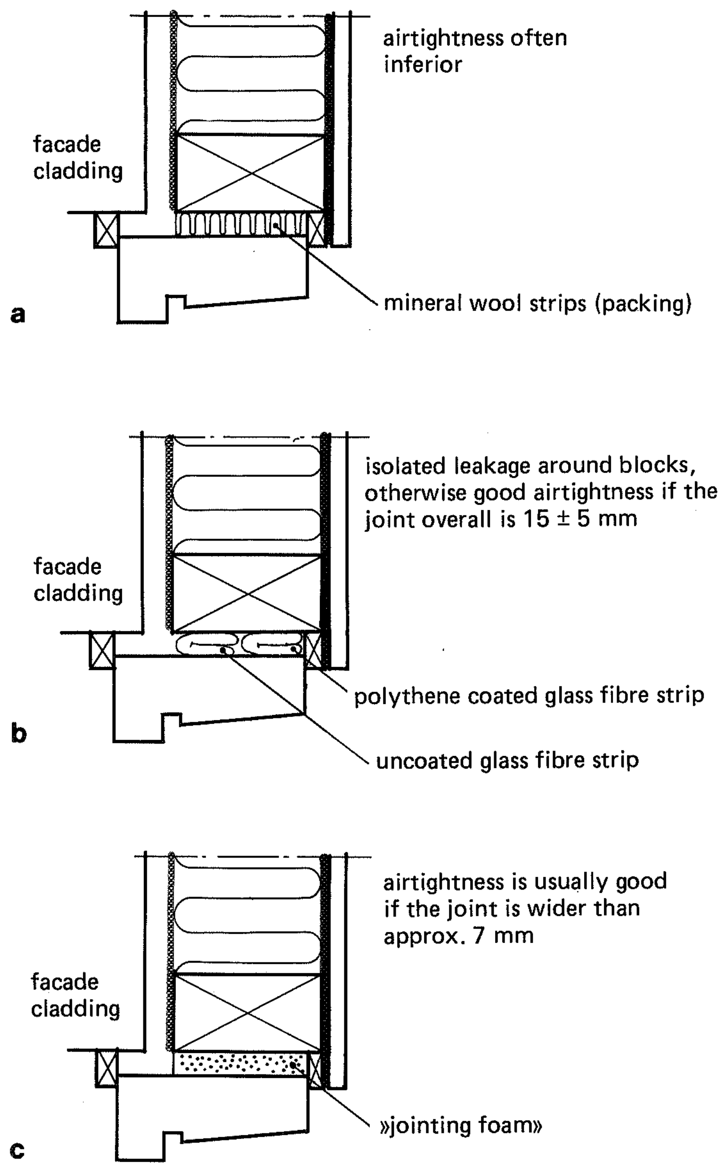


Figure 24. Sealing around windows.
a. Sealing with mineral wool strips. Airtightness is often inadequate.
b. Sealing with the »jointing fibre» system. Isolated leakage often occurs around blocks. Airtightness is otherwise good if the overall joint is 15 ± 5 mm.
c. Sealing with »jointing foam». This provides good airtightness if the joint is wider than approx. 7 mm. Special procedures with regard to precipitation may often be necessary when using certain facade materials or if the house is in an exposed position. The figures do not illustrate this case.

Results and comments:

Alternative 1 The function of joints sealed with simple, non-folded packing strips was usually inadequate. Air leakage occurred to a relatively large extent and recurred to varying degrees along extensive sections of joints between window frames and wall sections. Air movement at the points of air leakage varied depending upon the respective pressure difference across the construction. During inspections, two and twelve months respectively after the final inspection, a significant deterioration of airtightness had occurred compared with the check after the final inspection. (The function of this joint sealant could be improved considerably if supplemented with an internal jointing compound which then constitutes the actual air seal.)

Alternative 2 When measuring joints sealed with the joint sealing system »joint fibre» a mainly satisfactory result was observed during the final inspection. Adjacent to blocks and corners, where the packing strip was not continual, a certain amount of air leakage was however observed. The erection method for the frame has a considerable effect on the sealing result. The use of adjustment screws instead of blocks and nails allows the mineral wool strips to be positioned either side of the screw. In this way complete strips can be used to a great extent. The risk of isolated leakage should therefore be reduced. Unchanged results were obtained when checking two and twelve months respectively after the final inspection.

Alternative 3 Sealing joints with single-component polyurethane foam provided good sealing even near blocks and corners. The sealant exhibited good adhesion to adjacent materials (with the exception of polyethylene foil). The results remained unchanged at the different inspection times. The whole of the jointed depth between frame and wall should not be filled with foam. A few centimeters of the external section of the joint can be left unfilled to facilitate drying of the timber.

The construction of joints

Joints at ground plates

Joints between edge beams/joist structures at ground plates are a »coarse cold bridge». It is therefore important that both air sealing and thermal insulation between ground plates and foundation slabs/joist structures be carried out with suitable material and accurately. The following materials and methods are recommended bearing in mind the test results, discussed earlier, obtained by thermography, pressure testing and point leakage measurement:

- □ *EPDM rubber strip*. The strip is stapled to the ground plate before fitting. This method requires the concrete slab to be very smooth in order to achieve adequate airtightness.
- □ *Plastic coated mineral wool*. The mineral wool is best stapled to the ground plate before fitting. A smooth concrete slab or a pre-smoothed brick block is also necessary in this case to achieve an airtight joint.
- □ *Polyurethane foam*. The foam is injected between the slab and the ground plate. The minimum joint space is approx. 7 mm but the joint width should preferably be approx. 20 mm. This method of sealing joints is particularly suitable for blocked-up ground plates and blocked-up trabeation sections where relatively large tolerances can be accepted. The method is less suitable where construction elements are placed directly on smoothed concrete surfaces since there is no jointing space in such cases.

In the case of floors where the upper sides of blocks are insulated, airtightness can be ensured by drawing the plastic foil from the inside of external walls past the slab to be jointed – ground plate and out across the floor (figure 25a).

The corresponding procedure, where the insulation lies under the concrete slab, is illustrated in figure 25b.

Joints for concrete building elements

Considerable research has been carried out into the design of joints adjacent to facades (near the cold inside surface). The prime function of these joints has been to provide a seal against precipitation and wind. In such cases it is necessary to differentiate between high/large buildings and low/small

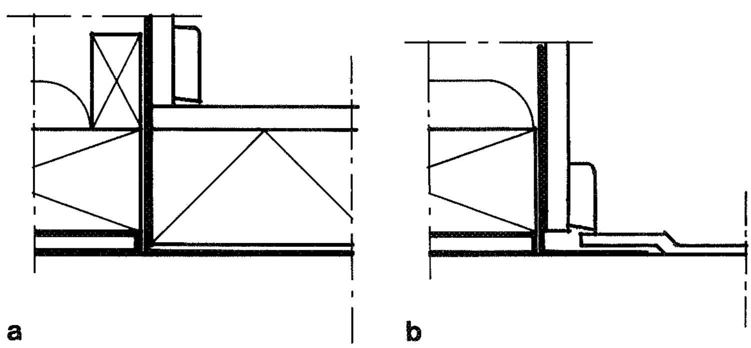


Figure 25. Positioning plastic foil on floors.
a. The insulation lies on the upper surface of the concrete slab.
b. The insulation lies beneath the concrete slab.

houses, where the effects of climate such as heavy rain, wind, running water etc. on the facade are considerably greater on high buildings. In the following, stress is placed on how airtightness is achieved in joints and possible complications. The method of producing joints to ensure good airtightness in concrete and porous concrete elements is in most cases relatively simple. Blomsterberg (1976), shows that existing technology applied to concrete elements in single-family dwellings satisfies the current practice recommendations of 3.0 changes/h (figure 26). Currently (1978) there are no investigations which indicate whether the recommendations can be fulfilled for high buildings using current applied technology.

Investigations reviewed in »Joints in concrete element facades» (Andersson, 1972) and the author's experience from site visits and interviews indicate that:

- ☐ During »long term» projects better workmanship is achieved the longer the project continues.
- ☐ Quite often, work supervisors cannot differentiate between sealing compounds and delegate the responsibility for this to the workers. Product marking needs to be improved and supplemented with merchandise declarations.
- ☐ Sealing compound manufacturers' knowledge about how airtightness is achieved is often inadequate. Unsuitable recommendations are not uncommon.
- ☐ Damage as a result of badly-constructed element joints occurs to a considerable extent.

A number of conclusions can be drawn from this experience

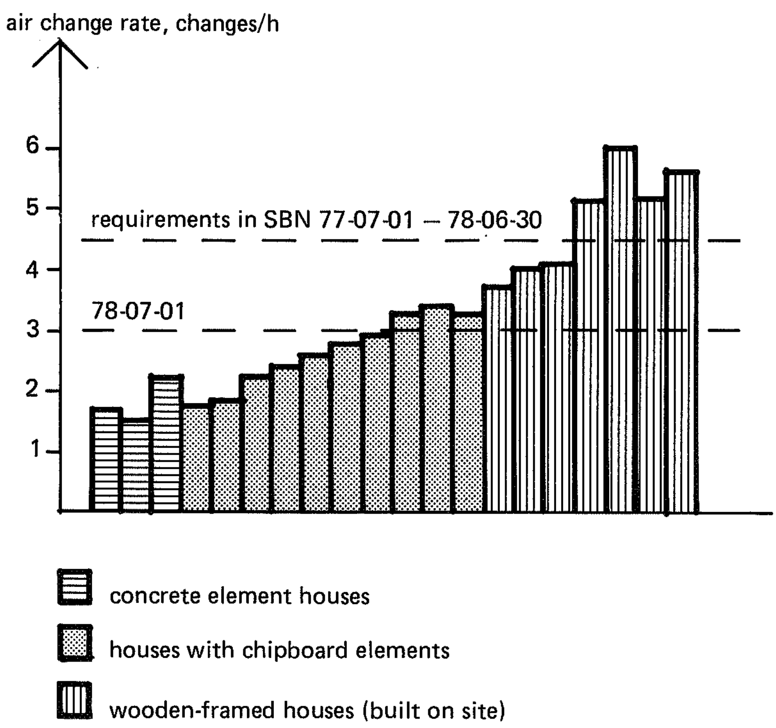


Figure 26. Air change rates in a number of single-family houses with an indoor — outdoor pressure difference of 50 Pa (Blomsterberg 1976). Concrete houses exhibit relatively good airtightness.

with regard to airtightness of joints between concrete elements when using sealing compounds. Knowledge of constituent building materials, sealing compounds and the requirements for a construction to function is relatively good but not sufficiently widespread. The following is necessary, in the short to ensure correctly-made joints using jointing compounds:

- ☐ *Inspection* (e.g. according to the proposal made by K-A Andersson, 1972).
- ☐ *Training of special sealing technicians,* thus avoiding the first part of each building stage being inferior as a result of new staff being given the job each time. However the task should not be more complicated than that which can be carried out by a normal building worker.
- ☐ *New design of internal joints* so that jointing compounds can be added or replaced. Bearing in mind ageing in jointing compounds, joints should be prepared for future changes and maintenance during newbuilding. In other words joints should be easily accessible.
- ☐ *Correct joint construction* bearing in mind joint widths, tolerances and jointing material.

The most suitable method of ensuring the joint's function is to carry out external sealing using the 2-stage principle for wind and rain sealing. This means that the joint is provided with a means of pressure balancing, draining and ventilation. A couple of examples of possible reasons for damage illustrate this:

If the internal air seal between concrete-porous concrete elements, is produced by cementing or by the use of a smooth bonding surface, the joint can crack as a result of movement in the framework. Combined with faults in external sealing, this can allow penetration of moisture/water as a result of capillary action as well as undesirable air leakage. This is further amplified by wind loading on the facade.

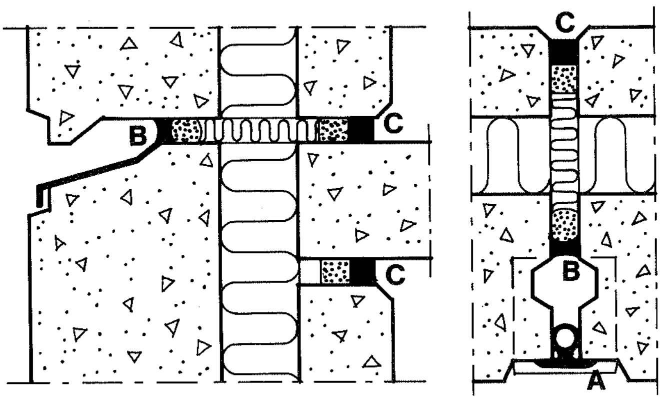
It is also possible to imagine a non-functioning joint, from the point of view of rain/wind, but where the airtight layer is intact. Bearing in mind that the joint is not well drained and the material in the wall and joist construction exhibits a capillary characteristic, moisture/water can penetrate joints and cause problems despite the internal airtightness.

The design of joints between concrete elements is, in our opinion, specific with respect to manufacturer and object. As an example of solutions the design of an element joint according to the 2-stage sealing principle is shown in figure 27. This is recommended by the Norwegian Building Research Institute. Experience of joint design according to the single-stage sealing principle is unsatisfactory in many cases.

Single-family dwellings built of wooden-construction building elements

The deciding factor for airtightness in single-family dwellings

Figure 27. Example of a two-stage seal in joints between concrete elements according to a building detail sheet from the Norwegian Building Research Institute. Sealing strip A in the vertical joint functions as a rain seal in this case. Behind this there is a ventilated air space which has a pressure balancing and draining function. In the horizontal joint the function of the rain seal is assumed by the dropnose, threshold and plate. The outer sealing compound B with the bottom strip is the true air seal and the inner jointing compound C with the bottom strip is the air and vapour seal. The external strip A will probably need to be changed on several occasions during the life of the house because of its exposed position. Sealing compound C will probably need to be changed as well and for this reason the internal joints should be made accessible.



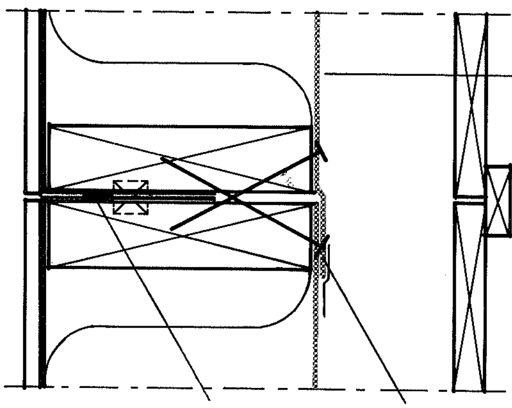
made of structural elements is the design of the joints between the different elements. A number of different variations and solutions are employed. Each manufacturer has his own solutions for element joints and connections. Many solutions do not inspire confidence when inspected. Airtightness probably varies to a considerable degree according to the accuracy and care in assembly at the actual work place. Documentation on resulting airtightness is limited. Gustén and Johansson (1978) have however published results from a relatively large number of measurements made on one type of mass-produced prefabricated house. The air change rate measured in these houses, at a pressure difference of 50 Pa, is often greater than the recommended value of 3.0 changes/h in SBN 1975. The houses were however built before the stated recommendations came into force. The following examples illustrate design solutions applied:

- □ Vertical element joints (figure 28). The joints between wall elements are sealed with rubber strips. The elements are supplied with plastic foil which has an overlap. This overlap is folded during assembly in over the edge beams and is clamped with the aid of factory fitted rubber strips. The wind protection is overlapped and taped. A limited clamping effect is achieved by the external wood panel mounted directly onto the wind protection without an air gap.

- □ Joint between outer wall-joist structure above creep spaces (figure 29). Ground plate sealing is achieved with EPDM rubber strips supplemented with careful application of both wind protection and vapour barrier according to instructions.

- □ Joint between roof elements for a dormer house (figure 30). Airtightness is achieved in that the plastic foil overlap on each element is rolled together and folded into the joint between elements. Thermal insulation in the joint is made up of mineral wool strips. Strips of the wind protection are rolled into the joint.

Figure 28. Vertical element joints. The sealing strips are factory fitted on edge beams of wall elements. The plastic foil is folded towards the edge beam, and past guidance strips where fitted. The wind protection is jointed with tape.



- ☐ A somewhat unconventional solution for element joints (figure 31). The internal plastic foil is fitted on site when the service installations have been carried out. Apart from using a complete internal foil, tightness is achieved using joint strips of expanded polyethylene with closed cells. During tests, the solution has shown to provide good air-tightness despite the fact that narrow strips of foil have been used.
- ☐ A solution of jointing between outer wall elements and joist construction elements above access areas (figure 32). Even in this case, airtightness is achieved by overlapping plastic foil fitted on site. Airtightness is increased by using jointing strips of polythene with closed cells.

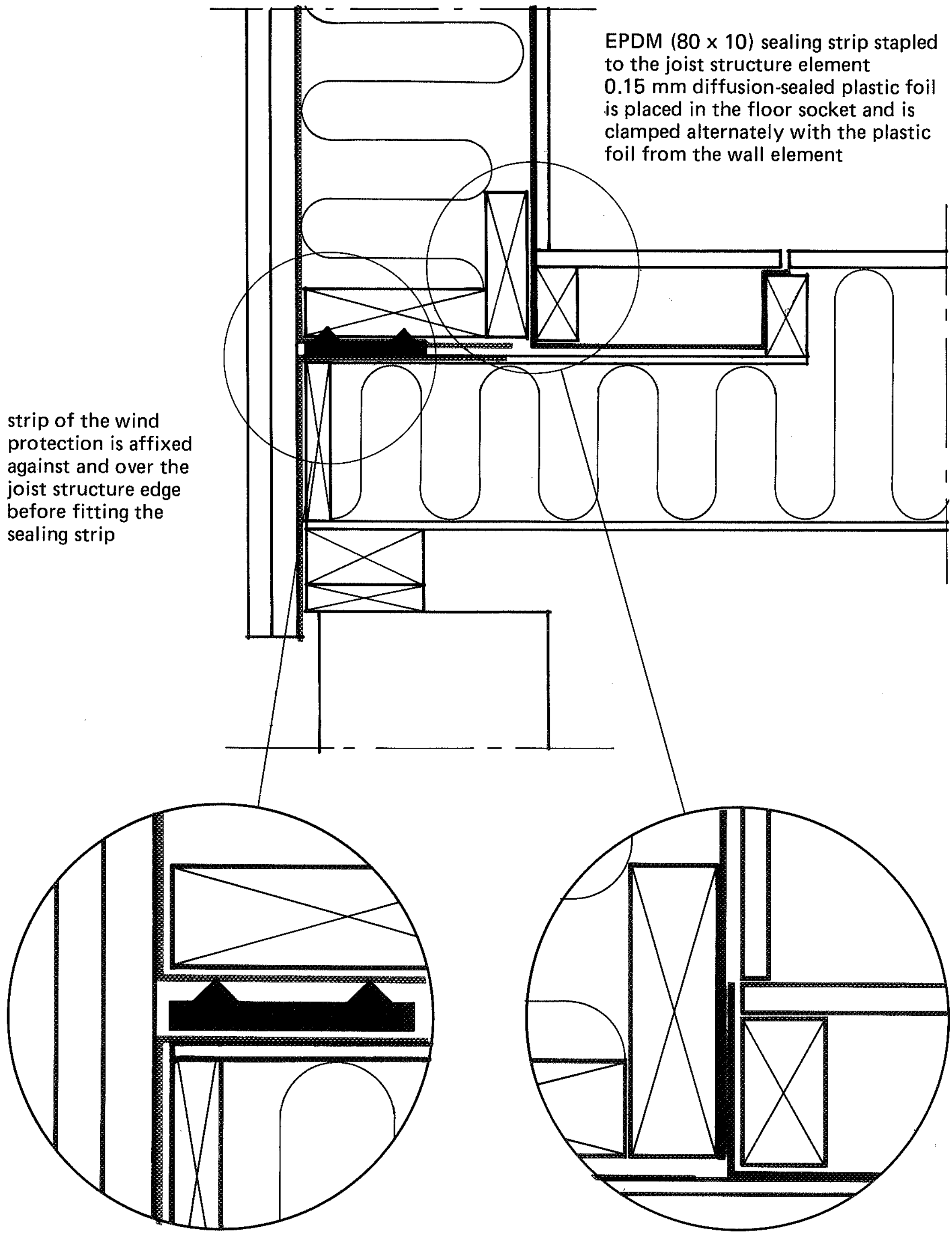


Figure 29. Joining an outer wall-joist structure above access spaces or cellars.

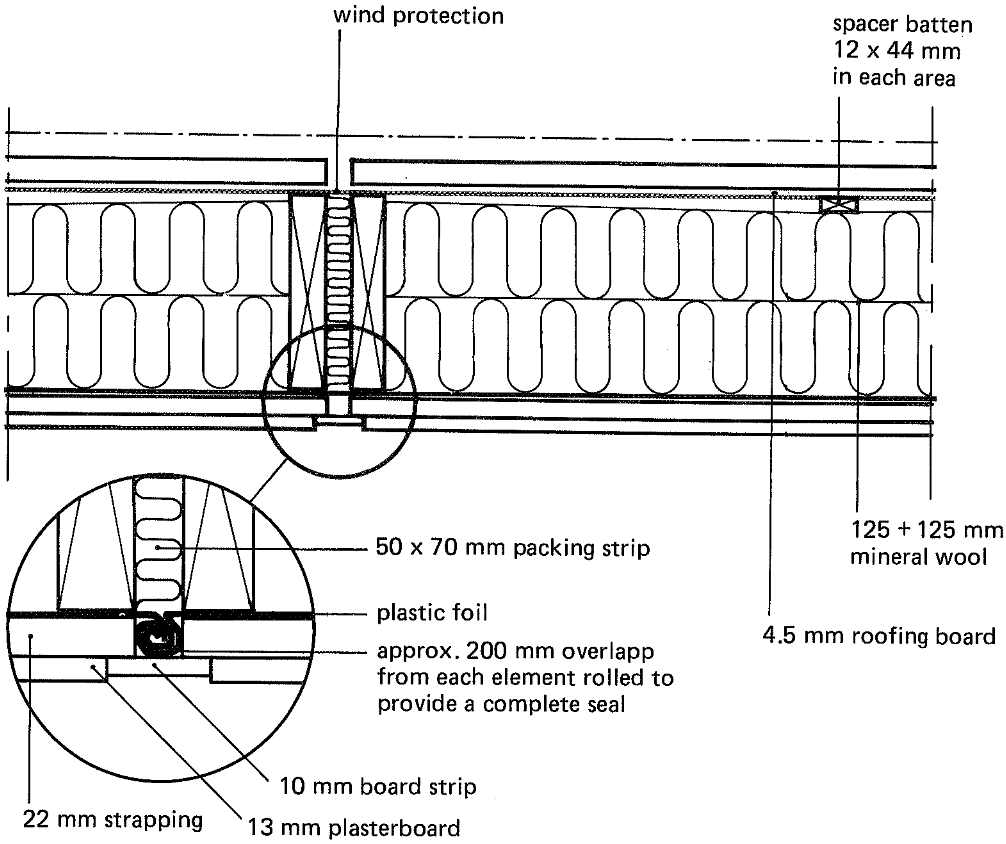


Figure 30. Joints between roof elements for a dormer house.

Figure 31. Element joints. Wind paper is folded over the jointing batten and is clamped between this and the covering plank. The plastic foil is not mounted on the outside wall element until the necessary conduits are fitted for electrical and h & w installations. Plastic foil is fitted to inner walls behind outer walls before the inner wall element is fitted. The holes in the plastic foil necessary for electrical junction boxes are not made until the plasterboard sheets are fitted and the plastic foil is securely clamped between the wood panel and the plasterboard. The diameter of the holes to be cut is the same as the inner diameter of the junction boxes. Jointing strip is made of expanded polyethylene.

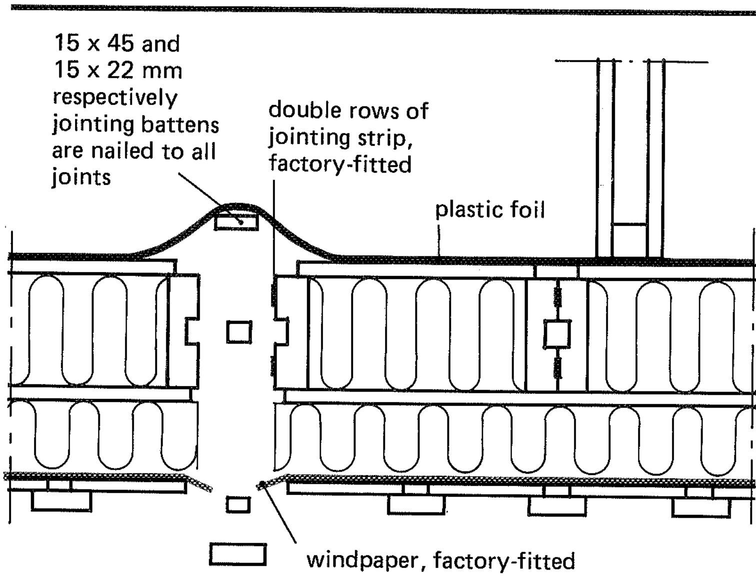
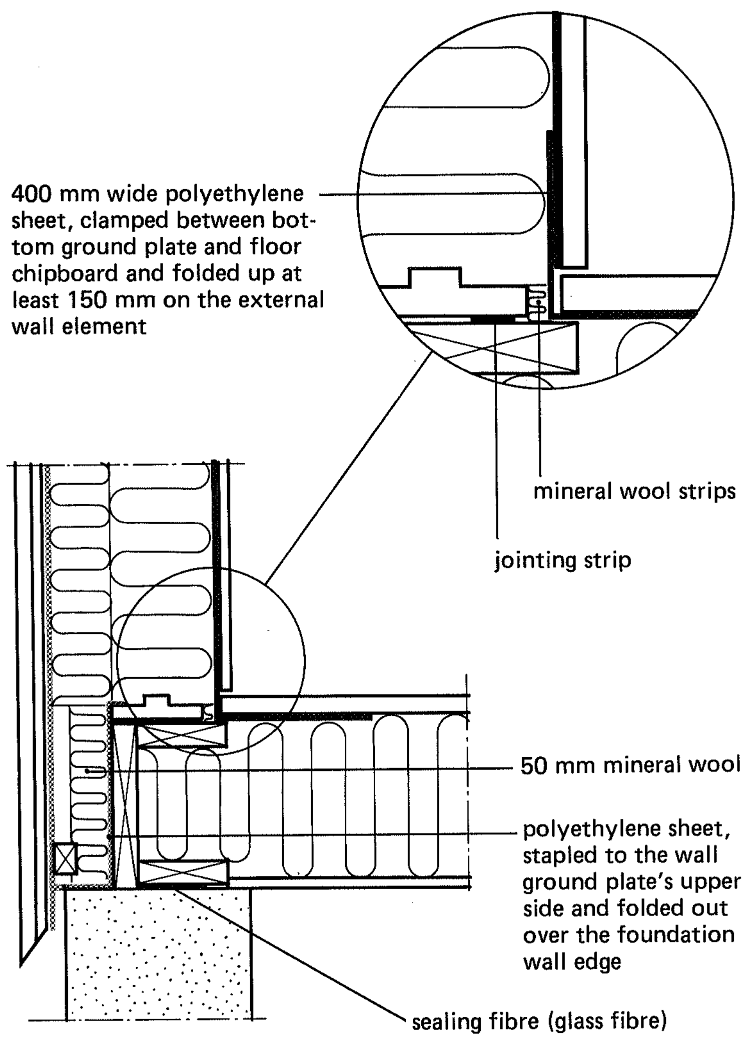


Figure 32. Joining outer wall element — joist structure above crawl space. »Sealing fibre» for ground plate insulation is a glass fibre strip covered with thin polyethylene foil. The ground plate must not be blocked up if good sealing is to be achieved.



Wooden constructions

The construction of frameworks for external walls

The requirements for thermal insulation in SBN 1975 often demand insulation thicknesses greater than 150 mm in wooden walls. This often means that thermal insulation, in practice, is divided into two or more layers. It is of course possible to use a single layer of insulation, but this leads to difficulties in correct assembling and several layers should therefore be used.

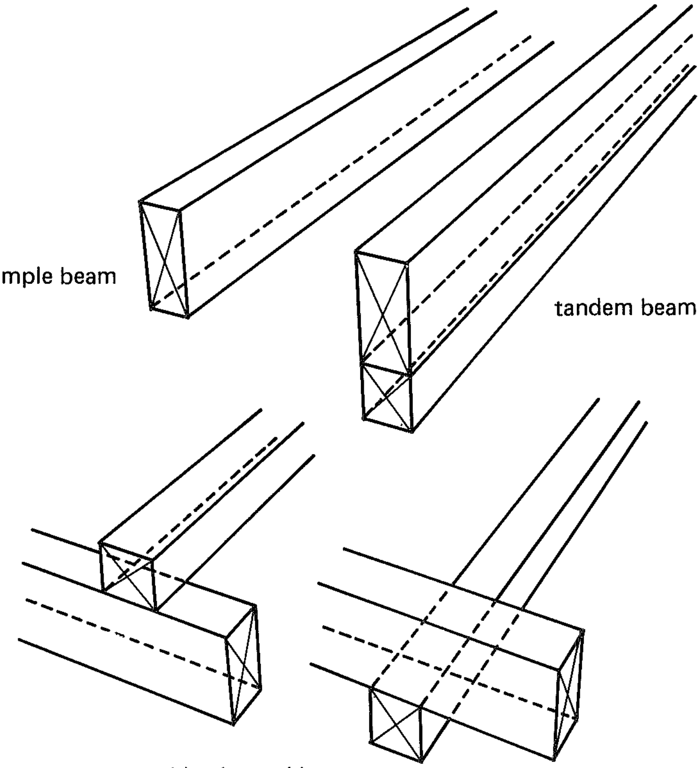
The division of the insulation layer can be suitably combined with a division of the framework into several layers. Framework timber with a thickness of 150 mm or more can be more expensive per mm than 150 mm divided into 100 + 50 mm, for example. The difference becomes greater for greater insulation thicknesses. Several different designs for frameworks are possible. These alternatives can be further subdivided bearing in mind the positioning of wind protection and air sealing functions.

If further insulation thicknesses are required (for example in the case of stringent insulation requirements based on calculated profitability, severe climate etc.), three frameworks may be necessary. Such designs can be carried out in different ways with regard to wind protection and air sealing functions.

The distance between framework members with regard to sheet and slab material and insulation design

There is a strong feeling that the distance between framework members should be a consistent 600 mm. Sheet material used as a wind protection and covering often has a standard width of 1200 mm. Experience has also clearly shown that by careful planning, a distance between framework members of 600 mm can be consistently maintained. A few cuts are however necessary. The format of insulation material is adapted to a spacing distance between framework members of 600 mm. Whole pieces facilitate good insulation procedures. Faults are far more common when the insulation material must be cut. From the point of view of insulation, it is also important to use as few framework members as possible since these constitute cold bridges. Extra wooden framework members should therefore be avoided as far as possible.

Figure 33. Different framework designs.



Different wooden wall frame designs affect the cutting and fitting of slab materials.

External sheet material

Frameworks with external horizontal beams

This construction is built with most of the sheet material on the outside. This means that vertical joints are not supported and this can jeopardize the function of the wind protection. The framework must be supplemented in order to support sheet joints which in turn means that the sheets need to be cut to a greater extent.

Framework with external vertical beams

In order to provide sufficient attachment for the sheet material at the corners, »joining» the sheets in the middle of the last upright member should be avoided – the whole of it should be covered. Two different alternatives are possible in order to avoid waste:

- ☐ In the case of a spacing distance between framework members of 600 mm, the whole sheet can be used beginning from the second framework member from one corner. In the last frame the sheet is cut so that it stretches past the corner beam (last framework member). A certain amount of waste is unavoidable. If the number of frames is even, the system functions »automatically», but if there is an odd number of beams, an extra cut is necessary since the width of sheets is normally 1200 mm (figure 34, alternative a).
- ☐ A distance between framework members at corners can be limited to about 450 mm. This means however that mineral wool slabs need to be cut. The method can also be applied to mineral wool slabs with an air perviousness $< 0.1\ m^3/m^2\ h\ Pa$, e.g. facade cladding mounted on a simple framework (figure 34 alternative b).

Internal sheet material

Frameworks with internal vertical framework members

By displacing the wall sections to a very limited extent, the sheets can be used to the whole extent of their width (no cutting). Without displacement, a certain amount will be lacking at corners, and make-up bits will become necessary.

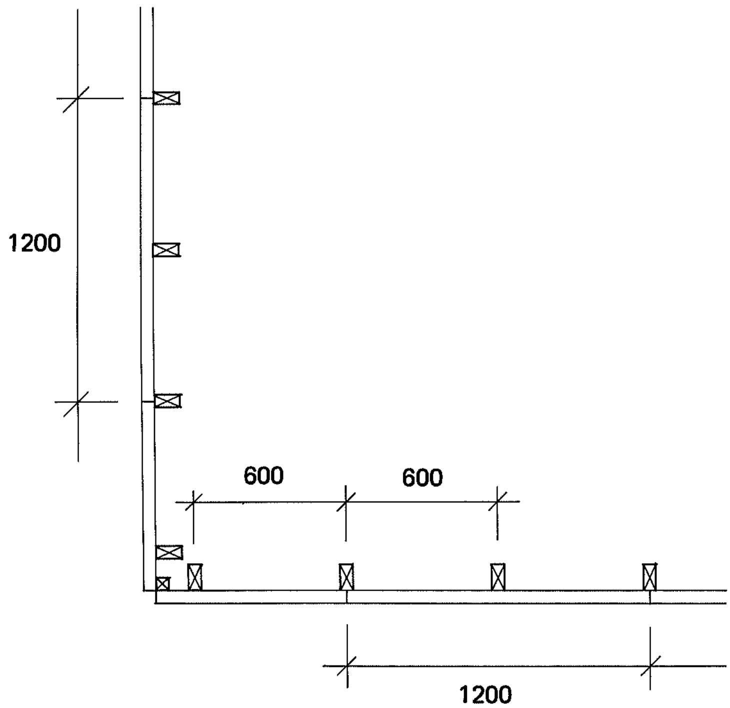
Frameworks with internal horizontal framework members

Normally the sheets need to be cut.

Normal wooden-framed walls

The fundamental design of a simple framework of wood is illustrated in figure 35. Insulation thicknesses of up to 150 mm are used in this case. Observe the actual insulation procedure. If the insulation is made up of a single layer, there is a risk that the insulation might be deformed and not fill out the whole space between the wooden framework members (figure 17). By dividing the insulation into several layers, the risk should be considerably less (figure 36). Make sure however that air gaps between slabs of mineral wool do not occur when using this assembly procedure.

Figure 34. The distance between framework members adjacent to corners so as to use complete sheets of external material where possible and to be able to use a consistent distance of 600 mm between framework members.
a. The framework members have been positioned so that the sheets adjacent to corners must be cut. Whole slabs of insulation material can be used, with the exception of the actual corners, using this method.
b. The distance between framework members has been adapted so that the external sheets need not be cut. It means however that the slabs of mineral wool must be trimmed to a greater extent with the subsequent risk of inferior insulation work.



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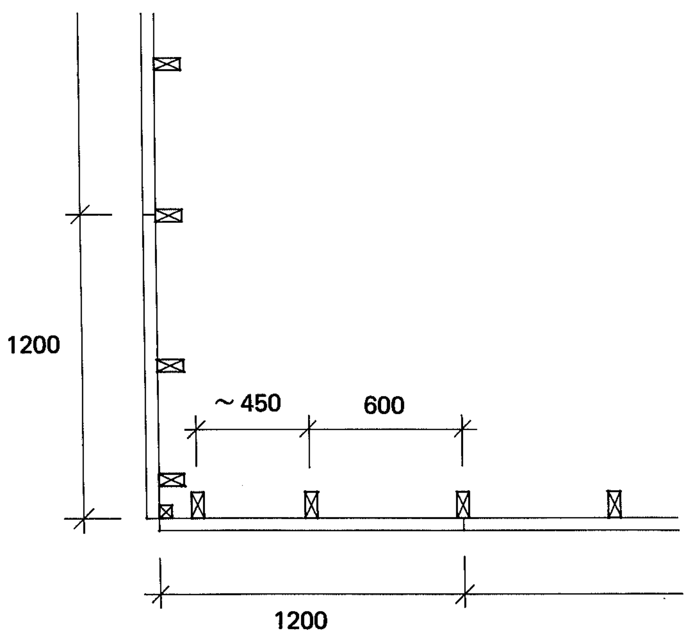


b

Figure 35. The basic design for a common wooden-framed wall.

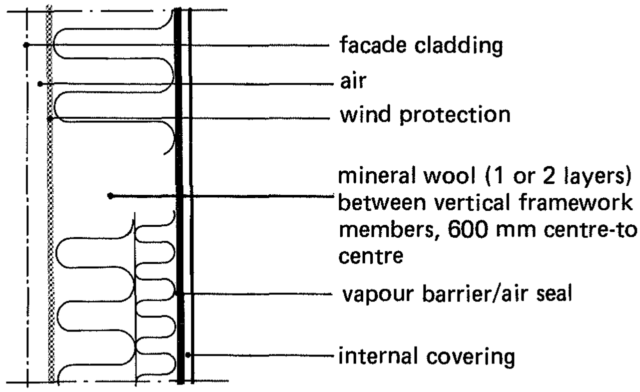
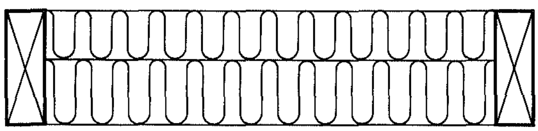


Figure 36. A division of the insulation layer reduces the risk of deformation.



Wooden walls with thick layers of insulation

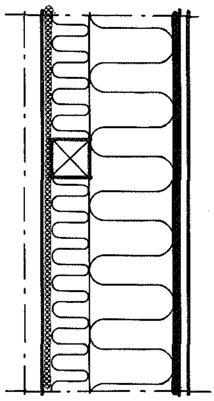
Insulation in several layers is best and is, in fact, necessary when the wall's thickness is built up using a compound stud, e.g. 45 x 45 mm on a 45 x 120 mm stud, or in the case of crossed framework members.

Greater wall thicknesses are obtained as well by using a special framework construction (and building system) (figure 37). Insulation must be carried out first adjacent to the web of the beam using relatively rigid mineral wool slabs. As far as the rest is concerned, the insulation work can be carried out as described above.

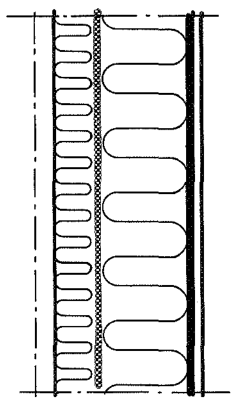
Figure 37. A design example. Insulation must be carried out adjacent to the beam work first using make-up bits of relatively rigid mineral wool slabs. The rest of the insulation can be carried out using 2 or 3 layers. This design can be seen to be advantageous particularly in the case of greater insulation thicknesses.

In the case of the wall in figure 38a, the airtight layer (plastic foil) has been positioned nearest the internal surface layer. The wall has external horizontal framework members and, on the outside, a wind protection of slab or paper material plus an air space and facade cladding. A wind protection of slab material is best. It provides better protection and the risk of damage during building time is less. A »porous» (low bulk density) quality mineral wool intended for normal wall insulation can be used.

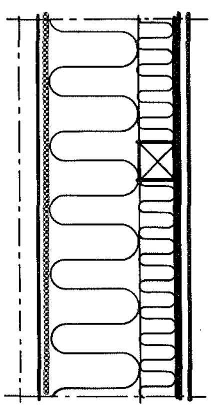
In figure 38b the external horizontal framework and the



a internal load-bearing vertical framework with external horizontal framework



b internal load-bearing vertical framework and external mineral wool insulation with a wind protection glued on



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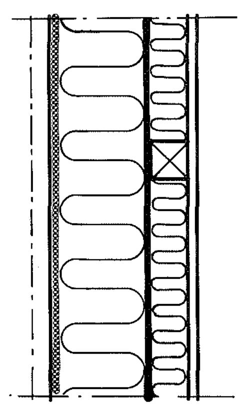


d

external vertical load-bearing framework and internal horizontal framework (the positioning of the vapour barrier/air seal differentiates the two methods)

Figure 38. External walls with two insulation layers. Normally the total insulation thickness for these types of walls in Sweden is 145 or 165 mm.

porous mineral wool has been replaced by a more rigid mineral wool slab with paper glued on as a wind protection. These products are called facade and sub-facade slabs. By mounting these mineral wool slabs with the paper against the framework members, the slab is protected during building time. Furthermore the joints will always be clamped against the wooden framework members and wind protection is more easily achieved.

There are special distance pieces available for mounting wooden facades. Similarly there are instructions on how the loads from facades shall be transmitted to the wooden framework.

When the wall is built with an internal horizontal framework (figures 38c–d) the airtight layer (plastic foil) can either be fitted against the inside surface layer or between the vertical and the horizontal framework. The first alternative has been most common to date.

The advantage of the latter is that any necessary electrical installations can be placed in the space between the plastic foil and the internal surface layer. The plastic foil can then be fitted without having to make holes. Cutting holes can easily jeopardize airtightness. In this situation the foil is better protected against damage when making holes in the internal surface layer, i.e. when putting up pictures, bookshelves etc.

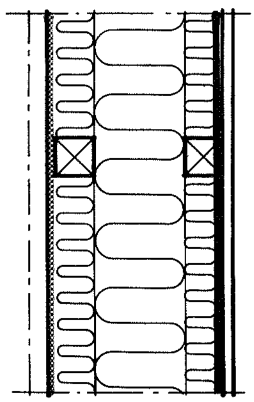
In the case of a construction with a »drawn-in» plastic foil, special consideration must be given to the condensation risk. In theory this is negligible as long as the plastic foil is not drawn in more than 1/3 of the wall construction's total thermal resistance. It is also necessary to observe the thermal-insulating function of armchairs, book cases, fixed cupboards etc., which, in practice, can mean that the foil is positioned too far out into the wall. In exceptional cases, this could mean a risk of moisture and mould damage in the construction. (Research on this is in progress 1980.)

To achieve the required thermal insulation effect in a construction with three separate frameworks (figure 39) it is necessary to plan the assembly work very carefully so that negative effects do not result from bad insulation work or by allowing unprotected insulation to be damaged by wind, water etc. during the building time. It is of the greatest importance to use a construction procedure which ensures that framework layer 1 is insulated before framework layer 2 is assembled etc. Four different wall alternatives are shown in the figure.

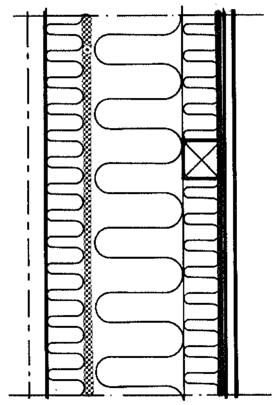
Outside corners

Great care must be taken when constructing corners on external wooden walls. The design of corners on external walls with internal horizontal frameworks results in particularly difficult problems. In order to be able to nail the internal covering in the same horizontal line and to avoid extra vertical framework members at corners, the best way is to bevel-

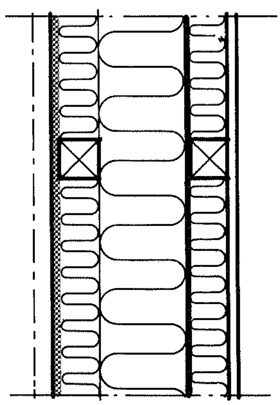
Figure 39. External walls with three layers of insulation. Three layers of insulation can also be used in walls using frameworks of the system shown in figure 37.



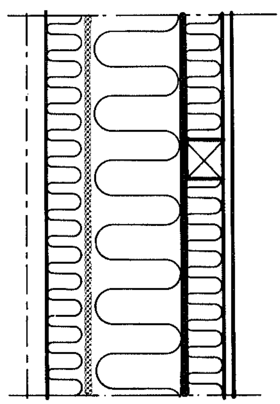
a three separate framework systems with a wind protection of slab material of paper



b the external framework has been replaced by rigid material wool slabs with paper glued on as a wind protection

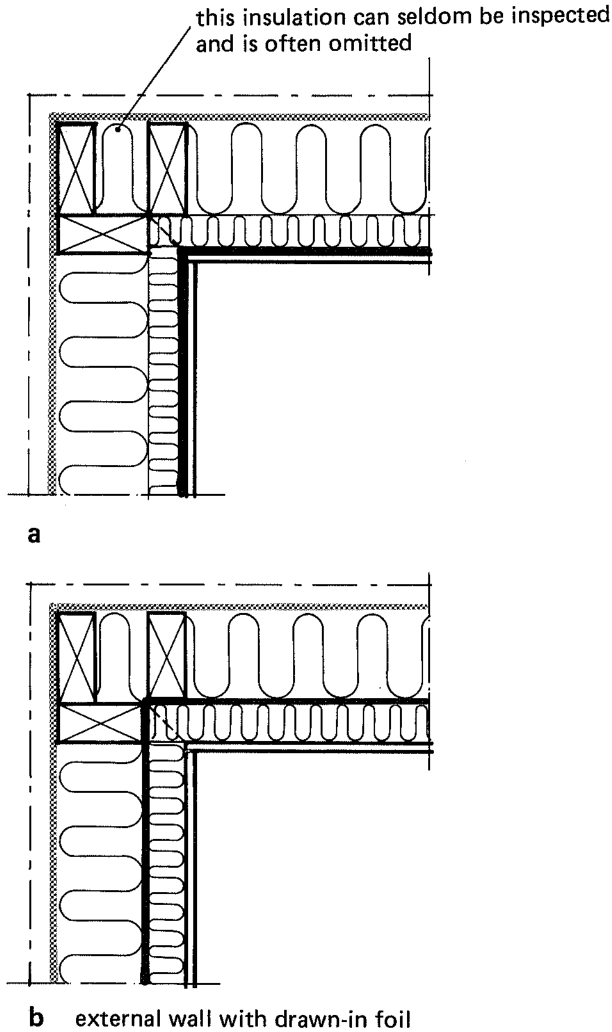


c three framework systems is used but, compared with alternative a the plastic foil has been placed between the vertical framework members and the internal horizontal members
the consequences of this are discussed in the text adjacent to figures 38 c—d



d in this design an external rigid mineral wool slab with paper is used in combination with »drawn-in» plastic foil — compared with alt. b and c

Figure 40. Corner design for external walls with internal horizontal frameworks. Horizontal sections. The internal horizontal frameworks are bevel-cut at the corner. If continual support is needed at the corners for the internal sheets, angle profiles of plate or possibly paper can be used.



cut the horizontal framework members so that these can be attached at the same height. Electric saws are available on most work sites today and therefore bevel sawing should present no difficulties. If better support is required for the internal covering at corners, angled profiles of plate (possibly paper) can be used instead of extra vertical framework members.

An extra wooden framework member is normally positioned at external corners so that the wind protection can be sealed. This means however that a very small piece of mineral wool must be fitted in the corner from the outside. Inspection work has shown that this insulation is often omitted. The extra framework member in the external corner also produces an extra thermal bridge. This can be reduced somewhat by using a smaller framework member.

Airtightness is ensured if the plastic foil is not joined at the actual corner but is drawn past it and jointed at some distance from the corner.

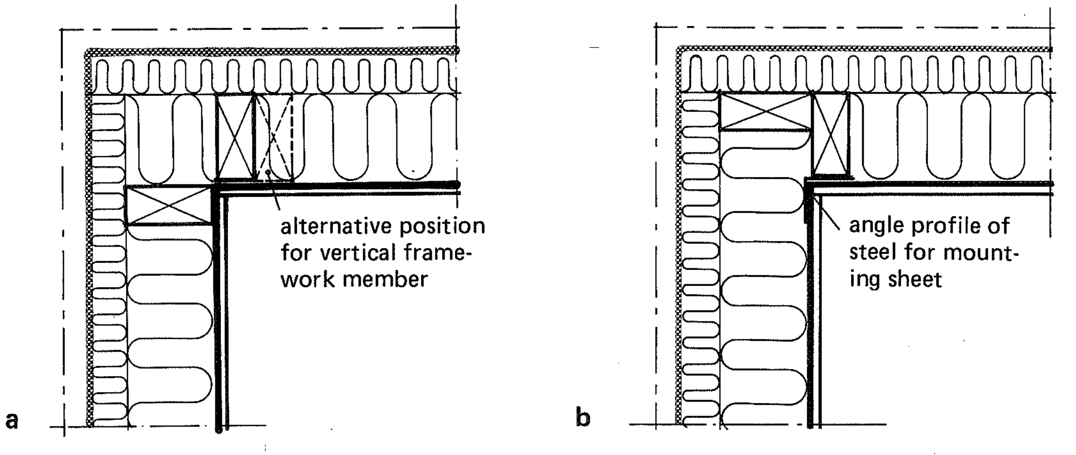


Figure 41.
a. Corner design for an external wall with an external horizontal framework. Horizontal section. The external horizontal framework members can be nailed to each other at the corner to provide the necessary anchorage. The alternative position of the vertical framework member means that the internal sheet is fitted using an overlap. The advantage of this is that the insulation can be inspected at the actual corner.
b. Alternative corner design which means that the internal sheets are attached at corners against an angle profile. This method facilitates insulation work.

External walls with drawn-in foils (figure 40b) demand roughly the same corner design as in figure 40a.
In the case of an external framework (figure 41a) stability in the construction is achieved most simply by nailing into the underlying framework's end wood. An »extra» wooden framework member in the corner is unnecessary in this case. Note that the insulation at an external corner must be fitted from the outside. Figure 41b shows an alternative which facilitates insulation work at the corner.
In cases where the external insulation layer comprises rigid mineral wool products, e.g. facade slabs, special sealing of the corner is necessary (figure 42). Strips of thin sheet metal can be used. However, the material manufacturers claim that sufficient sealing is provided by the rigidity of the slab. Special seals are recommended for tiled facades etc. A suitable method is to combine the seal with a nailing batten when the panel is fitted.

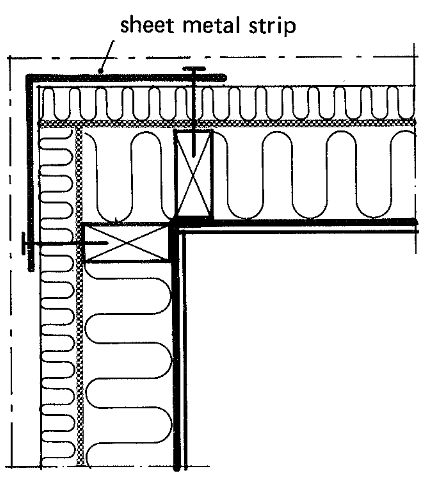


Figure 42. Corner design for an external wall with internal rigid mineral wool slabs. Horizontal section. Strips of sheet metal can be used in order to produce better stability in the construction at the external corner. Extra corner framework members are normally unnecessary. Note that the outer corner must be insulated from the outside before the external mineral wool slab is fitted. It is difficult to check whether this has been carried out. When covering the external cladding with an external panel, reinforcement of the external corner with a vertical 45 x 45 mm member may be necessary.

Figure 43 shows the different alternatives for anchoring corner members using as little timber as possible. The method selected depends on the loading, the form of construction, the working method, adaptability to plan dimensions etc.

Where wind protection of sheet materials are used, a wooden member is necessary at the external corner so that the sheet material can be sealed correctly. A 45 x 45 mm member should be sufficient but even this makes good insulation work difficult (figure 43d). Better static interaction can be achieved by using strips of steel.

Jointing external walls — load-bearing inner walls

Figure 44 shows a wall with an internal vertical load-bearing wooden framework with an external framework and, as an alternative, a wall with paper-covered, rigid, mineral wool with an air perviousness of < 0.1 m^3/m^2 h Pa.

A strip of plastic foil is fitted at the same time as the wooden member to the load-bearing inner wall. The rest of the plastic foil is jointed with this strip when the former is fitted at a later stage in the building work. In this way the foil is made whole and thus airtightness is ensured.

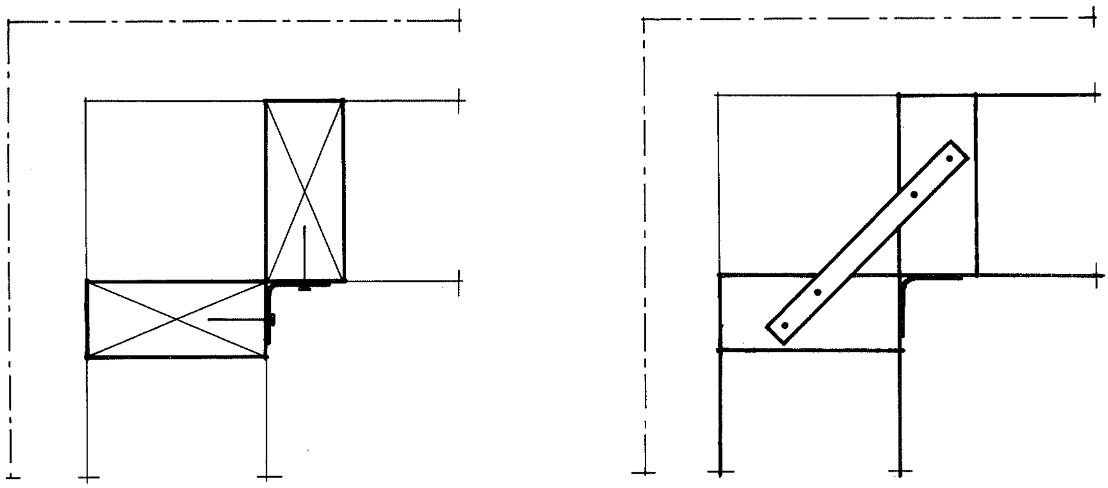
A wall with an internal framework is shown in figure 45 — the alternative with drawn-in foil. The outer wall foil is fitted before the erection of intermediate walls. The inner wall framework is nailed to the horizontal framework members. No extra wall members are necessary. Using this construction the insulation and sealing work on the external wall must be commenced before the internal wall can be fitted.

Principles for jointing frames — walls

The design of the joint between frame and wall section should permit airtightness to be supplemented where necessary. One possibility is to loosen the bevelled strips and then carry out additional sealing using sealing compound, polyurethane foam or other suitable methods. It is reasonable to assume that the sealing material has a shorter service life than the construction as a whole. See the chapter on »Ageing in materials».

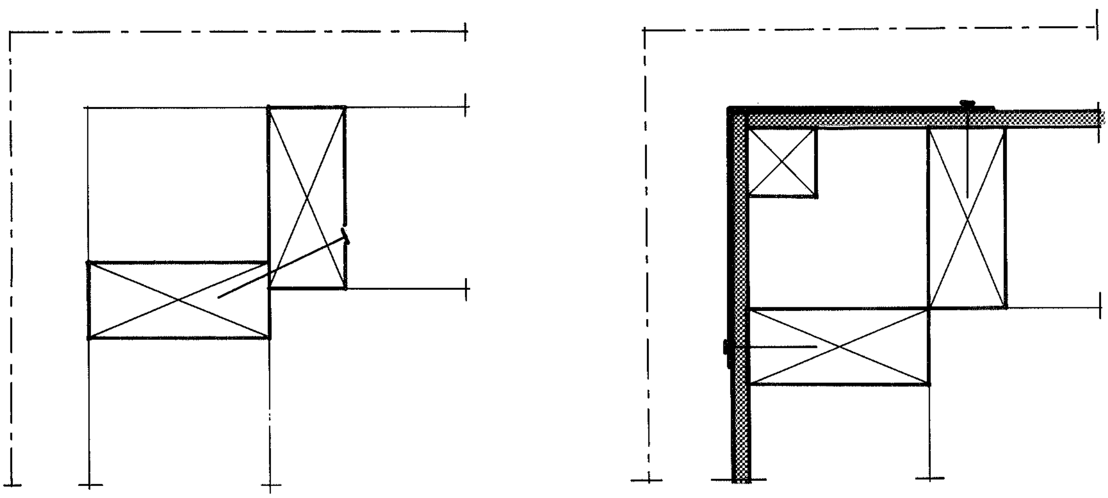
The difficulties with this item occur primarily in the case of horizontal internal frameworks (figures 46a—b). This applies when the plastic foil is adjacent to the plasterboard and in the cases of drawn-in foil in order to clamp it against the framework so that airtightness is ensured. The best way to achieve this is by nogging in timber, with the same dimensions as the internal framework timber, vertically between the horizontal members (see horizontal sections).

In order to ensure sealing of the joint between the window



a The corner members can be anchored with the help of sheet metal strips or cleats of angle iron. Cleats are fitted before internal vapour barriers and internal sheet cladding. When dimensioning, consideration must be taken of wind stability (also during the fitting), the positioning of roof trusses and the design of the gable head.

b Extre anchorage for corner members above top plates with the help of sheet metal strips.

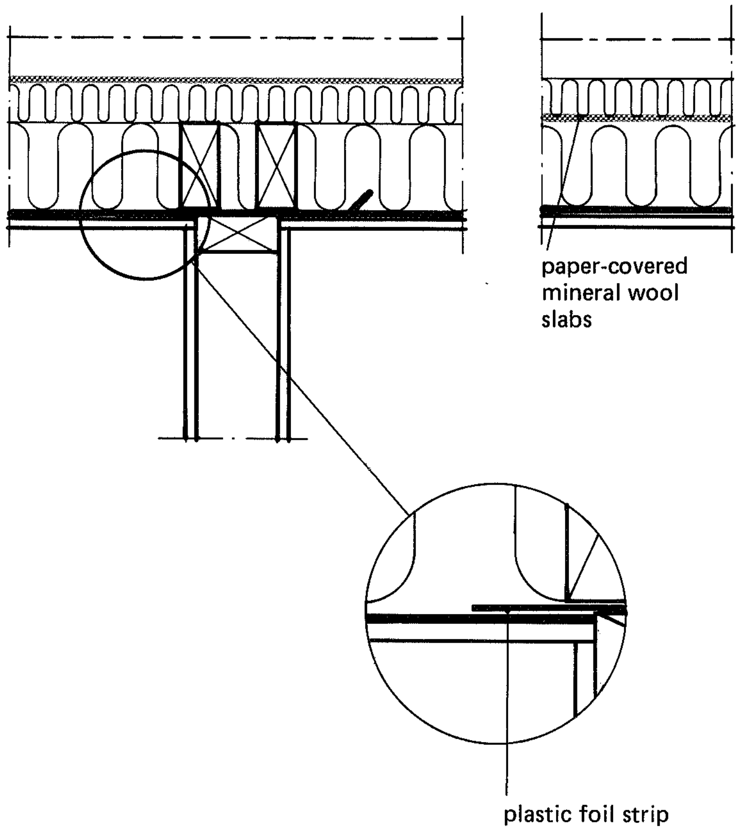


c Sideways displacement of corner members and tosh nailing. This method of displacement can contribute to the better usage of standard slabs.

d In cases where the wind protection comprises sheet material, jointing can be made using a strip of sheet metal and an extra 45 x 45 mm member at the external corner. This extra member makes satisfactory thermal insulation work difficult at the actual corner.

Figure 43. Different methods for anchoring corner members.

Figure 44. Jointing external walls with internal framework and loadbearing inner walls. Horizontal section. Strips of plastic foil are fitted at the same time as the members in the external walls. In this way, airtightness is achieved more easily.



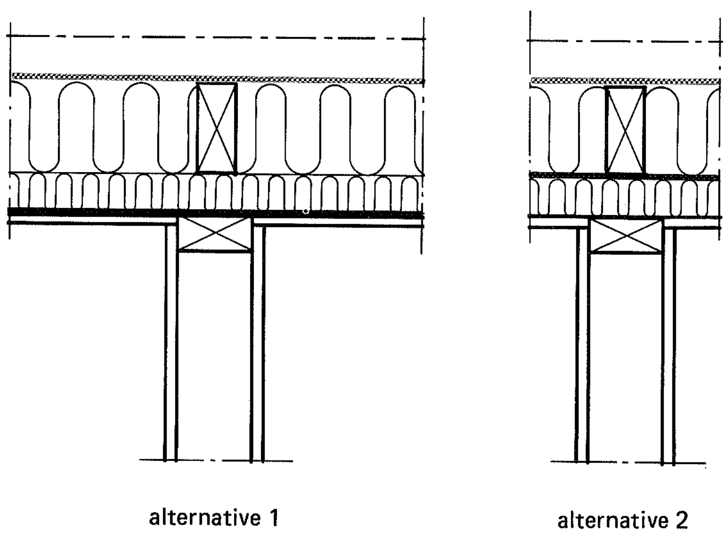
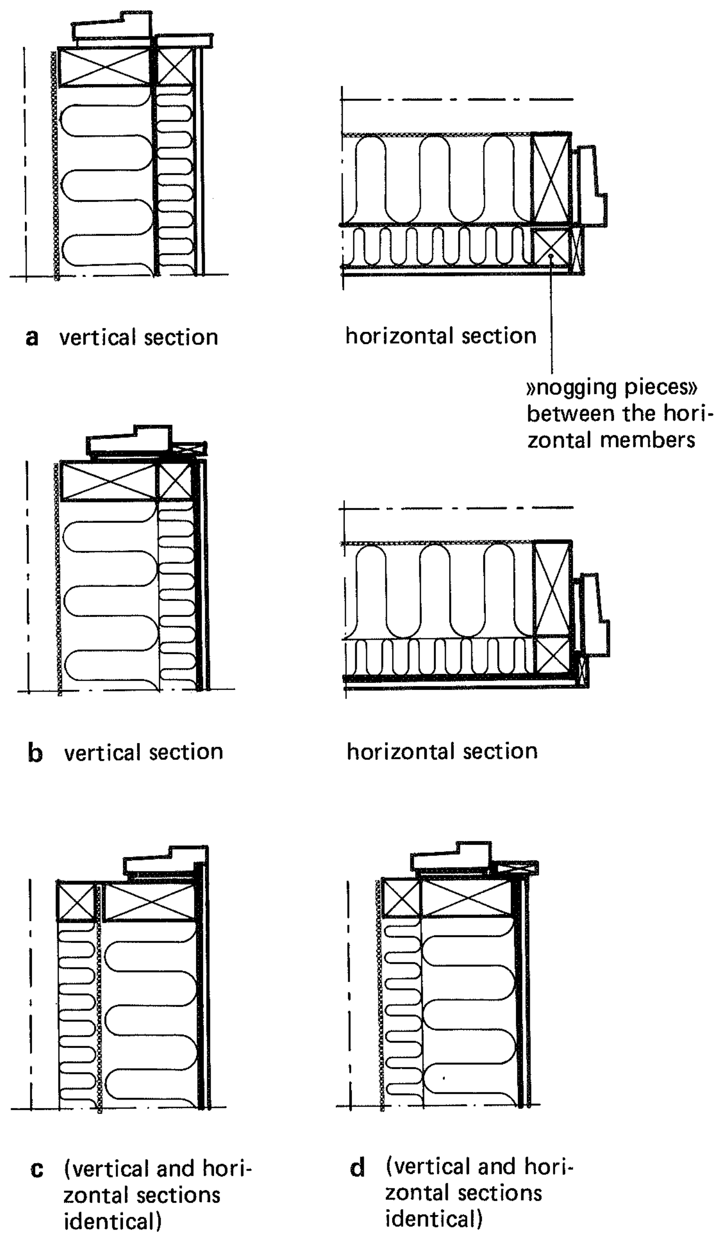


Figure 45. Jointing external walls with internal frameworks and inner walls. Horizontal section. The design assumes that insulation and sealing work is commenced before the internal wall is erected.

Figure 46. Principles for jointing frames and wall. Note that different methods for the actual joint sealing can be used (see the chapter »Joints materials and construction»). Airtightness is easiest and safest achieved if the air sealing in the wall and in the joint are in the same plane (figures a and b). Folding in the foil as illustrated in figure b can cause difficulty in achieving airtightness at corners.



frame – wall section it is best if the plastic foil can be drawn over the joint as well. Problems can occur where the window is not flush with the wall (figures 46a, b and d). At the »corners» it may be necessary to supplement the construction with tape etc. for this measure to be effective.

In the case of internal vertical framework members, no special difficulties are normally experienced apart from the fact that horizontal framework members must be positioned both above and below the window opening (figure 46d). Vertical and horizontal sections are identical for all intents and

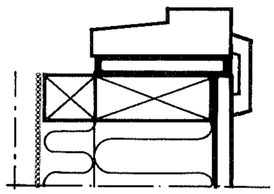


Figure 47. Joint between window frame and wall in places where the inner edge of the frame is flush with the inner edge of the wall. A special window lining is required.

purposes. A special solution is illustrated in figure 46c where the plastic foil is drawn over the frame and is clamped using the internal cladding sheet. A special frame is needed for this solution as is dimensional accuracy when erecting the frame.

In cases where the inner edge of the frame is in line with the inner edge of the wall, the window is mounted before the foil after which the latter is cut against the frame. This method assumes the use of packing which bridges the joint (figure 47).

We have not analysed in detail where the window is positioned in the wall. A number of factors which are outside the scope of this work dictate the positioning.

Pitched roofs

Pitched roof designs vary considerably. Rafters should be constructed so that sufficient space is left for insulation. Battens are often required as the construction may need to be supplemented with internal horizontal wooden framework members. In most cases, ventilation is necessary between the insulation/wind protection and the undercovering (figure 48). If the insulation is made up of normal mineral wool slabs, a wind protection of particle board is used which can be fitted using spacer blocks against the undercovering.

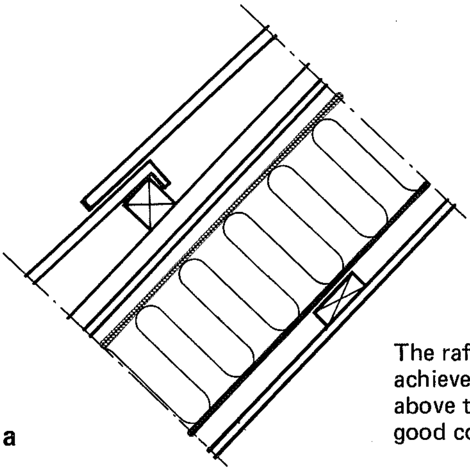
Another alternative is to use special mineral wool products with glued-on paper as a wind protection. In such cases battens are only needed to provide an air gap. However, a mandatory requirement when using this method is that the rafters have an exact centre-to-centre distance of 1200 mm and that they are erected squarely if the insulation and wind protection are to function efficiently.

Insulation work can be carried out both from the outside and from the inside. The latter is more convenient from a practical point of view but the risk of precipitation reaching the insulation is greater than if the insulation work is carried out from the inside when the undercover has been laid. Insulating from the inside is however less pleasant work bearing in mind falling dust from the mineral wool.

Figure 49 illustrates a particular solution in which the whole space between the vapour barrier/air seal and the undercover is filled with insulation. Thus there is no air space between the insulation and the undercovering. This construction has been used in trials with good results so far. Apart from a correctly constructed vapour barrier/air seal, this method assumes that the undercovering is sufficiently vapour pervious.

Column walls in dormer houses

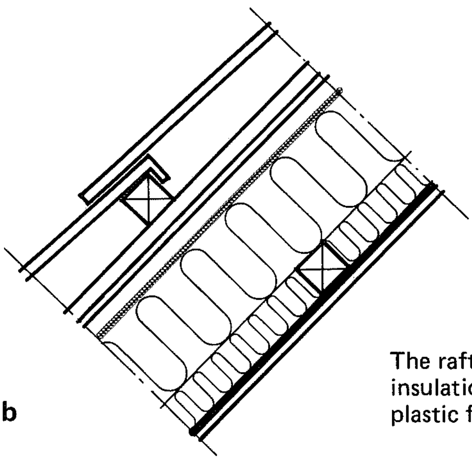
When building dormer houses, experience has shown that insulating and sealing work carried out externally in column



roof covering
undercovering
spacer battens for air gap
wind protection
mineral wool
vapour barrier/air seal
secondary spaced boarding
internal cladding

The rafter is spaced to allow sufficient insulation thickness. To achieve good insulation it is important that the plastic foil be placed above the secondary spaced boarding so that the mineral wool has good contact with the foil.

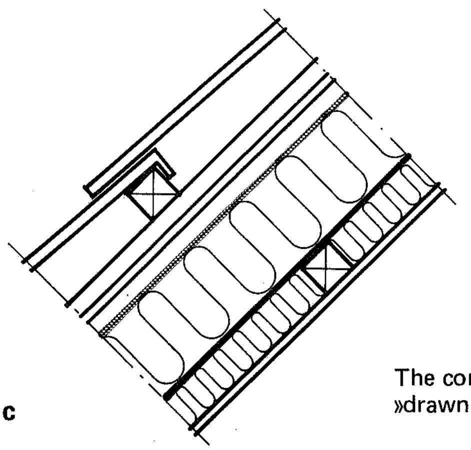
a



roof covering
undercovering
spacer battens for air gap
wind protection
mineral wool
mineral wool between horizontal battens
vapour barrier/air seal
internal sheet cladding

The rafter is supplemented with horizontal battens to give sufficient insulation space. The insulation is made up of two layers and the plastic foil is placed next to the internal cladding.

b



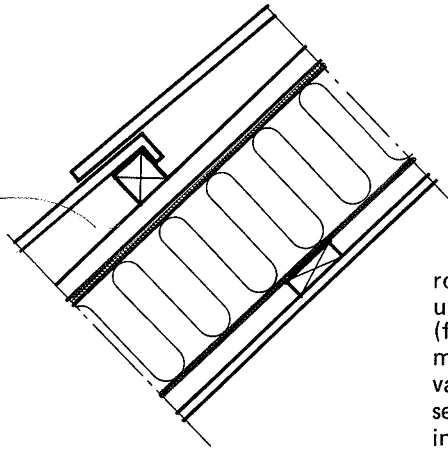
roof covering
undercovering
spacer battens for air gap
wind protection
mineral wool
vapour barrier/air seal
mineral wool between battens
internal sheet cladding

The construction principle is the same as in b but the plastic foil is »drawn in» into the insulation.

c

Figure 48. Common pitched roof constructions in dormer houses.

Figure 49. A special pitched roof design. Using this method, there is no air gap between undercovering and insulation. During trials this construction has functioned admirably. It assumes that the vapour barrier/inner airtightness is perfect — no damage can be accepted. Furthermore the under-covering must be watertight, e.g. by using non-jointed particle board sheets or by careful overlapping at the joints using such sheets. The roof covering should not allow too much water to penetrate. Using this method the rafter need not be supplemented for sufficient insulation thickness.



walls is difficult. This is particularly the case where one beam is drawn up to the top plate and the next beam is alternated with the brace (figure 50). The distance between beams is too great to be able to stand on them and work.

This means that the walls should be insulated from the inside. This means either that a single insulation layer is used or that the construction is complemented with an internal framework system. In this case it is possible to insulate using two layers. Very often the vapour barrier — plastic foil has been laid between the two layers of insulation (figure 51).

However it must be possible to fit wind protection of slab material from the outside and this demands careful work planning.

Vertical beams in brace walls normally have the same centre-to-centre distances as the rafters, namely 1200 mm. On the inside, this distance is too large to support the inner cladding and secondary spaced boarding or internal framework systems with horizontal members are used. Particular difficulties arise when joining to gable walls.

Figure 50. Alternating floor joists. Among the advantages of alternating, as illustrated in the figure, is that only half the number of holes need be made in the plastic foil.

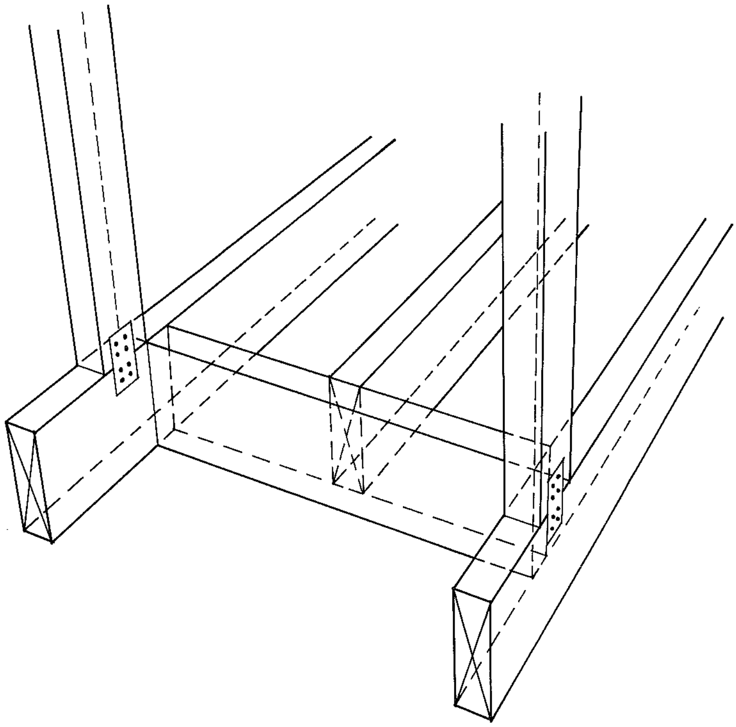
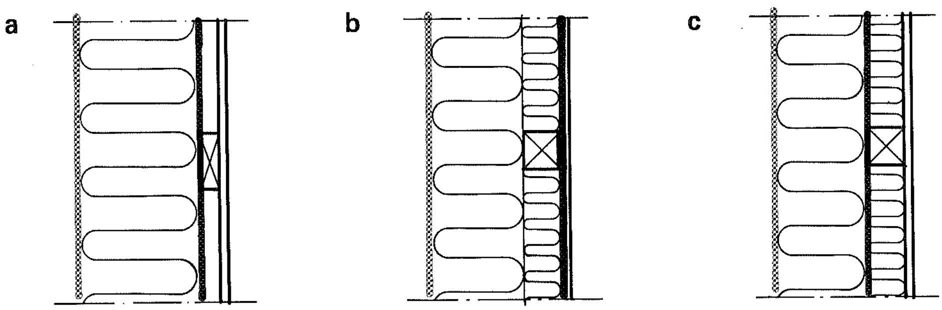


Figure 51. Different construction alternatives for brace walls.



a

wind protection
insulation between load-bearing beams, centre-to-centre 1200 mm
vapour barrier/air seal
secondary spaced boarding
internal sheet cladding

b

wind protection
mineral wool between vertical beams
mineral wool between horizontal beams
vapour barrier/air seal
internal sheet cladding

c

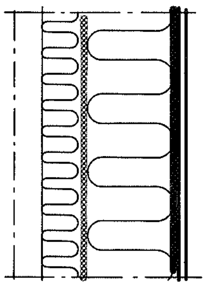
wind protection
mineral wool between load-bearing beams, centre-to-centre 1200 mm
»drawn in» vapour barrier/air seal
mineral wool between horizontal beams
internal sheet cladding

Figure 52. Gable head constructions in dormer houses. The constructions mostly agree with the corresponding wall constructions.

Gable heads in dormer houses

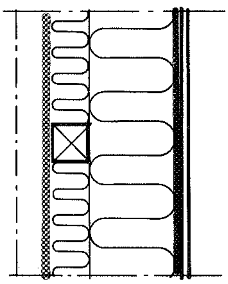
The construction of gable heads agrees in principle with the corresponding external wall constructions.

a



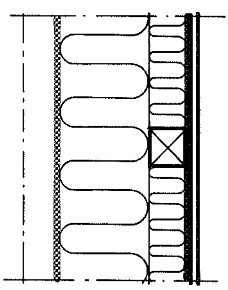
facade cladding
air gap
fully fitted insulation slab
with wind-sealing paper
mineral wool between beams,
centre-to-centre 600 mm
(or centre-to-centre 1200 mm)
vapour barrier/air seal
internal sheet cladding

b



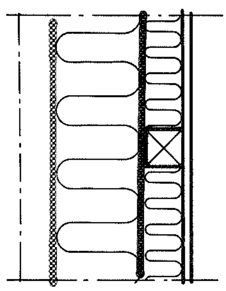
facade cladding
air gap
wind protection
insulation between external
horizontal beams
mineral wool between load-
bearing beams
centre-to-centre 600 mm
(or centre-to-centre 1200 mm)
vapour barrier/air seal
internal sheet cladding

c



facade cladding
air gap
wind protection
mineral wool between beams,
centre-to-centre 600 mm
(or centre-to-centre 1200 mm)
mineral wool between internal
horizontal beams
vapour barrier/air seal
internal sheet cladding

d



as in c but with »drawn in» foil

Jointing gable heads, gable walls and intermediate joists

These constructional details can be done correctly in a number of ways from an insulation aspect (figures 53, 55–57). Where airtightness is concerned, one should attempt as early as the planning stage to position the plastic foil in the same plane as the gable head and the gable wall. Continuity in the foil layer when joining is achieved by placing a strip of foil outside the outermost floor joist in the intermediate joist structure when erecting the shell. Figure 54 shows an example of erection technique for a construction with a prefabricated gable head. The internal sheet cladding is however erected on the building site. Using the solution illustrated in figure 54 it is preferable to have a special joint seal between the wall and the gable head. This strengthens the continuity of both the wind protection and the vapour barrier/air seal.

The intermediate joist structure can be filled with insulation in the frame next to the external wall. This reduces the risk of a cold floor in the upper section of the house. Apart from this a certain amount of insulation in the intermediate joist structure is necessary for fire protection and acoustic insulation.

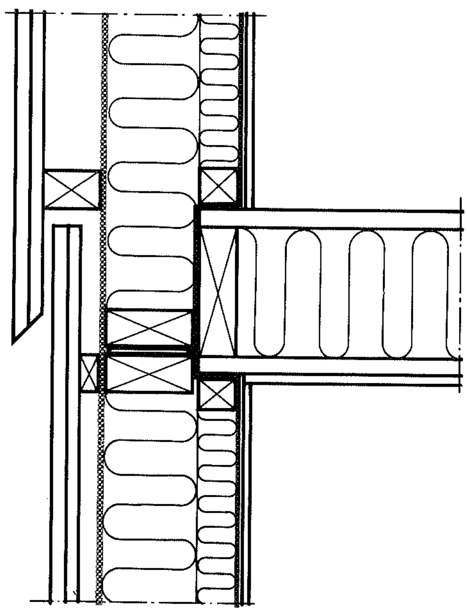


Figure 53. The joint between gable head, gable wall and intermediate joist structure in a wall construction with an internal horizontal framework system. The assembly procedure is shown in figure 54.

Figure 54. Working procedure for fitting plastic foil in the case of the design solution illustrated in figure 53. The plastic foil strip (1) is laid and fixed on the top plate when the floor joists are constructed. The plastic foil strip (1) is then folded out onto the floorboard and is temporarily attached to the secondary spaced boarding. The plastic foil in the lower floor (2) and the upper floor (3) is fitted after which the plastic foil around the intermediate joist structure is folded up and down respectively on the wall (4 and 5), and is taped where necessary (6). Airtightness is ensured since the joints are clamped behind the internal sheet cladding. If the cladding sheets are tightly nailed as well, or even better screwed, taping is unnecessary.

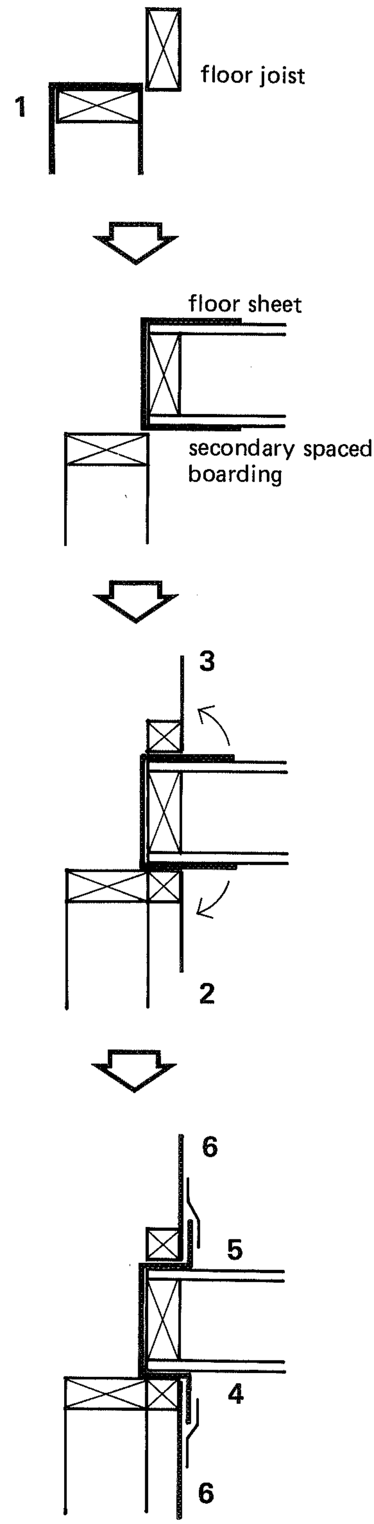
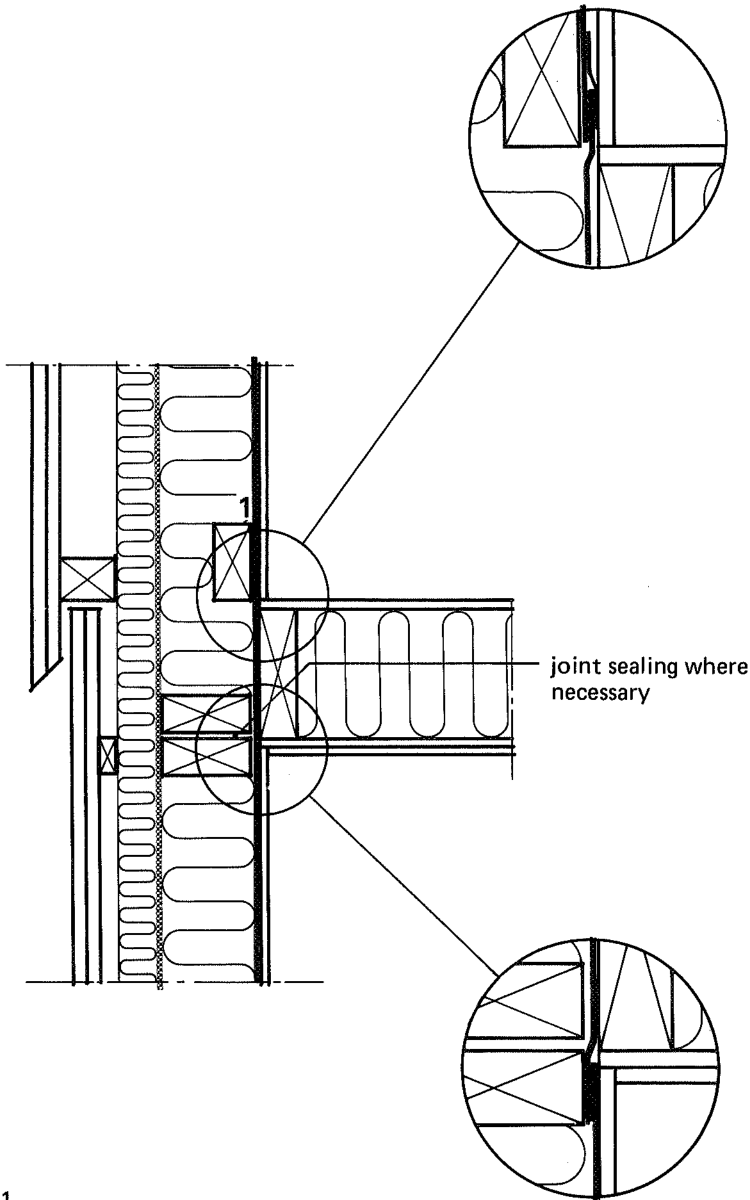


Figure 55. A joint between gable head, gable wall and intermediate joist structure in the case of a wall construction with »external» mineral wool slab. When constructing the shell, a plastic foil strip is placed around the intermediate joist structure against which the wall foil can be sealed. The design and working procedure agree in principle with figure 54. This method is suitable when prefabricating gable heads.



[1] The nogging piece commonly used is less suitable from an insulation point of view. It should therefore be replaced by a sheet metal profile to which internal cladding and possibly a skirting board can be attached.

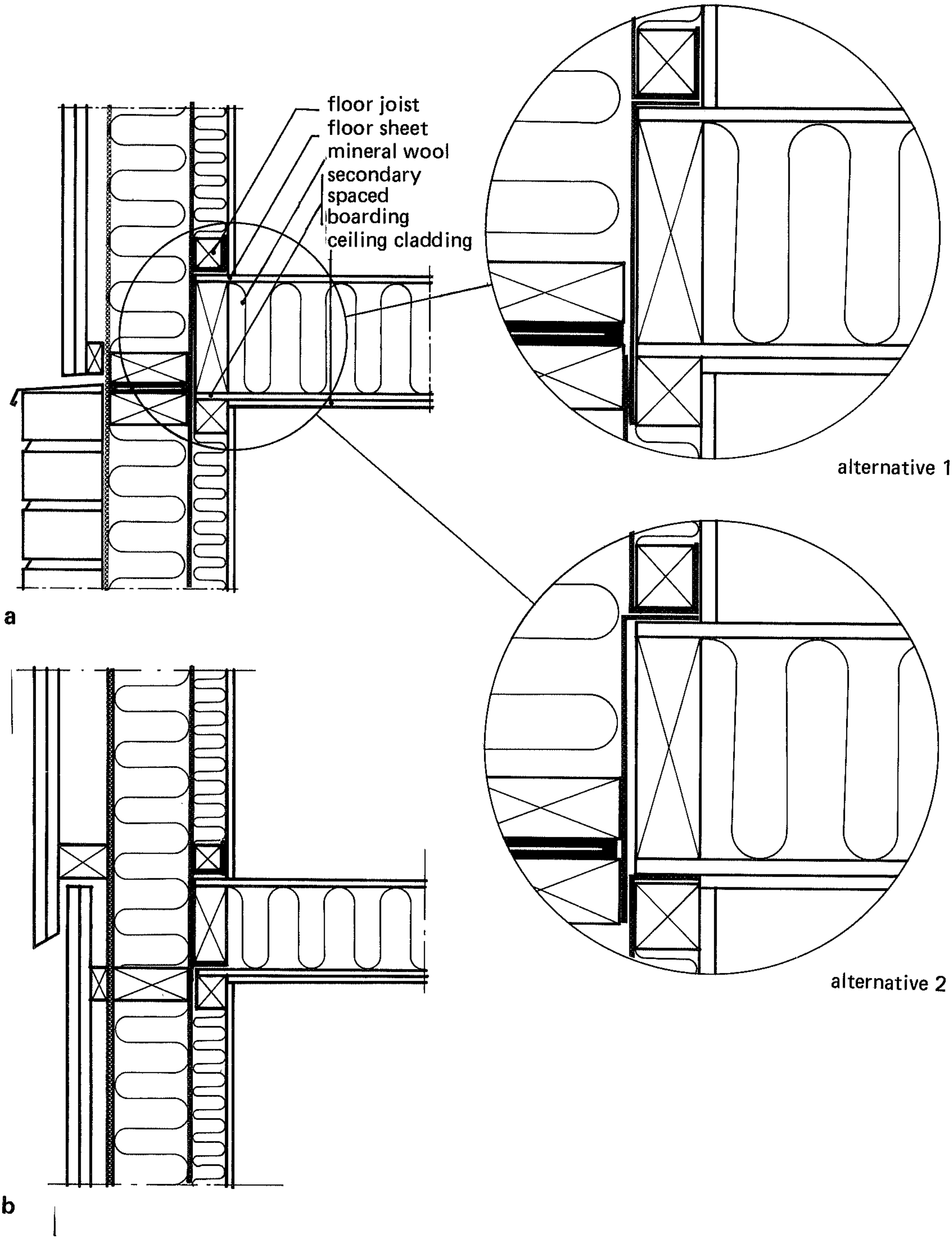
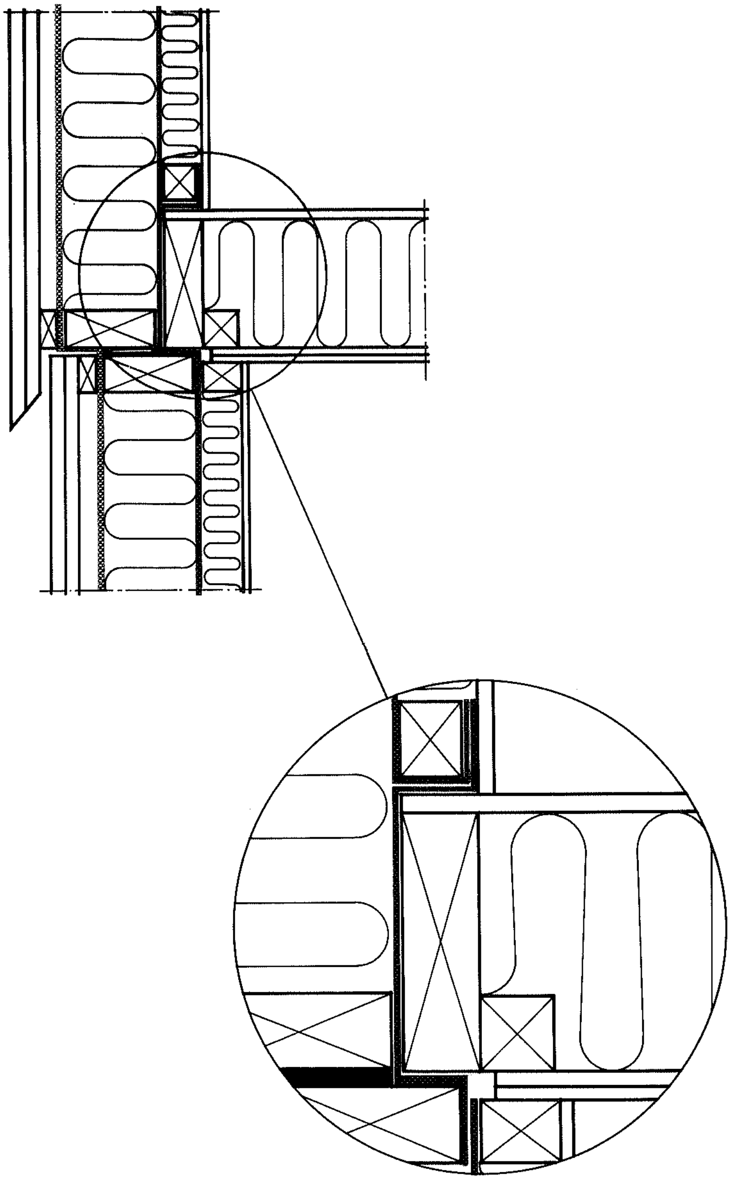


Figure 56. Joint between gable head, gable wall and intermediate joist structure in the case of a wall structure with »drawn-in» foil.
a. Masonry facade in the ground floor and wooden facade at the gable head.
b. Wooden facade throughout. This solution can be used for on-site construction. In this case it is possible to use unbroken wall beams which go all the way up to the outside roof. Using this solution the continuity of the vapour barrier/air seal is achieved most easily if a foil strip is laid between the intermediate joist structure when erecting the shell (figure 55).

Figure 57. A certain amount of displacement between the wall in the bottom floor and the gable head is not uncommon. This complicates the work of producing the air-sealing layer somewhat but in the main the foil can be laid in the same way as illustrated in figure 56. It is advisable to fill the outside frames in the intermediate joist structure with insulation in order to compensate for thermal bridges and also to reduce discomfort which can possibly be caused by minor leakages in the air seal. This construction allows more natural jointing of wooden facades.



Jointing gable heads and roof trusses in dormer houses or jointing gable heads and attic joist structures in 1- and 2-floor houses

In site-built constructions, airtightness is best achieved by overlapping plastic foil and clamping it against the hip. However investigation work has shown that difficulties often occur in achieving good continuity of the wind protection.

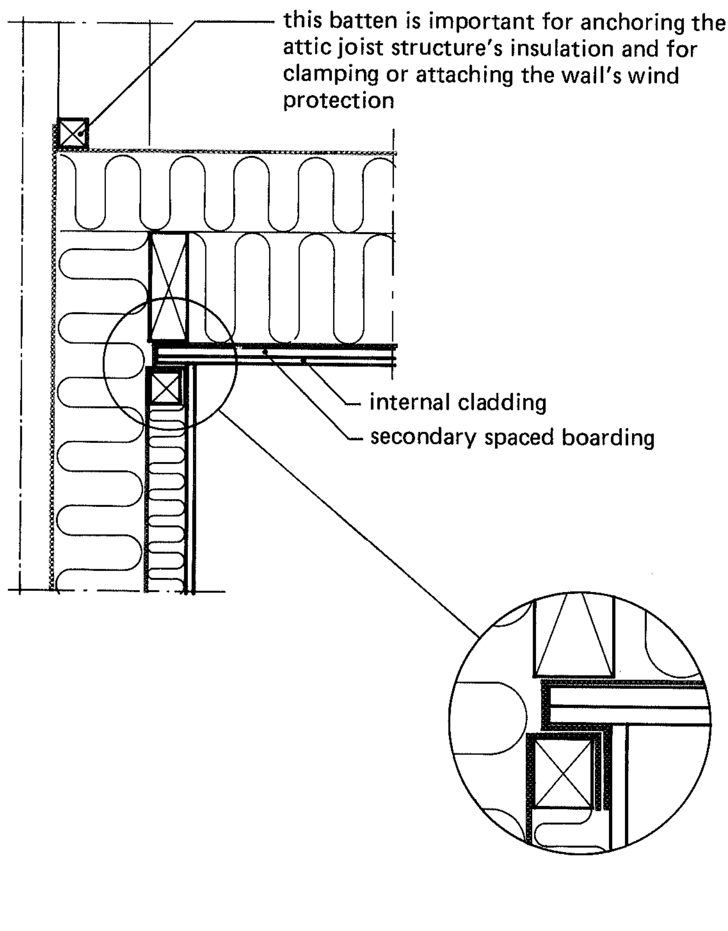


Figure 58. Jointing gable heads and roof trusses in dormer houses. The same solution can be used for jointing gable walls and attic joist structures in 1- and 2-floor houses as well. The foil in the joist structure is fitted before the foil in the wall. The overlap from the ceiling must be attached temporarily against the ceiling whereas the wall construction is supplemented with foil, internal horizontal members etc. The foils are folded down so that overlap and clamped seals are obtained when the internal sheet cladding is fitted.

Figure 59. Jointing gable heads and roof trusses in dormer houses. When the insulation is carried out from the attic the requirements for worker protection with regard to stepping through the insulation must be observed. This affects both the foil quality and the assembly method.

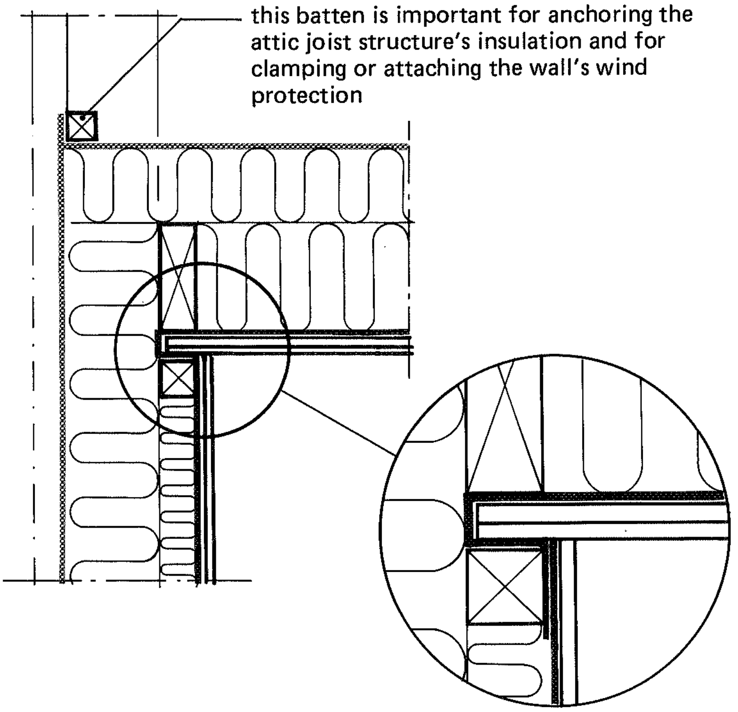


Figure 60. Jointing gable heads and roof trusses in dormer houses, design solution with external rigid mineral wool slabs in the wall. Nogging pieces are common but do not contribute to good insulation. In such cases it is better to use a rigid angle profile of paper or sheet metal. (Many use neither, and only tape or nail the internal sheet. This solution is however less suitable.)

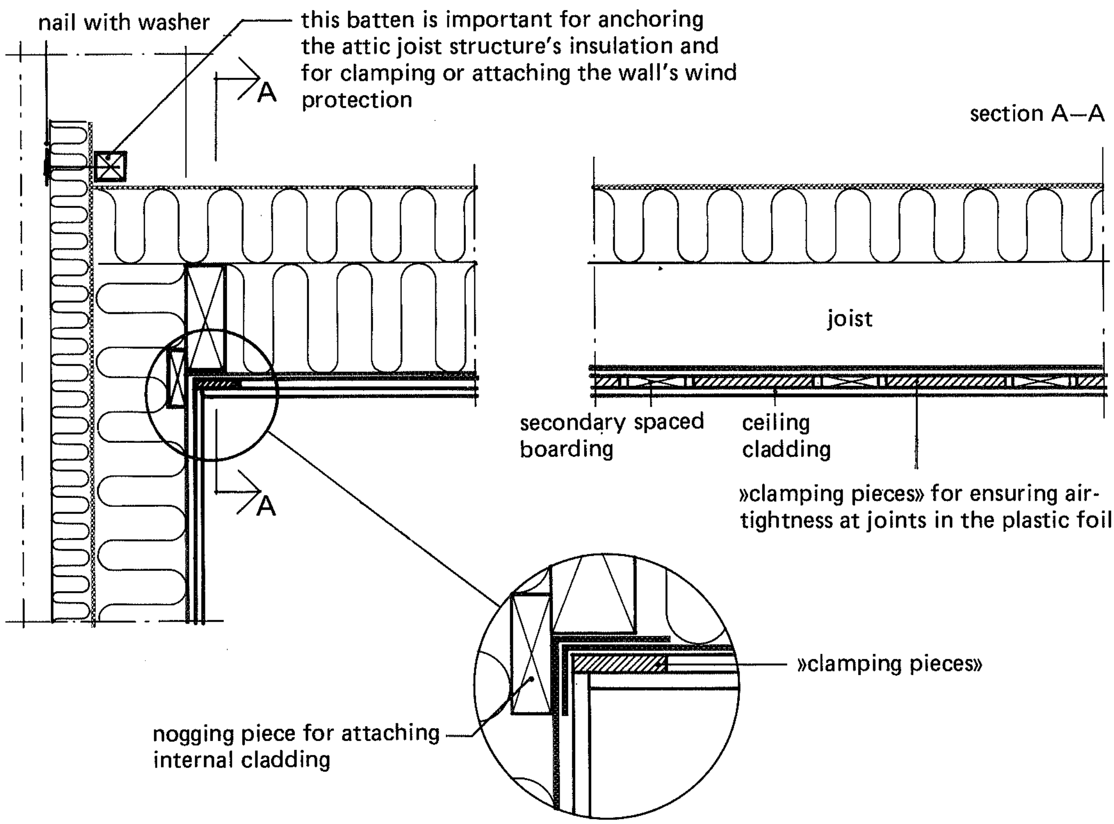
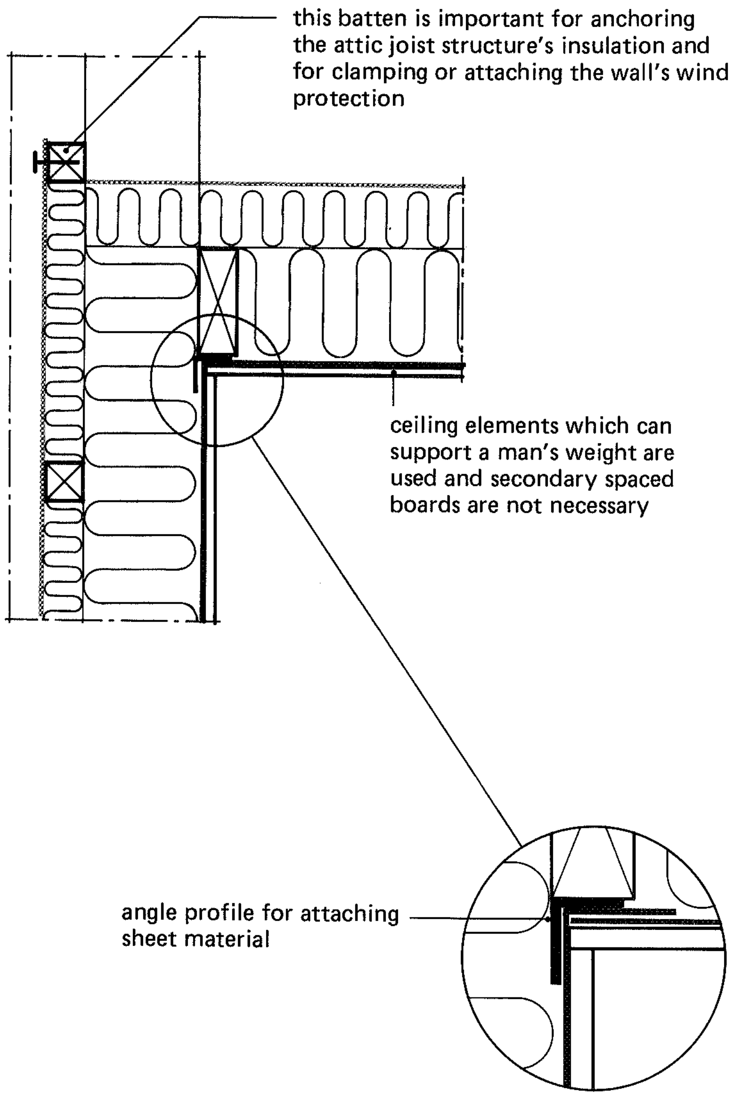


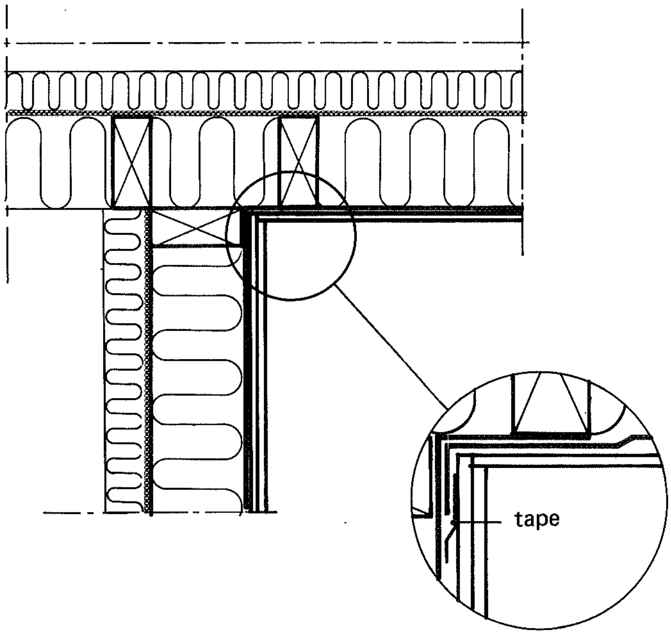
Figure 61. Jointing gable heads and roof trusses in dormer houses. An angle profile replaces the »nogging pieces» for attaching internal cladding sheets on the wall. The vapour barrier/air seal should be overlapped against the ceiling joist in order to achieve good clamping. The wall foil must be fitted before the ceiling element.



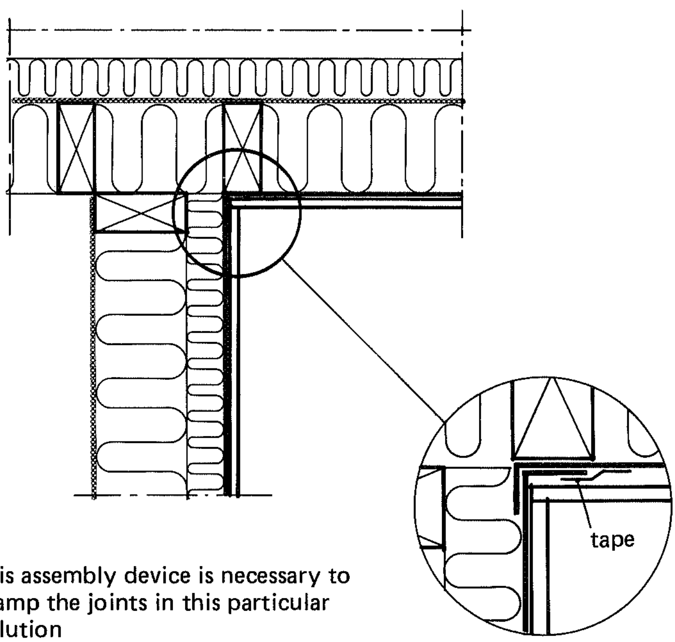
Jointing gable heads and column walls

This item is seldom shown on drawings. Investigation work has shown however that many inferior solutions are used on building sites.

Figure 62. Jointing gable heads and support walls. Horizontal sections for the different outer wall and column wall constructions.

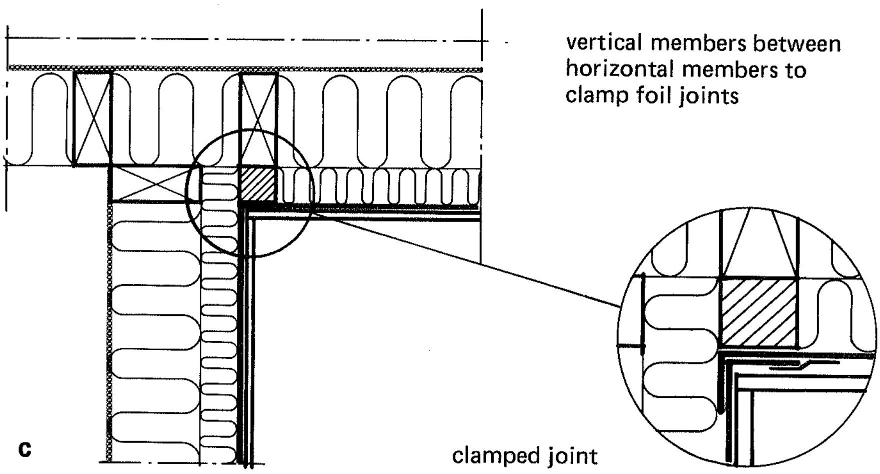


a

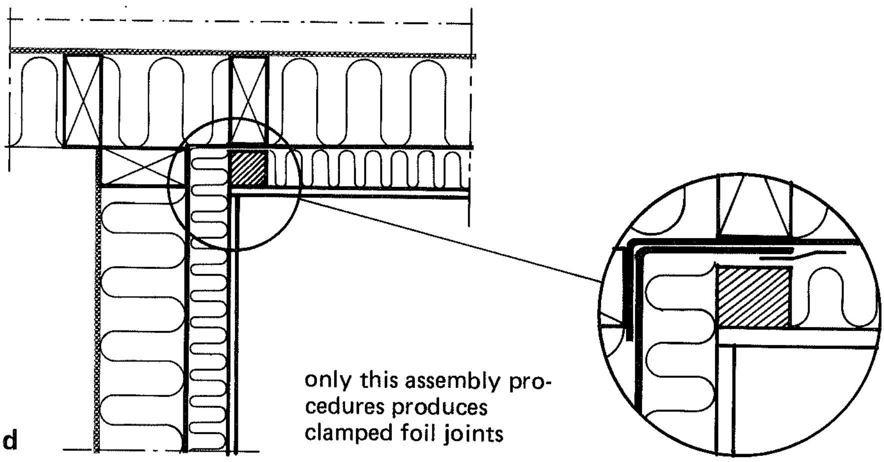


b

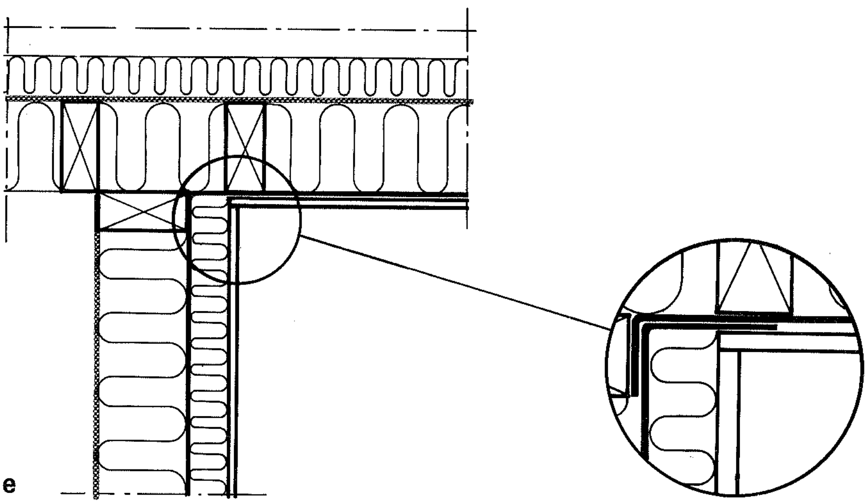
The internal cladding sheet on the column wall is not supported continually at the corner. If the horizontal members are close together, e.g. 400 mm centre-to-centre, support will probably not be needed. If support is needed, nogging pieces or angle profiles of sheet metal or paper are used. This also applies to figures c—e.


vertical members between
horizontal members to
clamp foil joints
clamped joint

c


only this assembly pro-
cedures produces
clamped foil joints

d



e

Jointing brace walls and pitched roofs

This item does not normally cause any significant problems. The assembly procedure must however by observed carefully particularly if the foil is drawn into the insulation layer in the braces and/or pitched roof. Often a practical solution is to join the foil here. Accuracy is needed when clamping the joints.

Mineral wool insulation should not be jointed at the actual intersection. The risks for spaces and gaps without insulation are great in that cases. Instead the insulation must be fitted continously at the intersection (figure 63c).

Accuracy is needed when jointing sheetings for wind protection at the actual intersection. Overlaps and special attachment battens may be necessary.

Eaves

In these solutions, great importance has been placed on ensuring continuity in both the insulation, wind protection and airtightness. It is important to design the eaves to leave sufficient space for insulation. This may require special reinforcement at the base of the eaves.

Energy questions should be given priority in relation to the static dimensioning of the actual roof trusses, particularly at this intersection. Experience clearly shows that faults appear quite commonly in this particular constructional detail in both air sealing, thermal insulation and wind protection. The reason is often that insufficient space is allowed for insulation.

When selecting insulation thicknesses for roof joist structures, it is very important that the insulation laid between the roof trusses has the same thickness as the height of the roof truss beams. Subsequent layers of insulation can then also cover the truss beams. Thermal bridges are reduced as is the risk of complete gaps in the insulation layer. In order to achieve good insulation work, the roof trusses must be erected accurately.

According to our field work, continuity in the wind protection is best and simplest achieved if both the wall's wind protection and the joist structure's insulation (with paper) is attached with a special wooden strip at the eaves. Solutions where the insulation matting is drawn down and attached to the wall often produce inferior results. This is because the wind protection against the truss beams is less acceptable using this method.

Figure 63. Jointing brace wall and pitched roof.

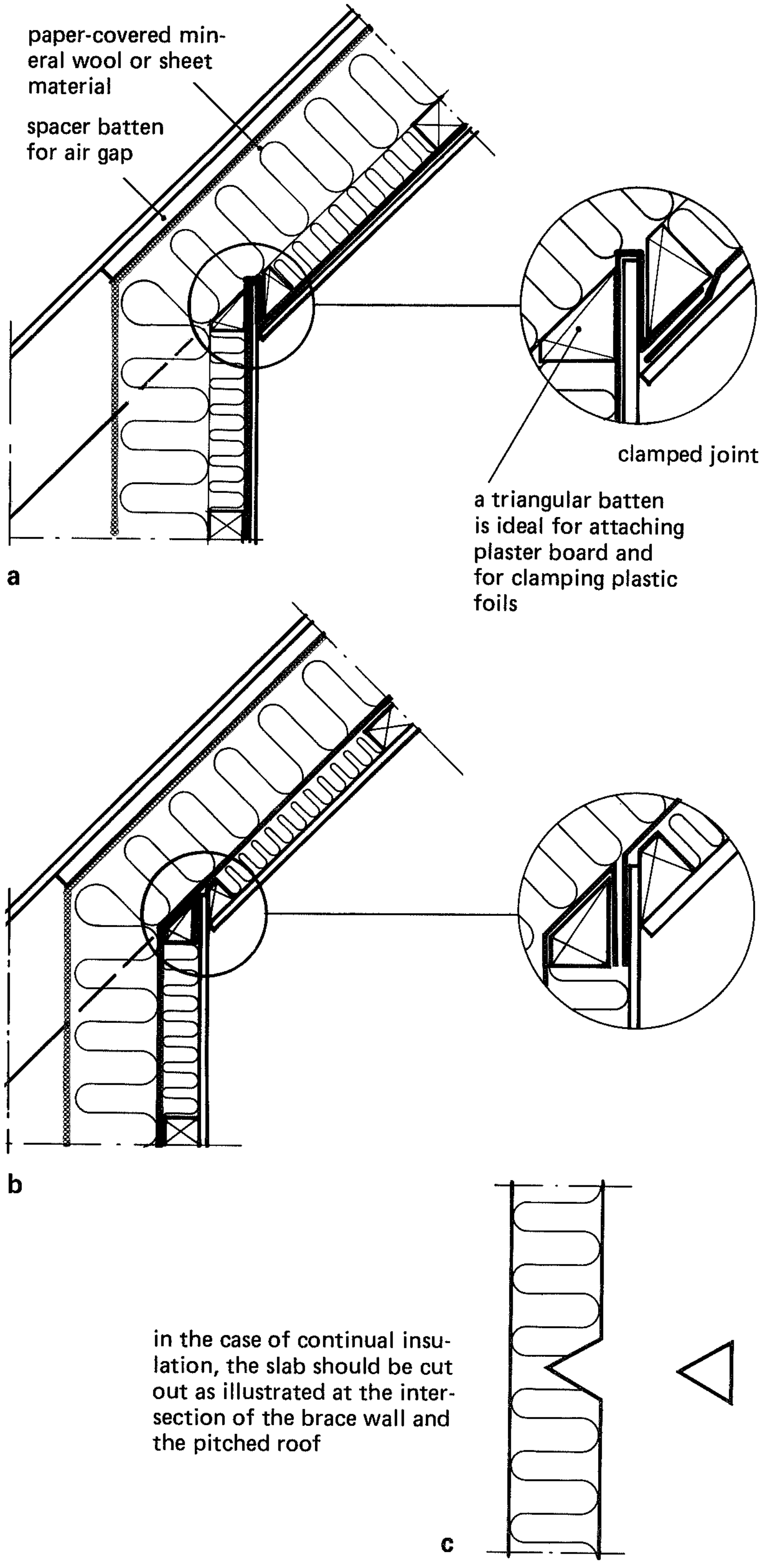
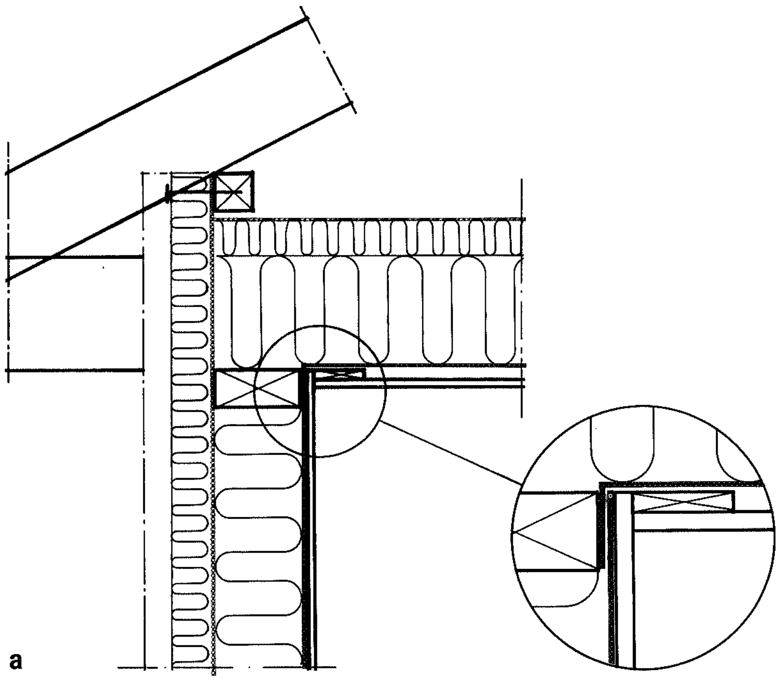


Figure 64. Solutions for eaves. The foil in the ceiling must be fitted before the wall foil so that an overlap is obtained at the joint. This overlap can then be clamped and sealed along the whole of its length.



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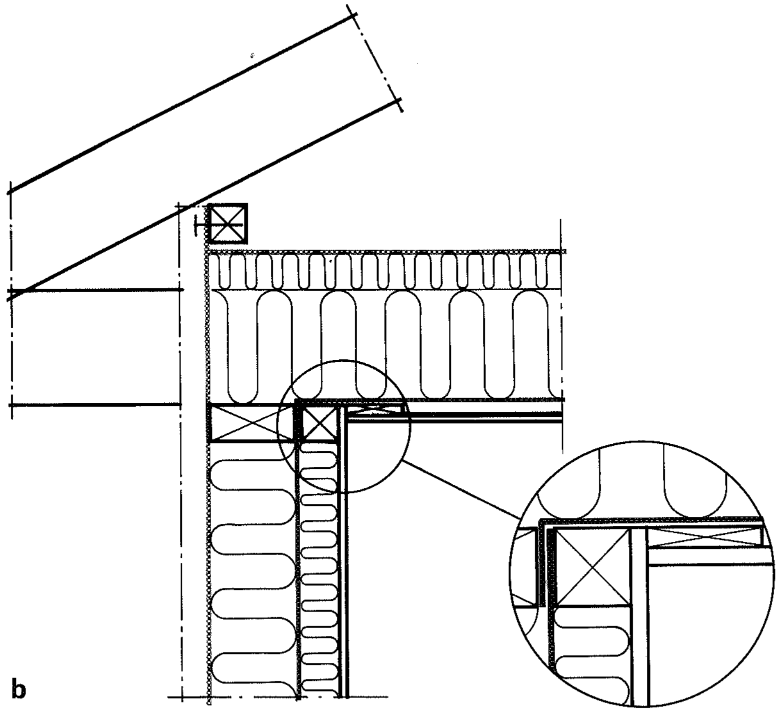

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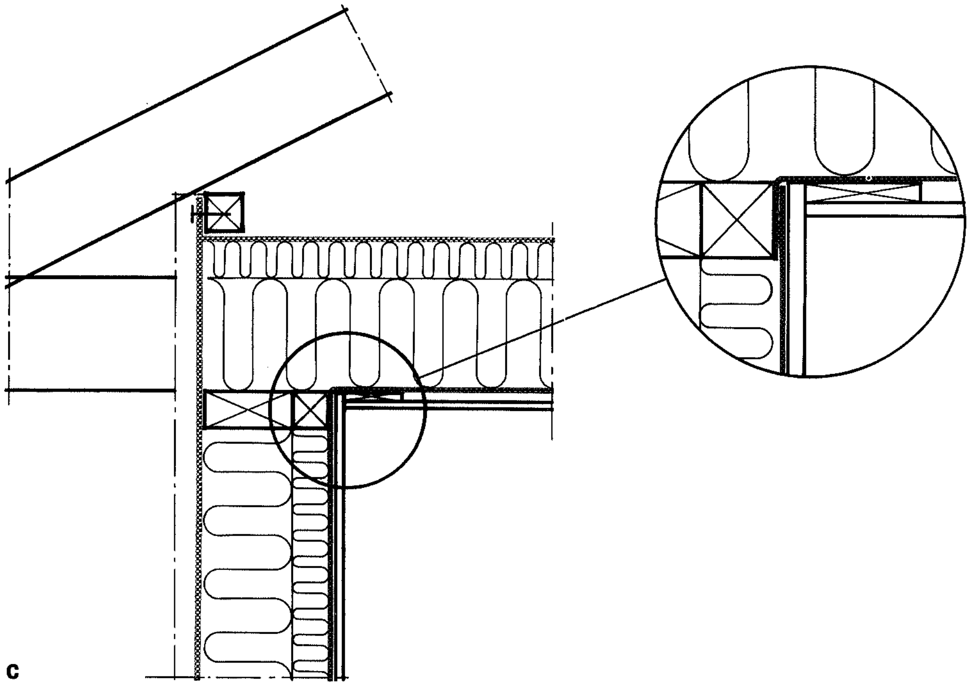

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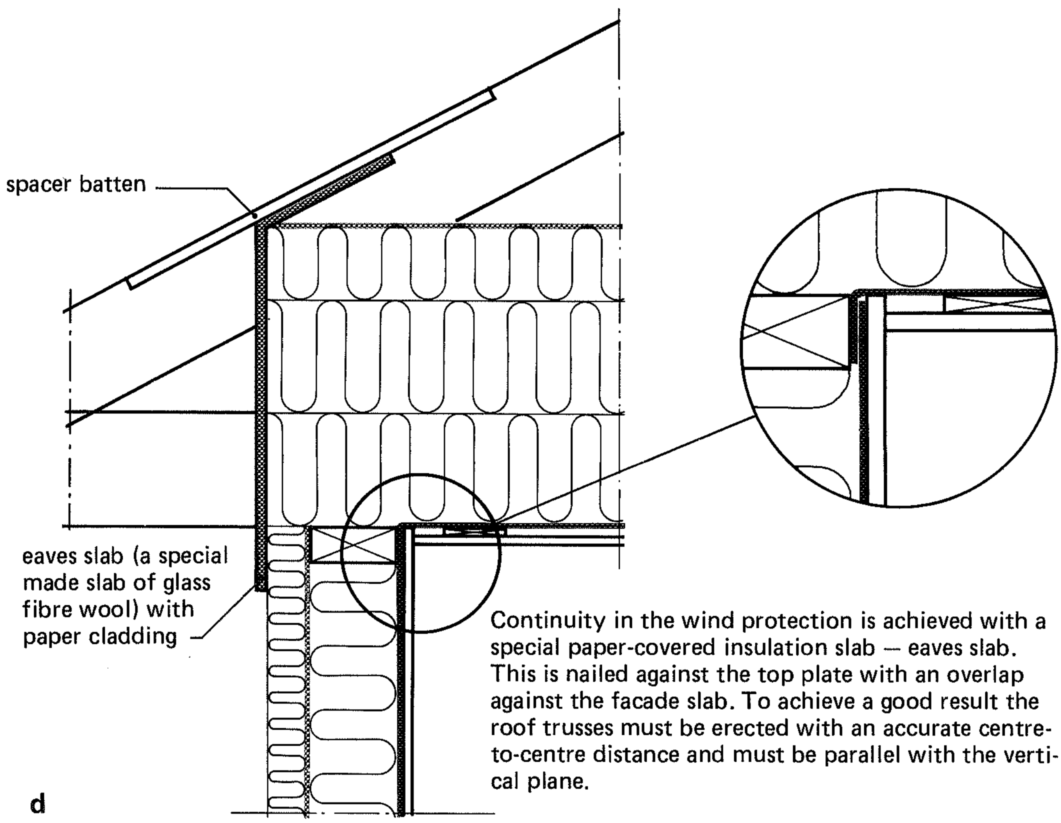


d

Continuity in the wind protection is achieved with a special paper-covered insulation slab – eaves slab. This is nailed against the top plate with an overlap against the facade slab. To achieve a good result the roof trusses must be erected with an accurate centre-to-centre distance and must be parallel with the vertical plane.

Jointing brace walls and intermediate joist structures

In most cases, this is the most complicated detail from an air-tightness aspect. A number of different solutions have been applied.

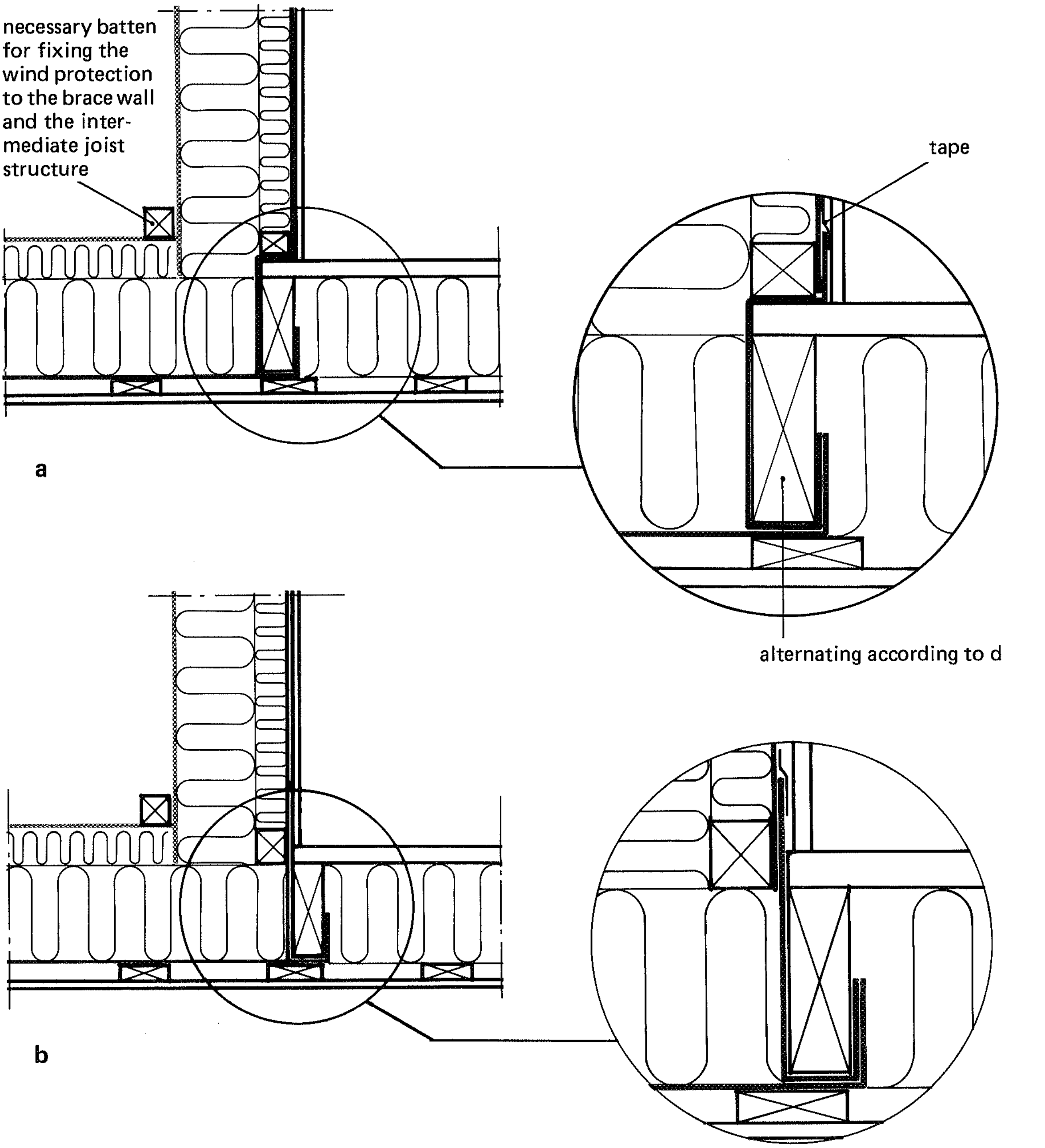
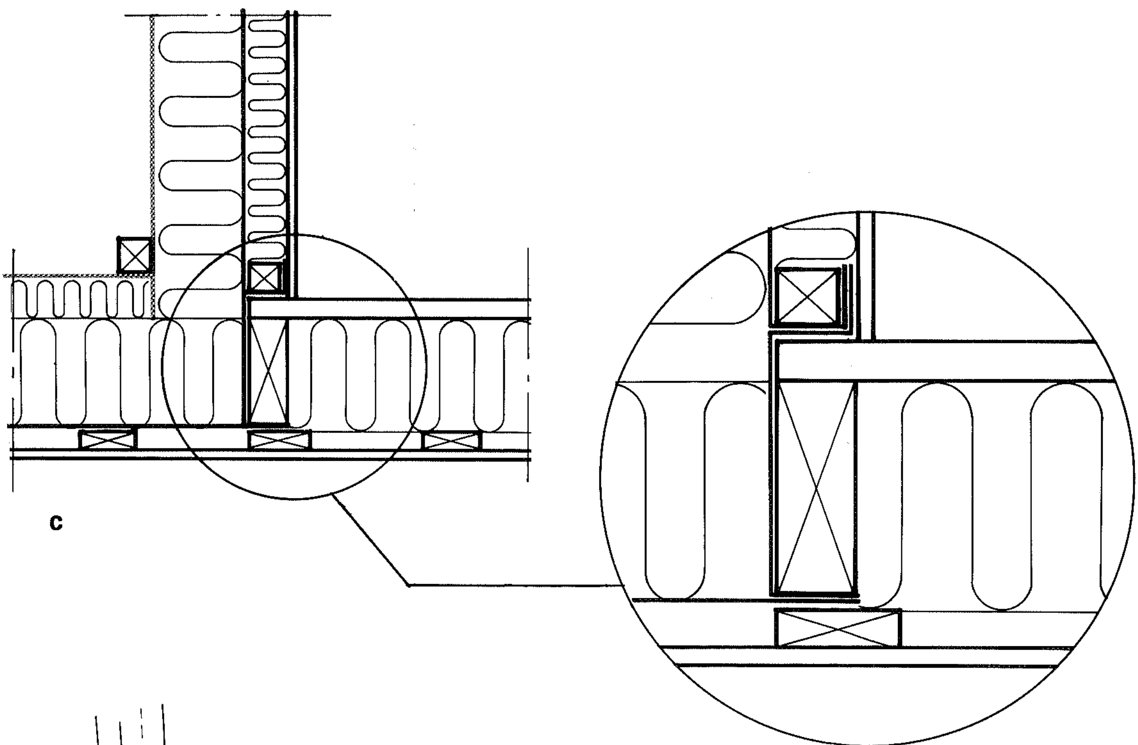


Figure 65. Jointing brace walls and intermediate joist structures in dormer houses. Here the joists have been alternated at the column wall. The number of joists which pass through the sealing layer can be reduced in this way.

As extra security against cold floors on the upper floor, the intermediate joist structure can be filled with insulation material in the vicinity of the brace wall. Because of the difficulties in erecting this joint, new truss constructions are coming into practice. In such cases the brace wall has been removed and the rafter insulated down as far as the eaves.



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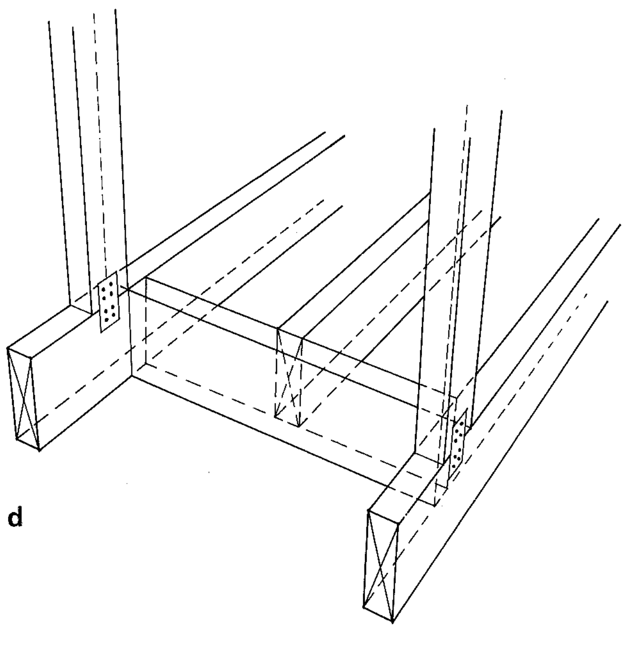

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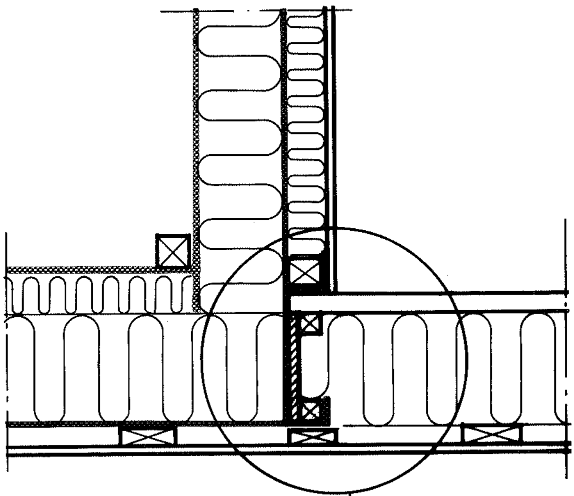
Alternating floor joist in the intermediate joist structure is a condition for the solutions illustrated in a–c. This alternation can be seen to have a number of advantages for achieving good airtightness. One example is the reduction of the number of joist transitions by half. Furthermore alternation helps prevent blow-through in the intermediate joist structure.

Figure 66. This solution is based on traditional designs. Airtightness between the intermediate joist structure is achieved by positioning sheets between the joists as a support for the plastic foil. Sheets with battens can be prefabricated providing the distance between joists is the same. So far it has been considered necessary to take the plastic foil around the joists. The design demands extra accuracy during the actual erection work.



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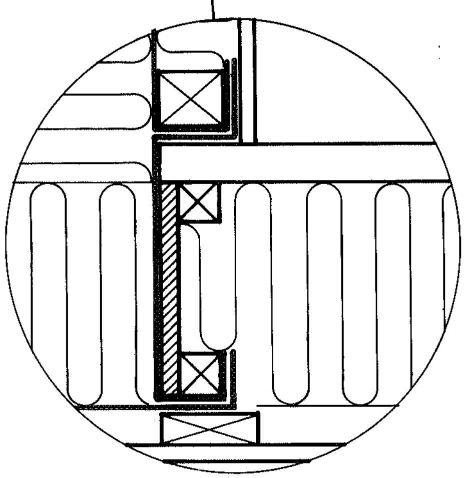
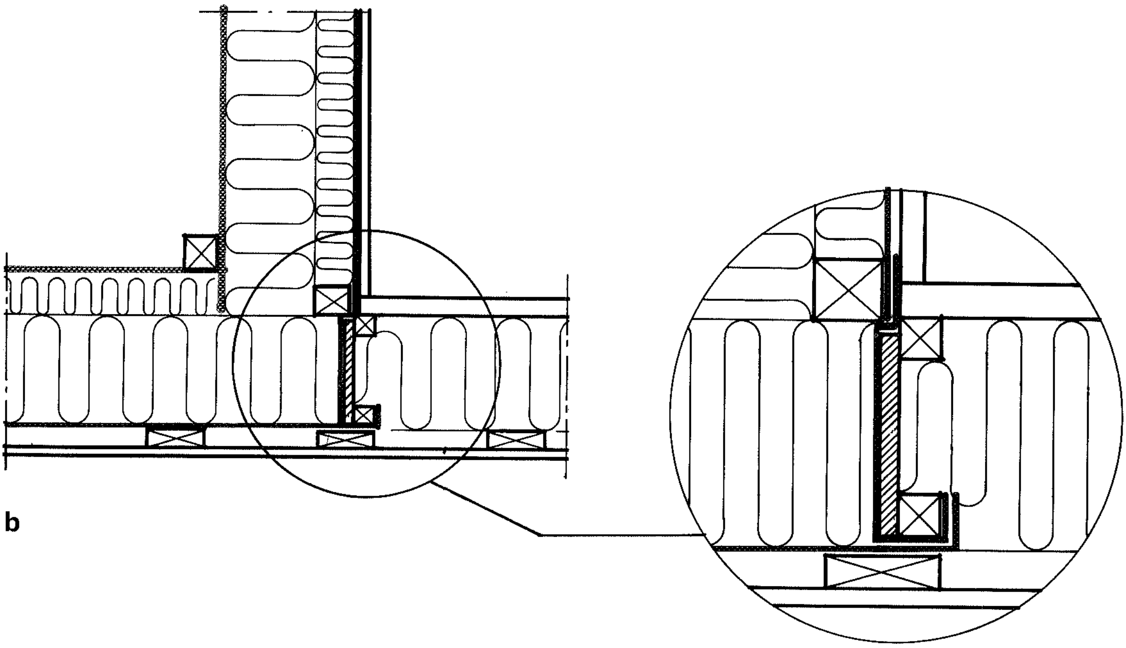


for airtightness it is important that a secondary spaced board strip »clamps» the foil overlap



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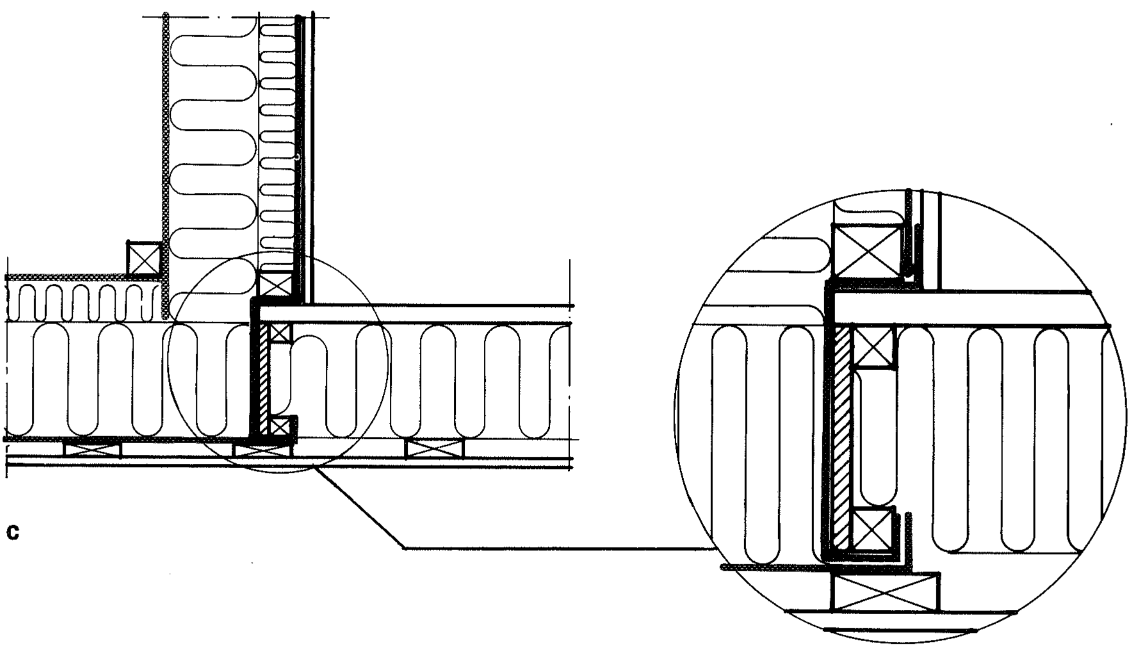


c

Edge beams

Joints at sills and at ground level slabs

Joist edges can give rise to considerable thermal bridges and it is extremely important to eliminate the effects of these. Figure 67 illustrates a few solutions which fulfill the requirements in SBN 1975 with regard to the insulation of edge beams and, when properly constructed, reduce discomfort caused by thermal bridges.

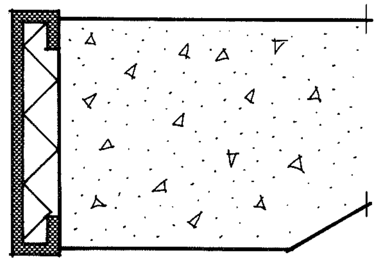
The upper section shows a construction with a highly-insulated edge beam element of cellular plastic and fibre concrete or cellular plastic and wood wool. The wood wool slab in this case provides a place for plastering the skirting. The parts also function as a permanent mould. They insulate the whole of the external face of the concrete. Finished skirting surfaces are available in certain elements.

The next section shows a different version with light ballast concrete blocks. Relatively large thicknesses are necessary for satisfactory insulation. The blocks function as a permanent mould and cover the whole of the concrete surface. The surface must however be grouted in order to reduce the effects of wind in the light clinker block.

The bottom section in figure 67 shows mineral wool slabs positioned in supports in the edge beam and bonded in place. They do not cover the whole of the concrete surface and leave a certain amount of concrete uninsulated. This method requires particularly good working procedures. The solution is applicable to external walls with brick facades. The brickwork can be supported on the external concrete edge in this case.

Apart from this there is a number of specific products and methods which fulfills the requirements in SBN 1975. It is often quite common to use a cast-in heater cable to increase the surface temperature of the floor adjacent to the external wall. An improvement in comfort is also achieved using hot water heating systems if the heater pipes are placed in the skirting board along external walls. Bearing in mind that joist structure edges nearly always produce a severe thermal bridge, it is very important that air leakage is prevented at the intersection between internal walls and joist structure. Such air leakages rapidly lead to discomfort. Methods for sill sealing are given in the chapter »Joints — materials and construction», figure 23.

Figure 67. Examples of design solutions for edge beam insulation. (Insulation above or below the concrete slab is not shown in the figures.)
a. Edge beam element of fibre or cellular plastic.
b. Edge insulation of light clinker concrete with plastered skirting.
c. Edge insulation with cast-in mineral wool. (Insulation is kept in place with special supports.)



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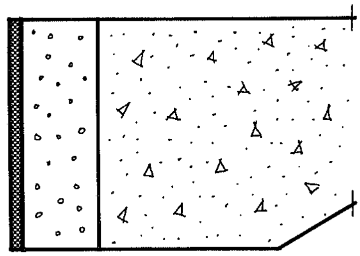

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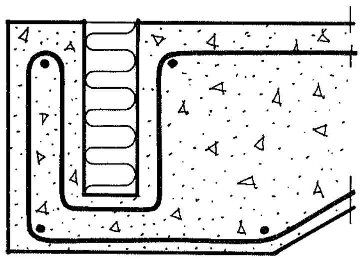


c

Figure 68. Jointing sills and outer walls with brickwork facades. The brickwork is supported on the concrete edge. A damp course of paper or possibly sheet metal should be fitted under the brickwork. It should be drawn up about 200 mm on the wall, possibly behind the wind protecting sheet material. The fourth supporting joint is not cemented in the first and third brick courses. Drainage openings in the bottom course are necessary — at least in the areas exposed to driving rain. Openings further up can possibly facilitate drying out of the brick wall after driving rain.

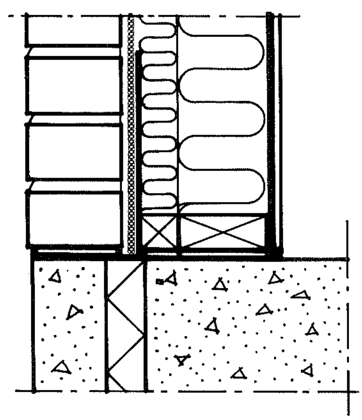


Figure 69. Example of a joint between wooden wall and concrete slab. The facade panel is extended so that it covers the joint. The concrete slab is insulated on the underside.

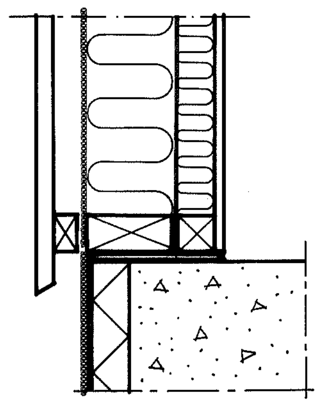
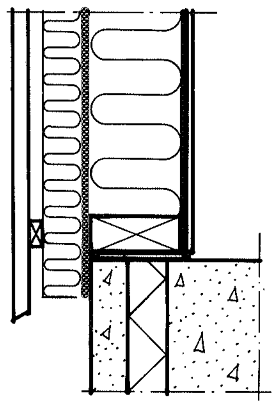


Figure 70. Example of a joint between a wooden wall and a concrete slab. In this case, where the wall has an external mineral wool slab, the latter is allowed to extend over the skirting. This reduces the thermal bridge at the skirting.



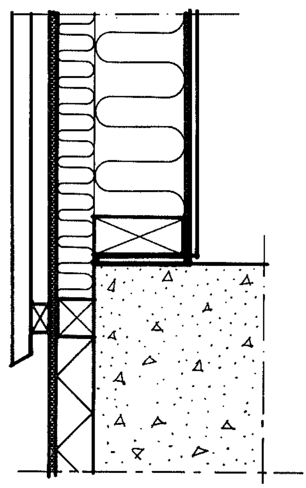


Figure 71. Example of a joint between a wooden wall and a concrete slab. The external insulation extends over the skirting. The wind protection, e.g. asphalt board, is jointed with the skirting sheet using fibre concrete for example.

Figure 72. A joint between a wooden wall and a concrete slab with insulation on the upper surface. Using this solution the plastic foil on the wall is drawn in under the floor insulation in order to ensure airtightness. Even if the concrete slab is insulated on the upper side, skirting insulation is necessary.

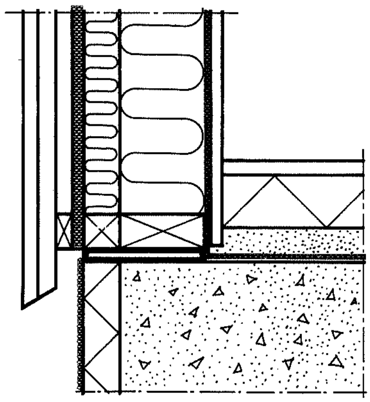
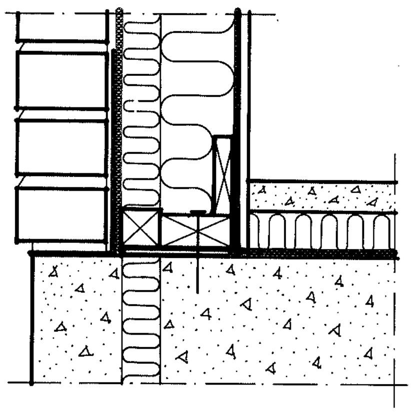


Figure 73. An example of a joint between an outer wall with a brickwork facade and a concrete slab with insulation on the upper surface. In this version, concrete is used as a foundation for the floor covering. This necessitates an extra wooden beam at the lower edge of the wall. As a variation of this solution the facade is allowed to extend somewhat over the concrete skirting. In all other respects the construction is the same. This design also requires insulation of the edge beam.



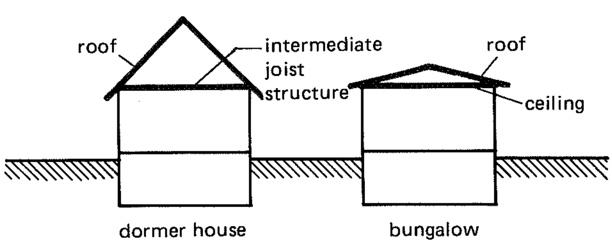
Cellular concrete constructions

Single-family houses with cellular concrete structures have been tested for airtightness. (Some of the results are shown in table 5.) The majority of these houses were built without special measures being taken to achieve airtightness. In houses with cellular concrete constructions in both walls and ceilings (examples 1, 3, 4 and 7) the measured airtightness varied between 1.28 and 1.75 changes/h at 50 Pa. In the other examples, intermediate joist structures and/or ceilings were of a wooden construction. In these, the measured airtightness varied between 1.72 and 3.25 changes/h at 50 Pa. Where the lower value was measured, it was noted that special attention was given to airtightness at stripped joints.

The results indicate that good tightness can be achieved

Table 5. Results from tightness testing on single-family houses with cellular concrete constructions.

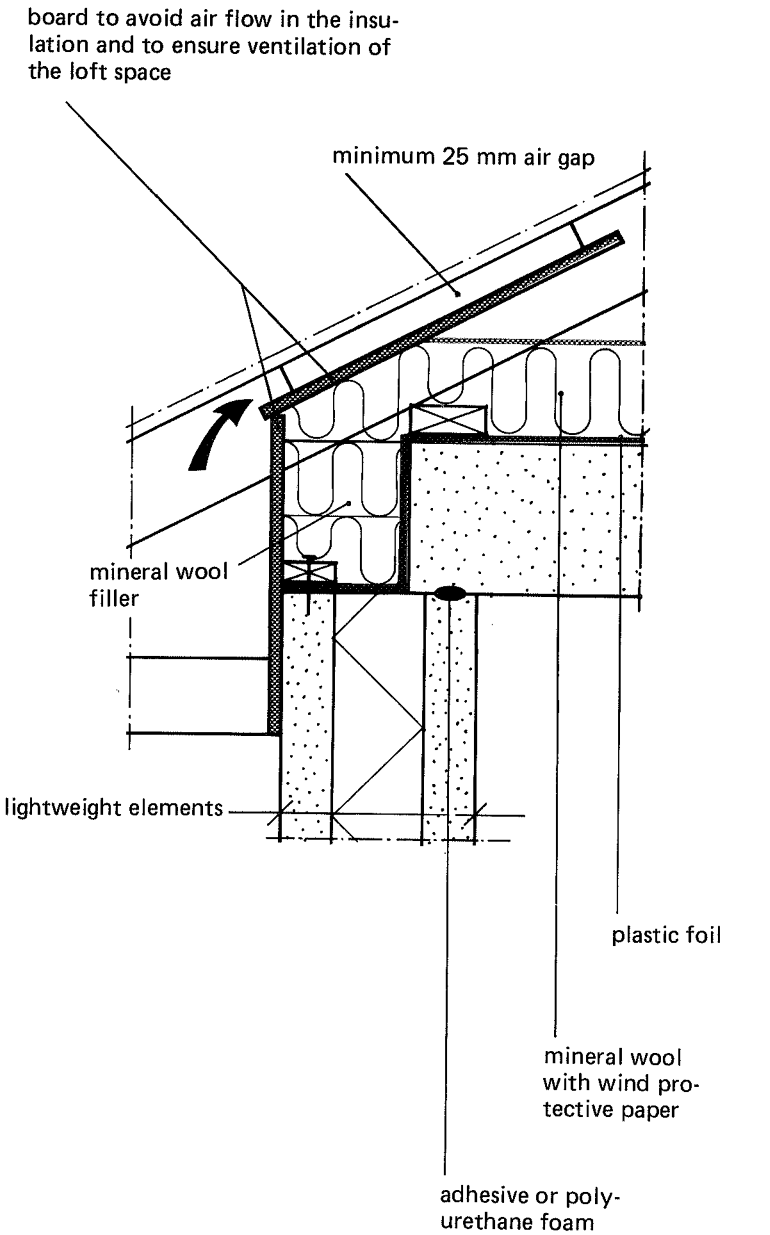
No.	House type	Cellular concrete	Combination wood — cellular concrete	Walls	Intermediate joists	Ceilings	Air changes/h at 50 Pa
1	Partly 2 floor	X		300 T	250 JPC	200 CPC[a]	1.38
2	Dormer		X	300 LE	200 JPC	Wood	2.44
3	Bungalow with cellar	X		Combination	—	200 JPC[a]	1.54
4a	Bungalow, terraced	X		250 LE	—	200 CPC[a]	1.75
4b	Bungalow, terraced	X		250 LE	—	200 CPC[a]	1.59
5	Bungalow with cellar		X	300 T	—	Wood	3.25
6	Dormer with cellar		X	300 T	Wood	Wood	2.70
7	Split level	X		200 SW	200 JPC	200 JPC[a]	1.28
8	Bungalow with cellar		X	300 SW	—	Wood	1.72[b]



[a]Plus soffit extension
[b]Extra sealing at interior purlins

JPC = joist elements of cellular concrete
CPC = ceiling element of cellular concrete
T = thin joint block of cellular concrete
LE = lightweight element of cellular concrete
SW = standing wall element of cellular concrete

Figure 74. Eaves design for external walls of lightweight elements and roof joist structures of load-bearing cellular concrete elements with supplementary insulation of mineral wool. Plastic foil constitutes the vapour barrier and air seal. This must be carefully attached and clamped against the lightweight element with a wooden batten. To reinforce the airtightness further at the corner of the roof it is suggested that the cellular concrete elements be laid on a string of polyurethane foam. To achieve a good wind protection for joist structure insulation, the eaves are »clothed in» with particle board sheets which are also mounted so that ventilation of the loft space is ensured.



relatively easily with cellular concrete constructions alone. Where these are combined with wooden constructions, greater attention must be paid to airtightness. Examples of constructions are shown in figures 74—78. In the Cellular concrete manual (*Lättbetonghandboken*) 1978, further solutions are shown which can, among other things, fulfill airtightness requirements.

Figure 75. The design of eaves adjacent to external walls of lightweight elements and wooden roof joist structures.
a. As was shown in table 5, it is difficult to achieve good airtightness in cellular concrete houses with roof joist structures of wood. It is particularly difficult to construct the eaves intersection. In this solution it is assumed that a strip, suggested width 1 m, of plastic foil is fitted at the same time as the top plate before the trusses are erected. The plastic foil in the ceiling is then jointed against these wall strips using an overlap joint which can be taped where necessary. It is however uncertain whether such overlap joints provide the necessary airtightness. If protection against putting feet through the foil is necessary, the joints cannot be taped with the tapes currently available (1980).
b. An alternative design which allows the complete foil to be fitted after the roof trusses have been erected. The foil in the ceiling is clamped against the top plate with battens and sealing strips. The foil strip, used in conjunction with the erection of the top plate, can thus be avoided and whole widths can be used.

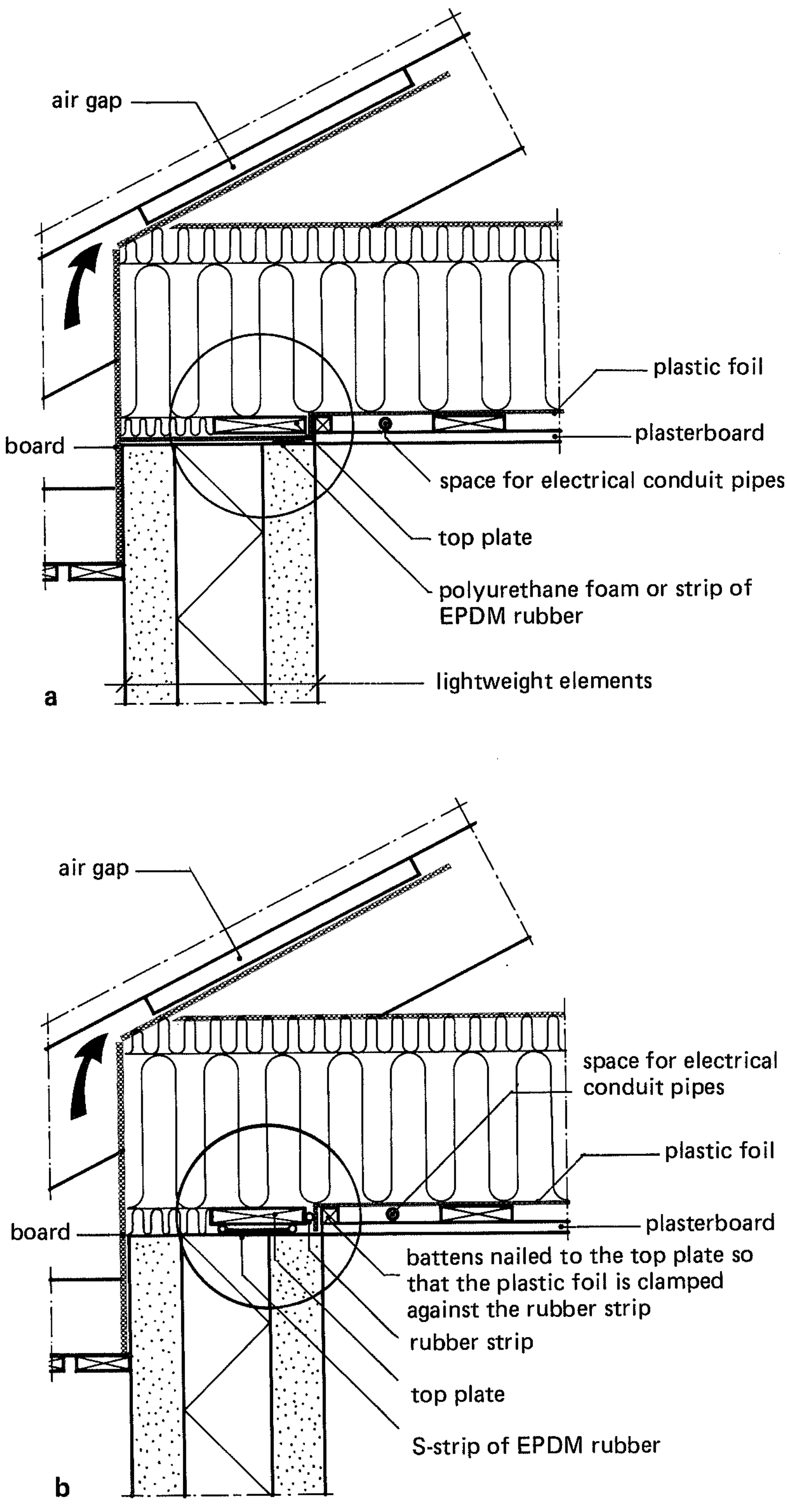
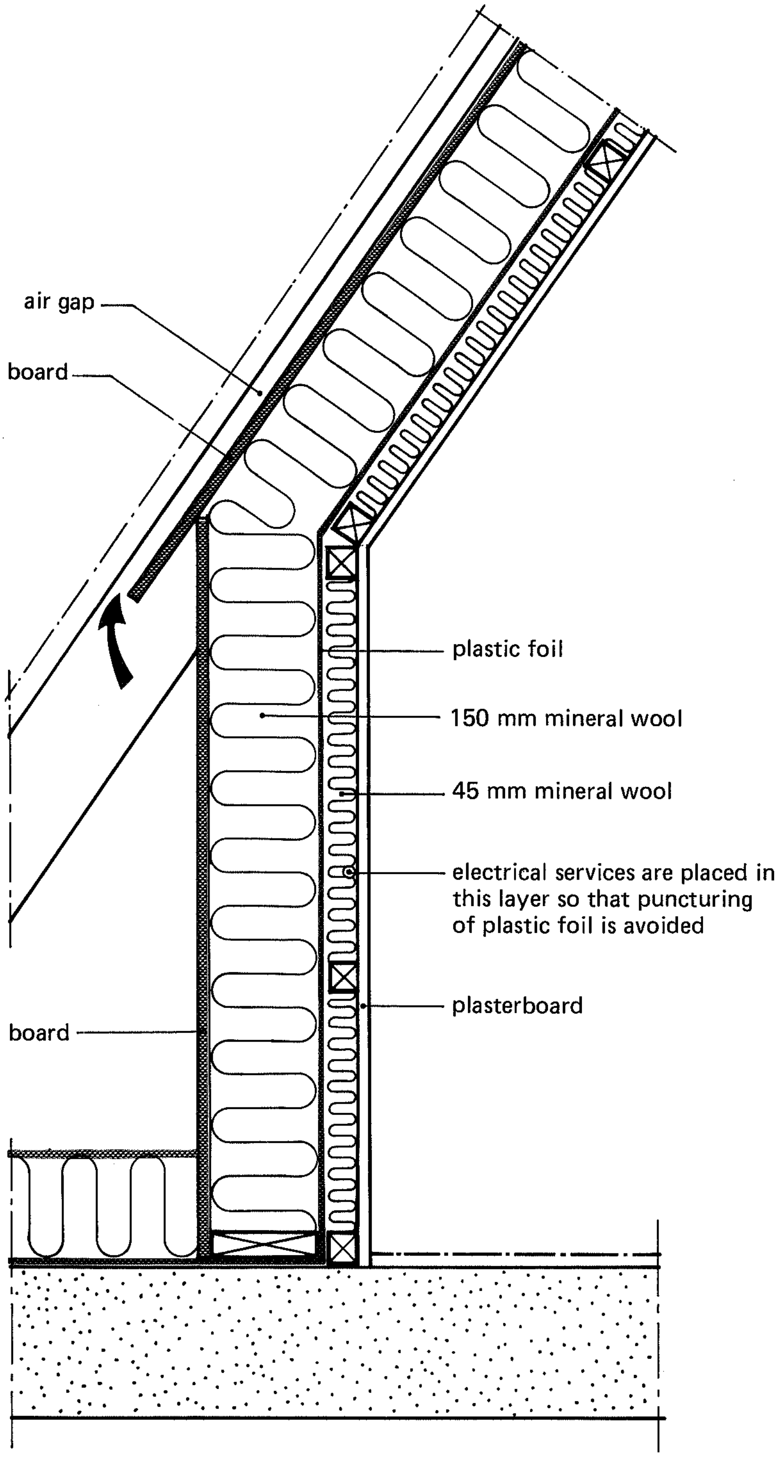
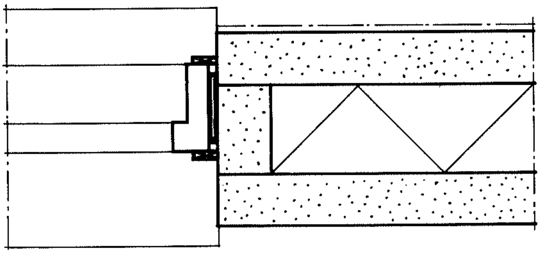


Figure 76. Brace wall in a dormer house with intermediate joist structure of cellular concrete elements. Airtightness is achieved with drawn-in plastic foil. The best airtightness is probably achieved if the foil is laid flat. The foil width should be the same as the height of the brace wall plus a certain overlap. Jointing need only be carried out at gable walls where all the joints can be clamped against wooden members. Corresponding assembly should be applied for pitched roofs.





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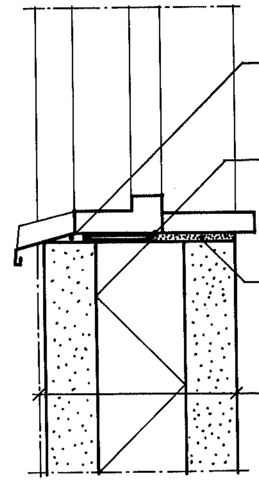


b

Figure 77. Window attachment in lightweight element. The window frame can be constructed with tucked-in wallpaper and a finishing strip through the actual joint.
a. Horizontal section.
b. Vertical section.

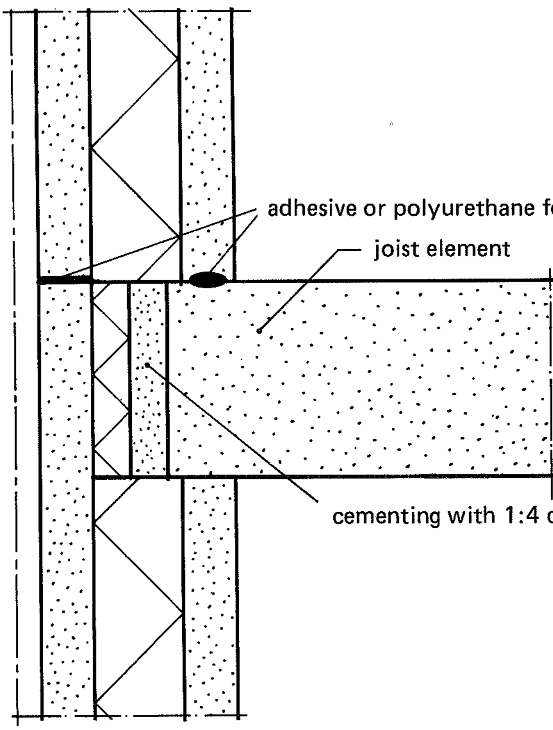


Figure 78. Joint between external wall of lightweight elements and intermediate joist structure of cellular concrete elements.

Curtain walls in multi-family housing

Comparative investigations have been carried out between site-built and prefabricated curtain wall elements (Karlsson and Leek, 1973). The problems in achieving good airtightness in buildings with curtain wall elements are concentrated in the joints between elements and shell. Different joint sealing systems have been studied. Thermography was used to assess airtightness and insulation.

The results of investigations indicate quite clearly that in the walls investigated, there was a difference between site-built and prefabricated walls with regard to insulation procedures. Surface temperature reductions appeared sporadically adjacent to framework members in site-built walls which indicated shortcomings in sizing and positioning of the insulation material. In the case of prefabricated walls, no such shortcomings were observed. The more favourable working conditions in factories compared with building sites probably provide the right conditions for better work procedures and a more even quality. Inspection facilities are also better in factories. Other investigations indicate however that insulation faults also occur in prefabricated elements.

Two different sealing methods between prefabricated walls and building shell have been studied systematically – both using conventional packing with mineral wool and sealing with two-component polyurethane foam. Interesting comparisons can be made in this context. Polyurethane foam clearly provides better airtightness than mineral wool. The foam also contributes to the wall element's attachment and allows the use of very simple attachment devices.

Mechanical exhaust air devices with a capacity of 90–140 m^3/h per apartment were common to all the examples investigated. True air supply devices were not fitted in the examples investigated but there were ventilation devices fitted in conjunction with windows. When these devices are closed – as was the case during thermography – intake air must be taken in in another manner. Since the concrete shell can be considered almost airtight, air supply is through facade walls and their joints to the shell. The cold air supplied to the apartments during the winter in this way and which is not heated by radiators can be expected to cause discomfort and »draughts».

The results of investigations show that where walls and joints are relatively tight, air leakage still occurs between window frames, balcony doors, ventilation blocks and frames and between frames and walls. The results underline the importance of a controlled air supply to the rooms in question. For this reason, the methods should be examined for providing facade walls with suitable air supply devices, containing filters and

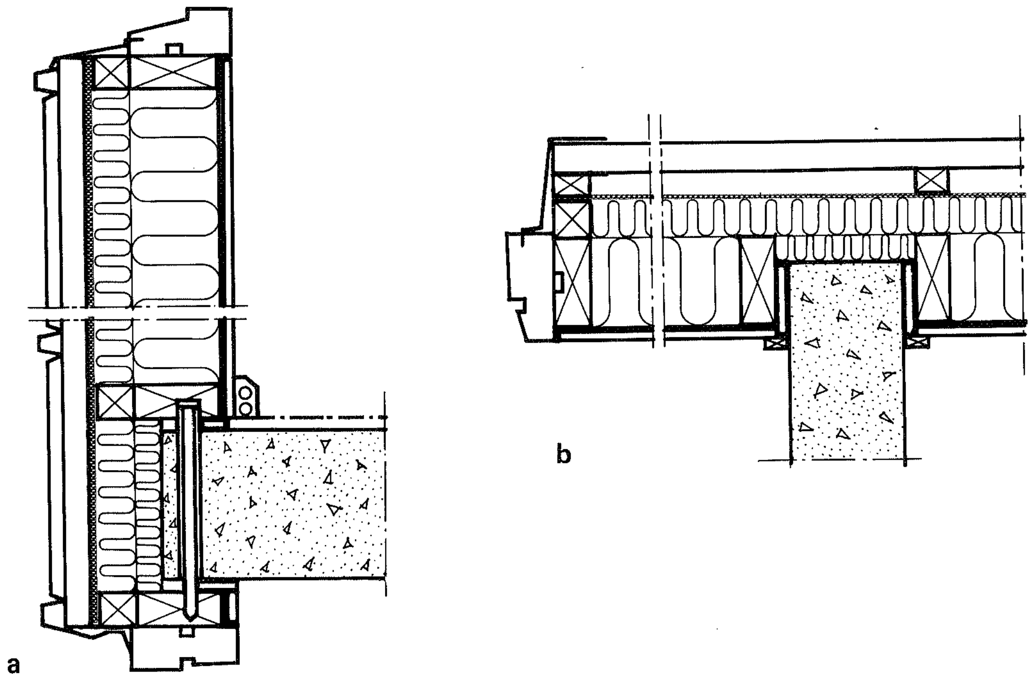


Figure 79. Examples of joints between curtain wall elements, joist structures and intermediate concrete walls. Suitable air sealing at joints is achieved with polyurethane foam. In the facade elements investigated the window frames were attached with adhesive to the framework. This has obviously provided good airtightness. However the method has several disadvantages and has now been rejected by manufacturers.
a. Joint between curtain wall element and joist structure.
b. Joint between curtain wall element and intermediate concrete wall.

possible control devices if the ventilation plant is not supplied with intake air.

The jointing of other structures sealed with polyurethane foam, shows a relatively even, high surface temperature. No air leakage was observed. It is considered that the functional requirements have been properly observed using this type of joint sealing. Joint sealing with polyurethane foam has complied with the tolerances in question between elements and shell. Figure 79 shows examples of joints between curtain wall elements and concrete joist structures and intermediate walls respectively. A construction of elements and joints against window etc. agrees in principle with the solutions given in the chapters »Wooden structures» and »Joints – materials and construction».

The Täby project

Design solutions

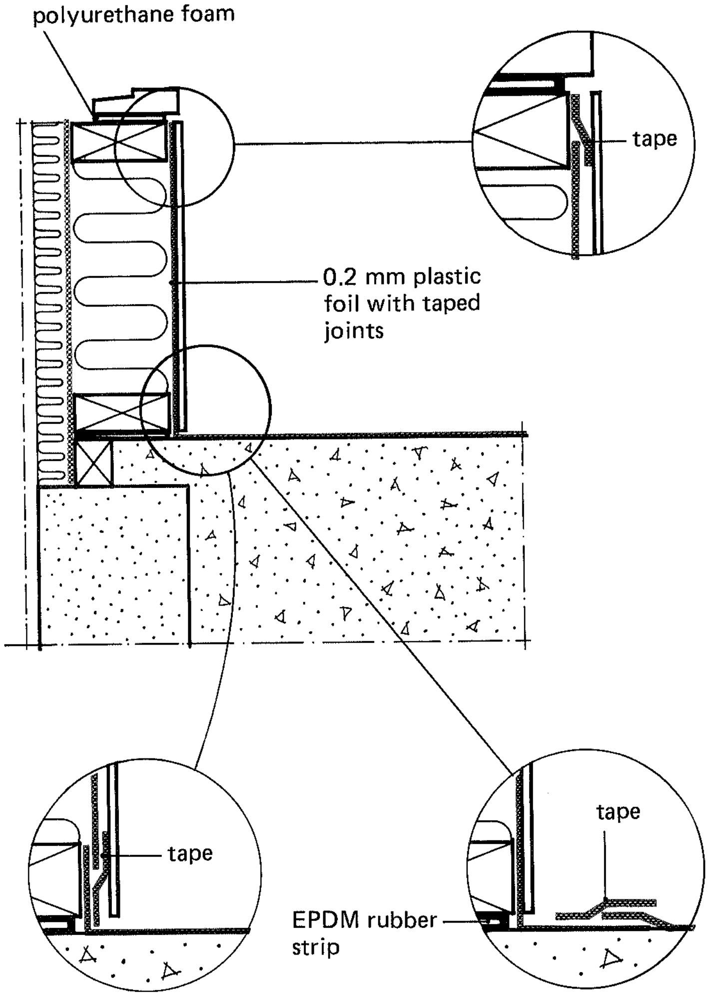
At Täby, north of Stockholm, a series of approx. 25 test houses was built in the autumn of 1977. In these houses a number of different installation procedures were tested for energy saving. The test houses were dormer houses of wooden construction built on site. The thermal insulation fulfilled the now valid requirements of SBN 1975. A considerably higher degree of airtightness than that demanded by the code has been sought. However the goal has not been set higher than that expected to be achieved by workers during normal series production. Airtightness was tested in 15 houses. With a pressure difference of 50 Pa, air leakage was between 0.7 and 1.4 changes/h in all expect one of the houses tested, where a leakage rate of 1.8 changes/h was measured. Several of the values were very close to 1.0 changes/h. (Lind et al, 1978.)

Airtightness measures

Airtightness was based on careful construction of vapour barriers using 0.2 mm plastic foil and with taped overlapped joints. The measures carried out are primarily the following:

- ☐ An EPDM rubber strip (figure 80) is laid between the lower horizontal wall member and the wooden profile cast into the concrete slab.
- ☐ The vapour barrier/plastic foil is taped to the members around windows and doors and at floors.
- ☐ Overlap joints in the plastic foil are taped.
- ☐ Joints between windows and door frames and adjacent members are filled with polyurethane foam (figure 80).
- ☐ Where floor joists in intermediate joist structures penetrate the plastic foil when jointing to column walls, the foil is cut and taped to the floor joists (figure 82). (In order to keep a check on this taping – probably the most difficult item in the house – it is suggested that, when laying chip-

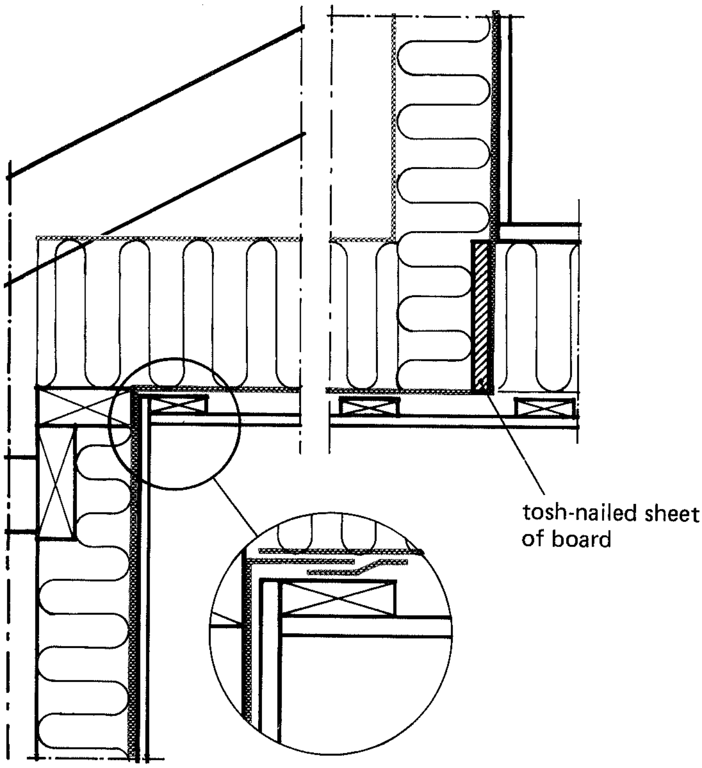
Figure 80. Fitting plastic foil at sills and on walls.



board and floor joists, about 200 mm be left over along each column wall. This allows the sealing between plastic foil and floor joists to be supplemented if an early pressure test shows leaks. The floor is later complemented with sheets of chipboard along the column walls.)

☐ Where it is necessary to make holes for circular items (conduit pipes for electrical cables and larger holes for ventilation ductwork and waste pipes) a square neoprene rubber collar is stretched over the circular items. This collar is provided with punched or cut holes which are slightly smaller than the circular items. The rubber collar is taped to the foil.

Figure 81. Joints between intermediate joist structures and external walls and between intermediate joist structures and column walls.



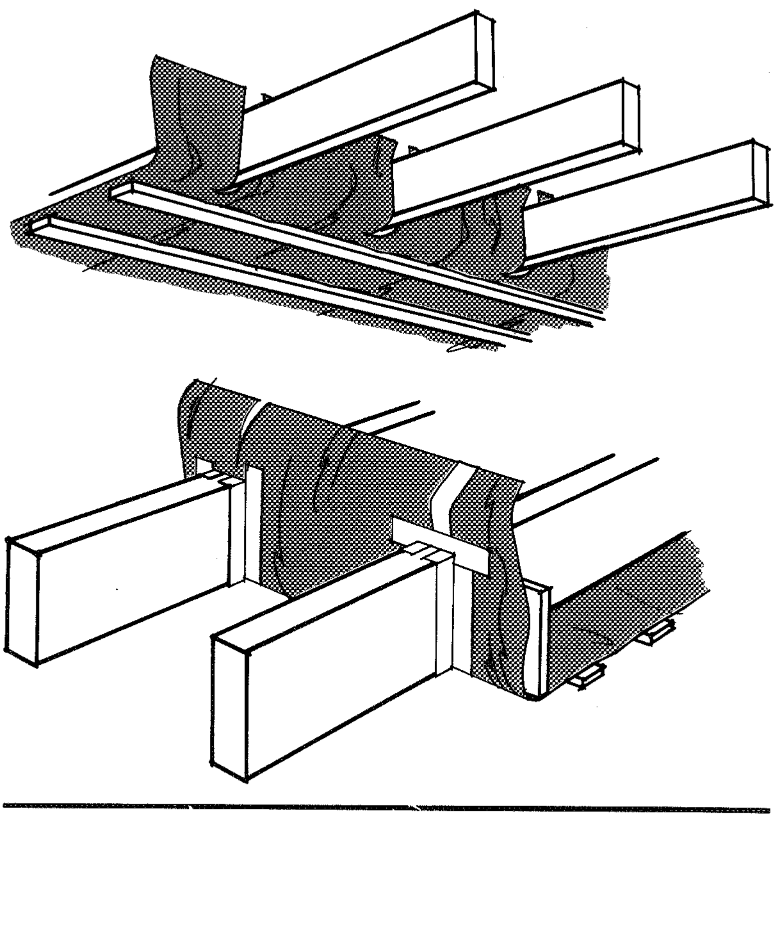


Figure 82. The foil in the ceiling is slit and folded up between the joists, taped together over these and then taped at the joint between joist and foil.

The STFI project – test houses in Umeå

Background

For a number of years, a project has been in progress at the Swedish Forest Products Research Laboratory (STFI) with the purpose of developing generally applicable technical solutions for site-built wooden houses and to coordinate these in a building system. The project is backed up by the sawmills' efforts aimed at further refinement of sawn wood products. The building system can be considered a common frame of reference for production of building components. Use of components with well-proven solutions should also contribute to the improvement of building technology.

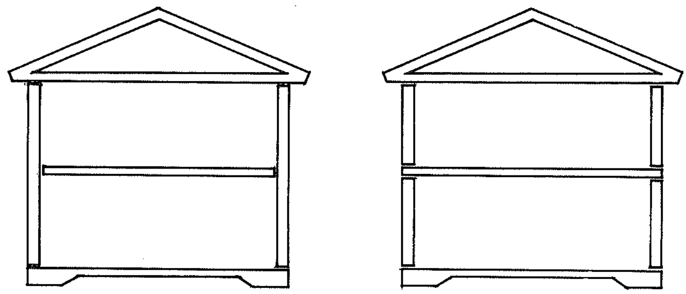
The development work is based on common building site technology. Considerable work has been carried out to develop suitable technical solutions and working methods (Englund, 1978). Work is in progress at STFI to provide answers to certain questions regarding climate balance in sections of buildings where different principles are applied to meet airtightness requirements. Measurements are being carried out both in laboratories and in a number of test houses in different parts of the country.

Two test houses were erected at Umeå in 1977. The houses form part of a group of 14 semi-detached houses which are identical in plan and appearance. One of the houses is designed to fulfill the requirements stated in SBN 1975 whereas the other is fitted with a type of extra energysaving device, e.g. a heat exchanger. The purpose of this is to gain experience from the building of low energy housing intended for normal building production and to determine the houses' energy consumption.

Design solutions

The two houses are two-storey houses, which simplifies sealing work somewhat. The external walls are identical in both houses but the shell was built according to different methods.

Figure 83. Balloon and platform systems respectively.



In one house the »balloon principle» was applied, whereas the other was built according to the platform method (figure 83). These two methods of building have led to different solutions in intermediate joist structure joints.

The framework shells were measured accurately according to the 6 M modulus, which means that the members were always positioned with a centre-to-centre distance of 600 mm. Displacement of framework members at windows has been avoided by the use of specially made windows with a smaller external size than normal. (Swedish standards cannot be applied.) Efforts were also made during the planning work to make sure that loading from rafters was directed straight down to the foundations in order to avoid a large number of intermediate beams in the external walls. Such intermediate beams are only necessary in one place. Thus the amount of insulation cutting was kept to a minimum.

The external walls comprised a triple layer construction with a cross work frame system (figure 84). The load-bearing shell comprised vertical studs with dimensions 48 x 95 mm. Horizontal studs with dimensions 50 x 50 mm were affixed to these and similar horizontal studs with dimensions 48 x 45 mm were placed on the inside of the walls. The advantage of this apparently complicated construction is that the three layers of insulation can be installed with displaced joints which reduces the risk of continuous gaps in the thermal insulation. The total thickness of the thermal insulation is 190 mm.

The principle for air sealing is that *one sealing* layer is fitted without breaks, as far as possible, round the whole of the house. The layer, which comprises a 0.2 mm thick plastic foil, was placed between the two inner framework systems. In this way a 45 mm deep installation zone for electrical cables is obtained. The risk of damage to the sealing layer in conjunction with insulation work is thus considerably reduced.

The details have been designed so that no »difficult folds» are necessary in the sealing layer. The sill joint has been sealed with an EPDM rubber strip and a string of jointing compound on the inside in which the plastic foil has been securely clamped (figure 85). The spaces around window frames were packed with mineral wool. Airtightness was achieved using internal jointing compound. The plastic foil in the wall has been clamped against the sealing compound with wooden

Figure 84. Outer wall construction.

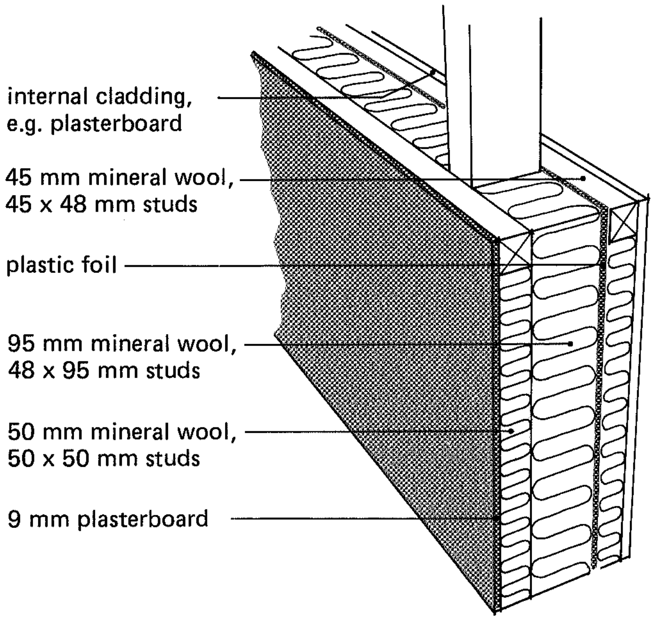


Figure 85. Joint between outer wall and foundation. Sill sealing is achieved with an EPDM rubber strip internally reinforced with elastic jointing compound. The plastic foil is clamped against the jointing compound. A considerable barrier against air leakage is achieved.

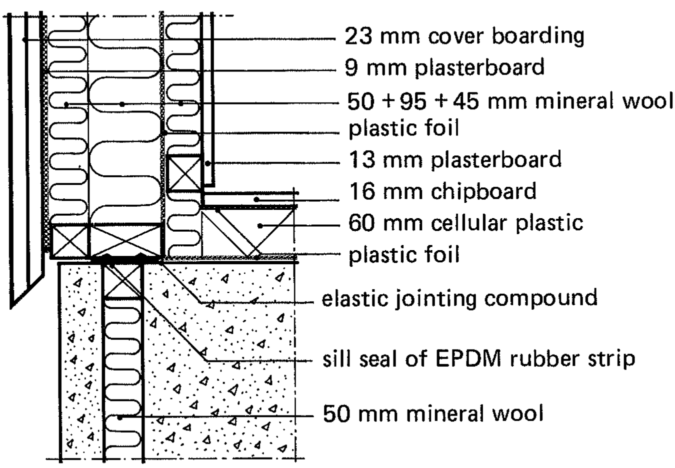
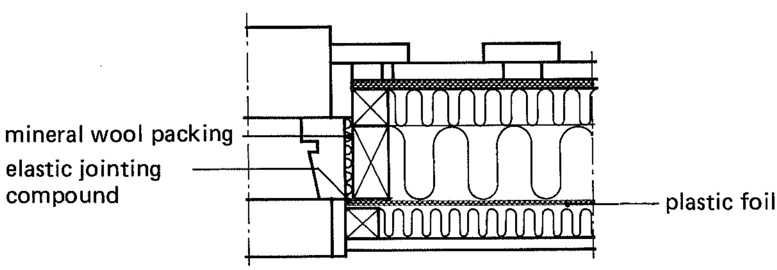


Figure 86. Window joint. Horizontal section. Between the frame and the wall, traditional packing with mineral wool is used. The actual air seal is achieved with internal elastic jointing compound. Only a rain rejecting covering strip is used externally.



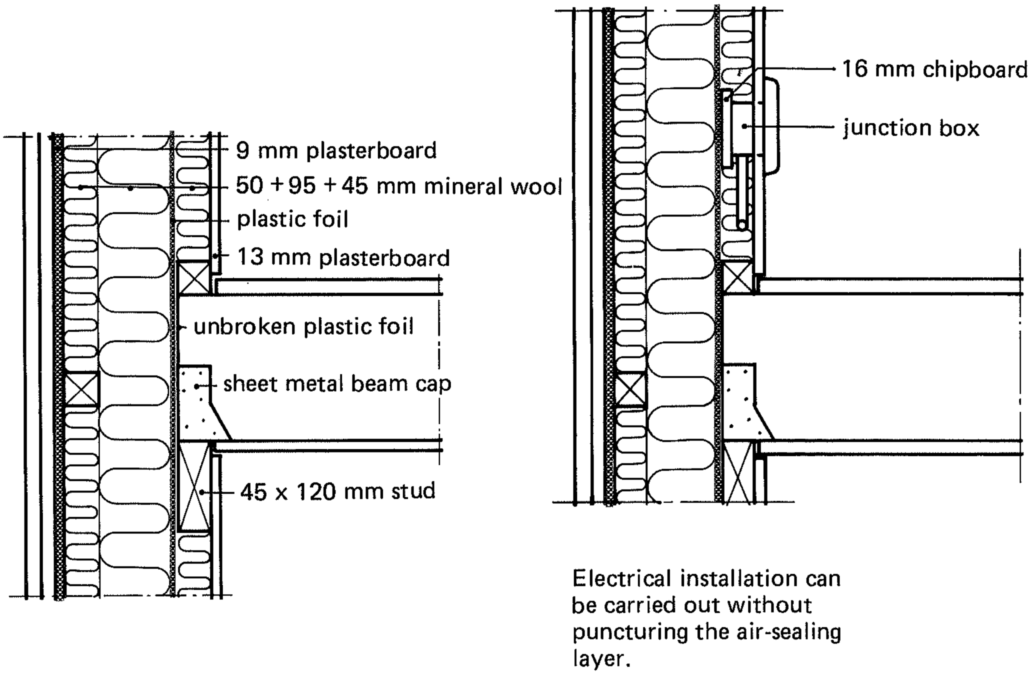


Figure 87. A joint between external wall and intermediate joist structure in the »balloon house». The intermediate joist is supported both on the inner horizontal studs and the sheet metal beam caps of the vertical framework. The design also means that both the insulation and the air sealing layer can be extended past the joist structure joint without complicated overlaps. The most important aspect of this is the reduction of air leakage risks.

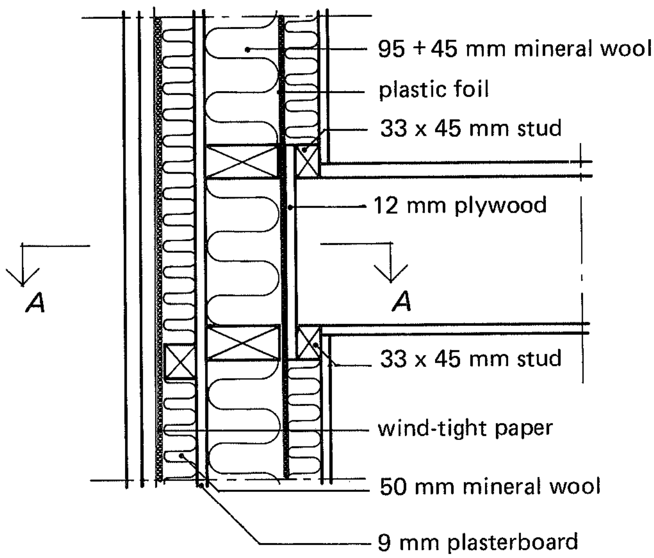
studs. Using this method, continuity in the air sealing layer is good, both in walls and at joints. Furthermore, airtightness is facilitated in that the layer is in the same plane overall (figure 86).

The joist structure joints are different in the two houses. In the »balloon house» the sealing layer goes past the joists which are attached to wall studs with fixing cleats (figure 87). The joints between sheets of foil have been taped.

In the »platform house» the jointing has been carried out as illustrated in figure 88. The plywood sheet between the joists has a double function in that it provides both rigidity and airtightness. The foil joints are clamped against this with the horizontal studs.

Even if airtightness has been achieved with the inner sealing layer, air sealing on the outside has been carried out with great care. In the »balloon house» this comprises a 9 mm plasterboard (of a special type for external use as wind protection) positioned on the outside of the horizontal framework section. The joints have been taped and the sheets are supported at the external corners with a fixing cleat (figure 89). Covering boarding has been used for facade cladding.

Since the houses have a two-floor design, eaves construction is simple (figure 90). Overlapping the foil at corners is easy.



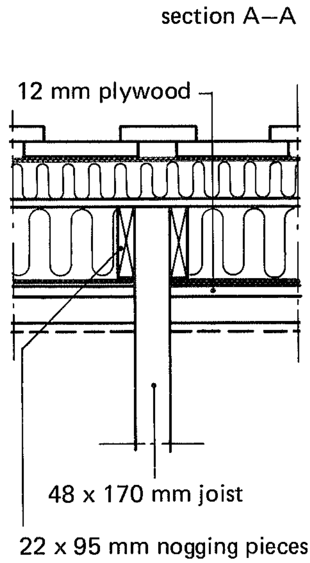


Figure 88. A joint between outer wall and intermediate joist structure in a »platform house». The plywood sheets between the joints make the shell structure more rigid while at the same time facilitating the application of plastic foil with clamped joints at each joist section.

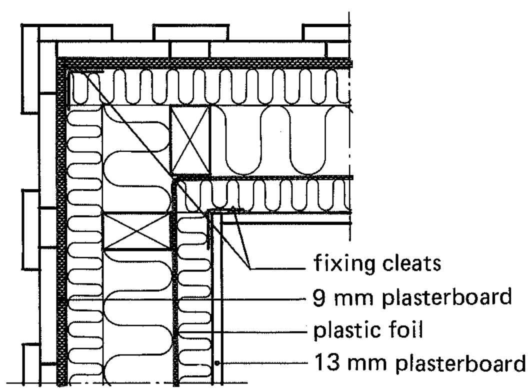


Figure 89. Corner design in the »balloon house». Instead of extra wooden studs at the corner, fixing cleats have been used. Sheets of plasterboard can be easily screwed into these. The advantage is that whole mineral wool slabs can be used to a greater extent. The risk of inferior insulation is thus reduced. Furthermore, timber is saved.

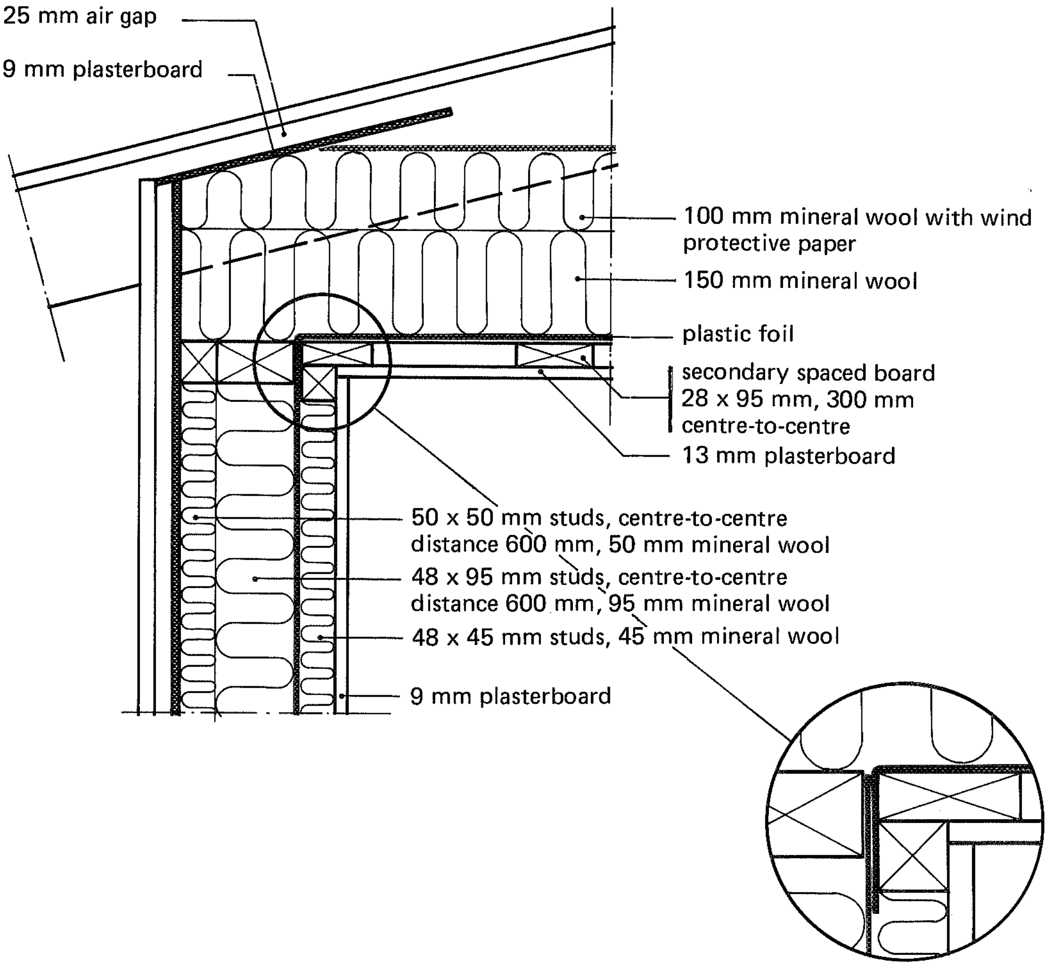


Figure 90. A joint at the eaves between external wall and roof construction. At the roof intersection, the plastic foils can be overlapped. The joints are clamped using the horizontal studs. Where wind protection is concerned, good continuity is achieved between wall and joist structure by using extra plasterboard sheet which fits tightly against the wall's plasterboard placed under the roof.

Pressurization testing

When pressurization testing the houses, an air change rate of 0.7 changes/h was measured in the »balloon house» and 0.5 changes/h in the »platform house» at a pressure difference of 50 Pa. These are very low values.

The principle of using a sealing layer drawn under the insulation for protection obviously gives good airtightness. It is also probable that the function will be maintained providing that age-resistant foil is used. It would seem that there is a certain amount of risk with the »drawn-in» foil positioning in that it can cause moisture damage. It is therefore important to investigate further how the construction works from a climatic point of view. Measurement work on a wall's climatic balance is planned by STFI (1980).

The Åkersberga project – the development of singlefamily houses

A small area comprising a group of houses has been built in a Stockholm suburb. These are dormer houses and are single family dwellings. They are constructed according to the requirements for thermal insulation and airtightness in SBN 1975. The construction has been planned according to the principle that the internal vapour barrier of plastic foil shall comprise the actual air seal. The aim was to attain a higher degree of airtightness than that demanded by the code.

Airtightness in the finished houses was measured by the pressurization test method. The number of air changes per hour varied between 0.67 and 0.86 for the seven houses. These are very low values. The prime reasons for this are:

- ☐ Accurate and, in our opinion, well thought-out planning.
- ☐ Careful work procedures and good work control.
- ☐ Careful choice of material for air sealing.

General description

The group comprises 7 dormer houses each having a living area of 138 m^2. The shell is built up of two framework systems, the inner vertical and the outer horizontal. The load-bearing construction uses timber sawn to an accuracy of 1 mm. The standing framework was nailed on the horizontal concrete slabs and raised wall by wall. The horizontal framework was then erected after which windows and doors were set in. The framework system was carefully designed so that the centre-to-centre distance between framework members was 600 mm overall. Whole standard format sheet material and insulation can therefore be used to a great extent. This has facilitated good workmanship.

The thicknesses of the mineral wool insulation were: 120 + 50 mm in external walls, 195 mm in pitched roofs, 195 + 50 mm in roof joist structures and 100 mm in floors. The insulation work in the roof was done from the inside, allowing the roof to be erected at an early stage. This comprised rigid wood fibre sheeting, battening and trapezoidal profile plate.

The insulation work between the horizontal members in the external walls was carried out from the outside. This was

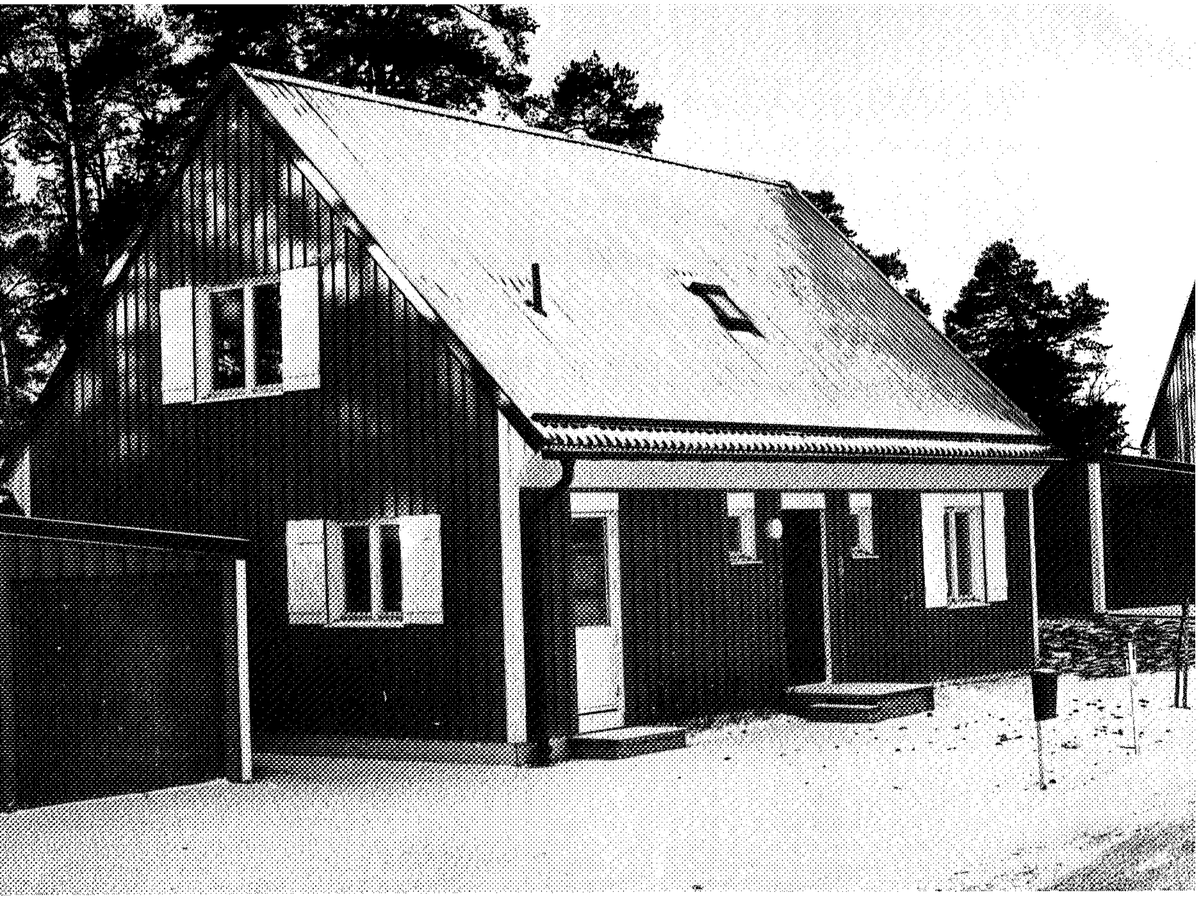


Figure 91. A house in Åkersberga.

done in conjunction with the application of the wind protection paper. The pitched roof was insulated from the inside whereas the roof trusses (the upper roof joist structure) were insulated from above after which the plastic foil and the secondary spaced boarding were fitted. After the insulation in the walls and the pitched roof was installed, the plastic foil was fitted. The work was commenced at the gables of the upper floor followed by the sealing of the upper floor and finally the ground floor.

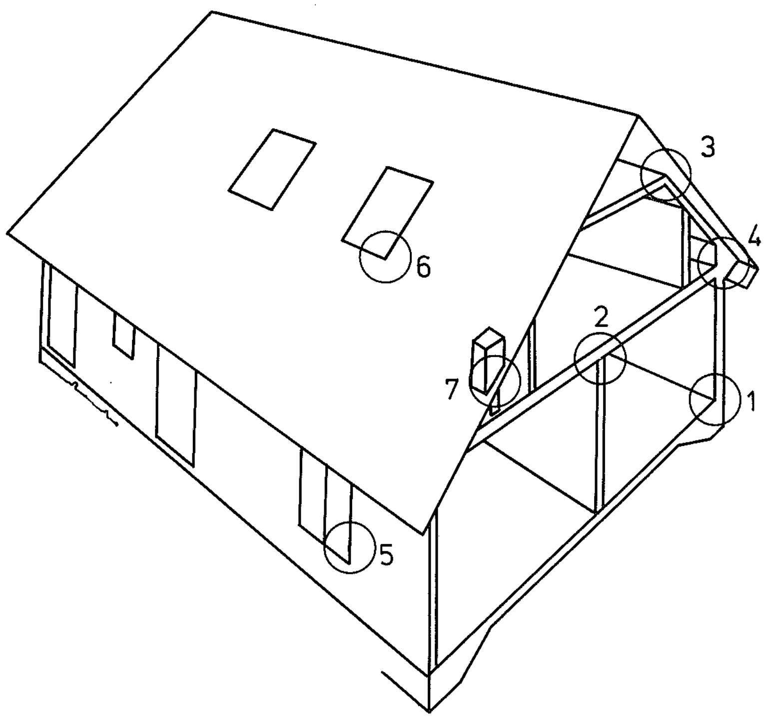
Sheets of chipboard were used for internal wall cladding on the gable walls and plasterboard elsewhere.

The floor on the ground floor comprises chipboard or oak parquet flooring on floor joists with intermediate mineral wool insulation. Plastic foil was laid between the concrete slab and the insulation.

Constructional details

Figure 92 shows some of the details in this house type to which special attention must be given during the construction in order for the house to be airtight. The procedure for these details is illustrated below.

Figure 92. Details of joints whose construction is of great importance to the house's airtightness.



1 external wall – ground floor structure
2 load-bearing internal wall – gable wall/attic floor
3 roof joist structure – pitched roof
4 eaves
5 window joints
6 roof light joints
7 penetrations for services

Item 1: External wall – ground floor structure

Here a sealing strip of EPDM rubber is stapled to the underside of the sill before the latter is placed in position and affixed to the surface ground concrete slab with expander screws. The vertical framework is then raised.

Airtightness is built up of three components:

1 A continuous wind protection paper is drawn past the sill and down to the skirting.
2 A sealing strip of EPDM rubber is clamped under the sill.
3 On the inside a sealing layer of plastic foil is applied. The joint between the plastic foil on the wall and floor is overlapped and *taped.*

From a work point of view, this item is not too complicated and this reduces the risk of errors in the final construction. For this to function as intended the concrete surface under the sill must be very smooth. It is fully possible to achieve sufficient accuracy using this method.

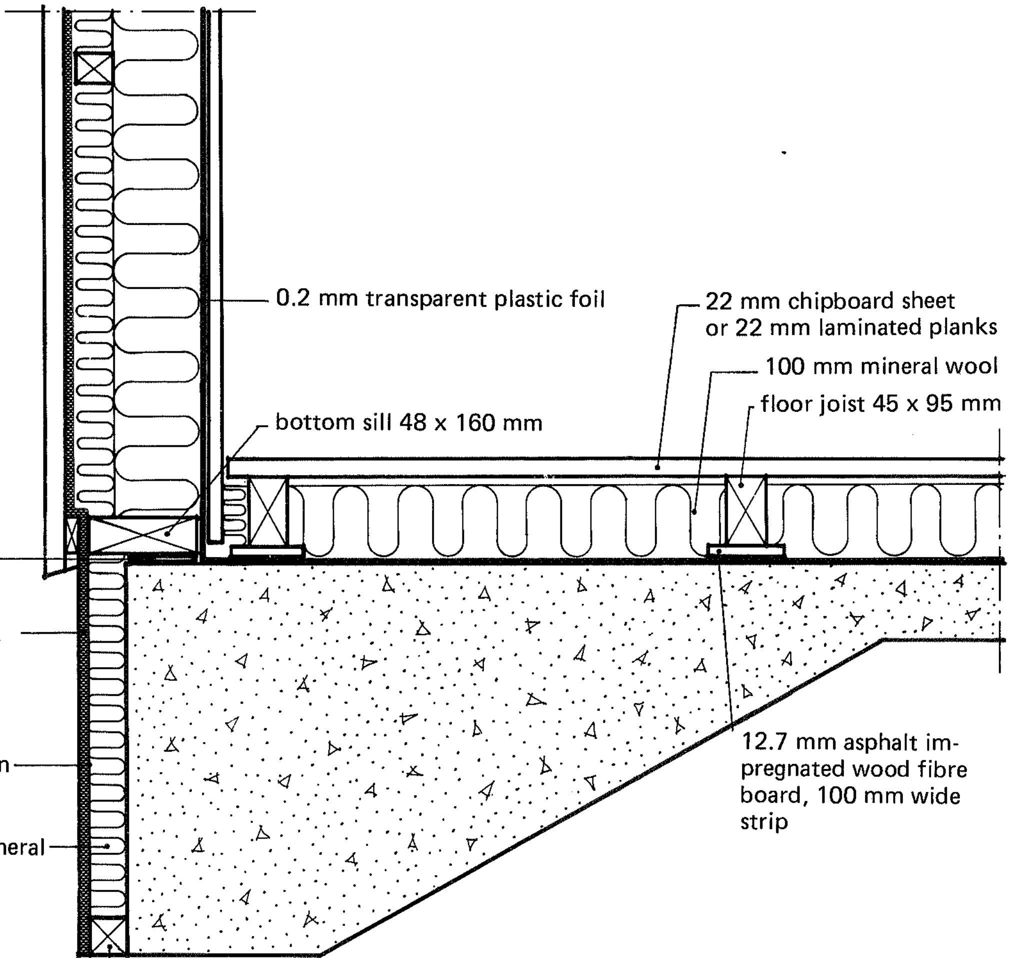


Figure 93. Joint between external wall and the ground floor.

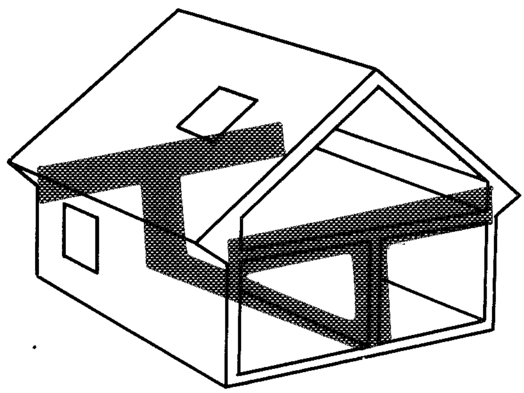
Item 2: Load-bearing internal wall, attic floor structure — gable wall

The sealing work is prepared during frame erection by placing strips of plastic foil under the load-bearing internal walls, between these and the gable wall and between gable wall and attic floor structure (figure 94). These strips allow continuity in the internal sealing layer. The strips should be approx. 600 mm wide to allow for sufficient overlap.

Figures 95—96 show how the constructions have been designed at the joint between load-bearing internal walls and gable walls and between gable walls and attic floor joist structures respectively. The plastic strips are thus fitted in conjunction with the erection of the shell.

The erection of the shell and the fitting of plastic foil on walls and ceiling is carried out during different phases of work. The erection of the shell is normally carried out at a forced rate and this can mean that the strips of plastic foil

Figure 94. The sealing work is prepared by placing plastic foil under load-bearing internal walls, between these and gable walls and between gable walls and attic floor structures during the erection of the shell.



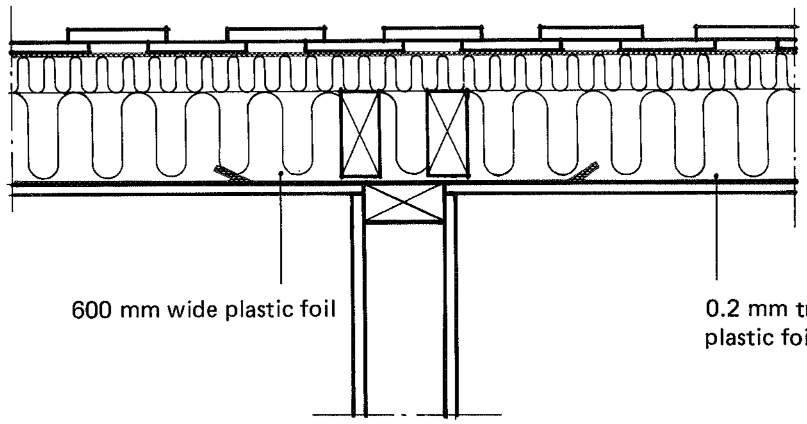


Figure 95. Gable wall — load-bearing internal wall, horizontal section.

mentioned above are easily forgotten. To prevent this carefully mark the strips on the shell drawings and give instructions regarding the work tasks during which the strips are to be applied.

Item 3: Attic floor structure — gable wall

Airtightness is ensured if the plastic foil is overlapped at corners and carefully taped (figure 97). In the attic floor structure, the foil is laid over the secondary spaced board so that good contact between the mineral wool and foil is ensured. In this way a reduction in the insulation properties through convection will be avoided.

Item 4: Eaves

From the point of view of airtightness, the most difficult task in a dormer house is the point where the sealing layer goes past the intermediate joist structure at the eaves. The large

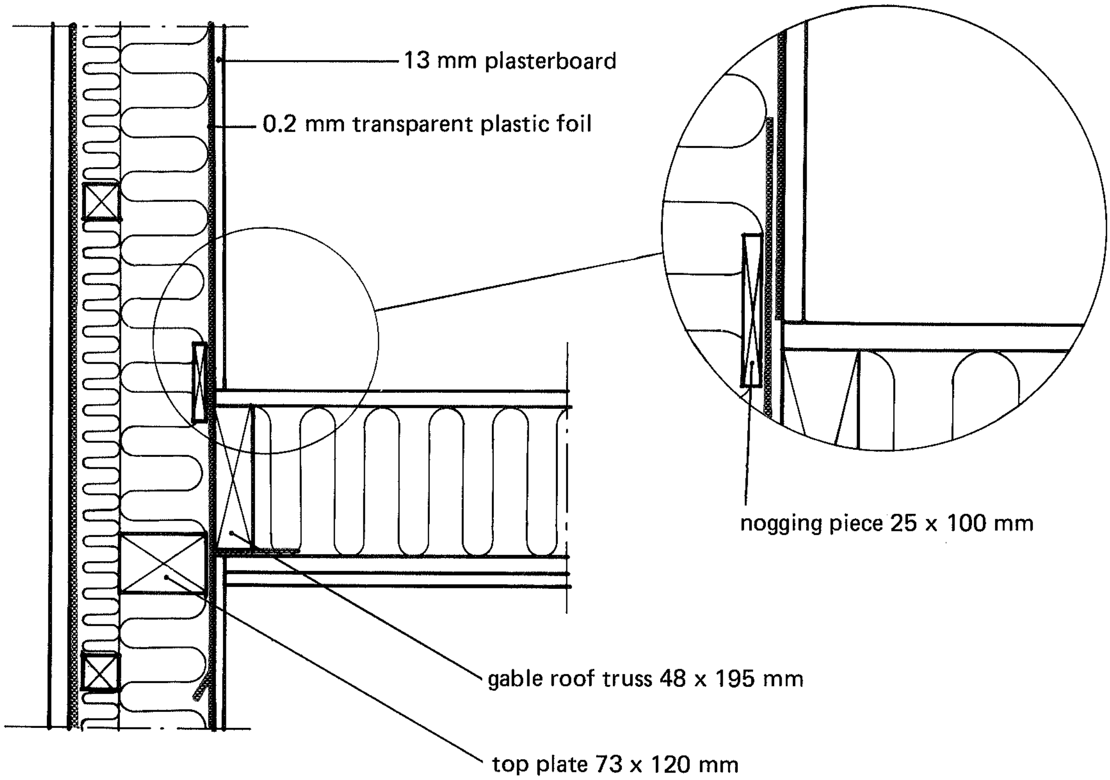


Figure 96. Joint between gable wall and intermediate joist structure.

number of penetrations and the square shape of the joists make sealing work both difficult and time consuming. The design at the eaves should therefore be given particular attention during planning.

The conventional dormer house rafter (figure 98) with an insulated column wall 1–2 m from the outer wall layer creates insulation and sealing difficulties in several places. Air leakage in the intermediate joist structure has often caused discomfort through low temperatures. For this reason a roof truss with drawn-out brace wall was selected (figure 98). The problems with air sealing are concentrated using this solution and thus preventative measures can also be concentrated. It is possible to seal from underneath, which is a great advantage.

The space outside the frame structure lightweight wall can be used to advantage for installation purposes. Consequently none of the living area need be used for ductwork and piping. Furthermore the number of intersections through the air sealing layer can be limited.

To achieve a good seal at the joist structure intersection, plastic foil is clamped against the joists. The plastic foil is clamped between plasterboard and nogging pieces (figure 99) which are nailed to the joists and top wall plate after erection

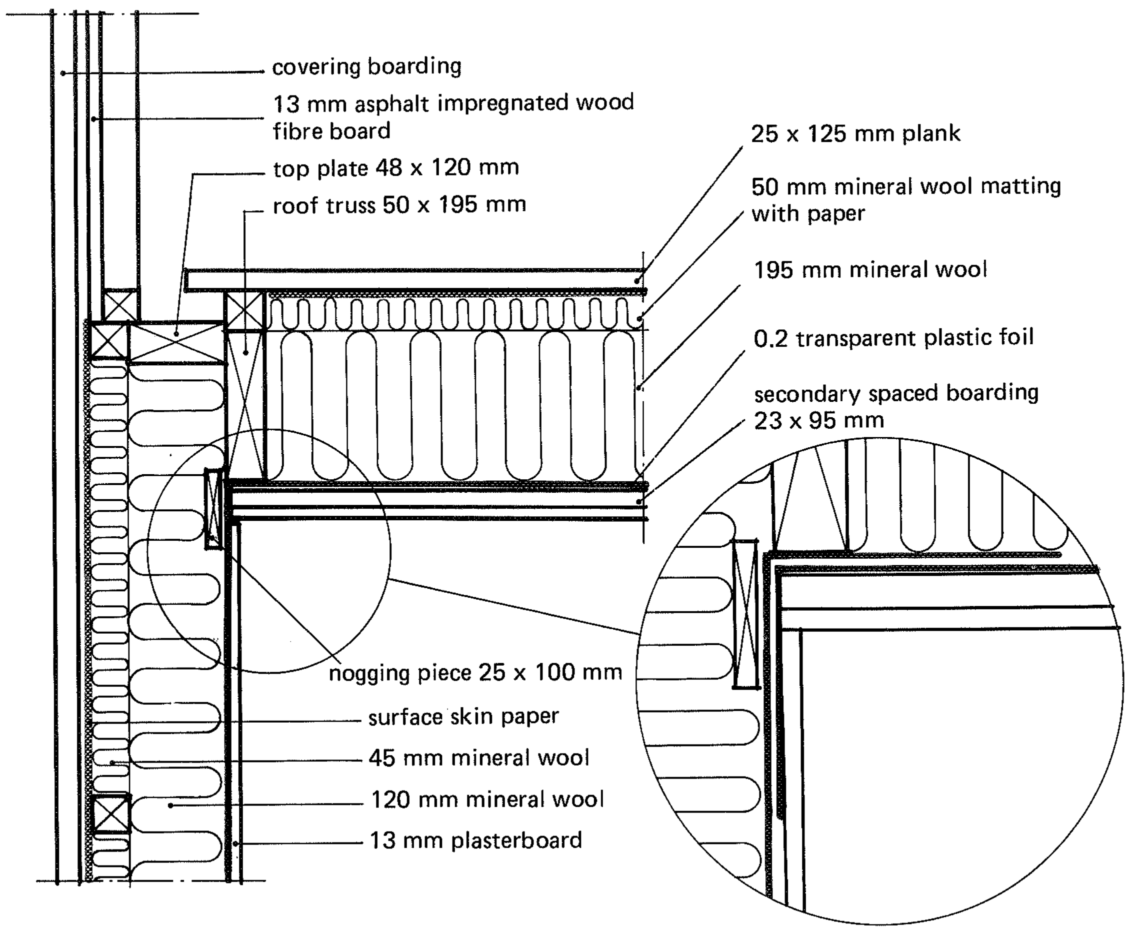


Figure 97. Joint between attic floor structure and gable wall.

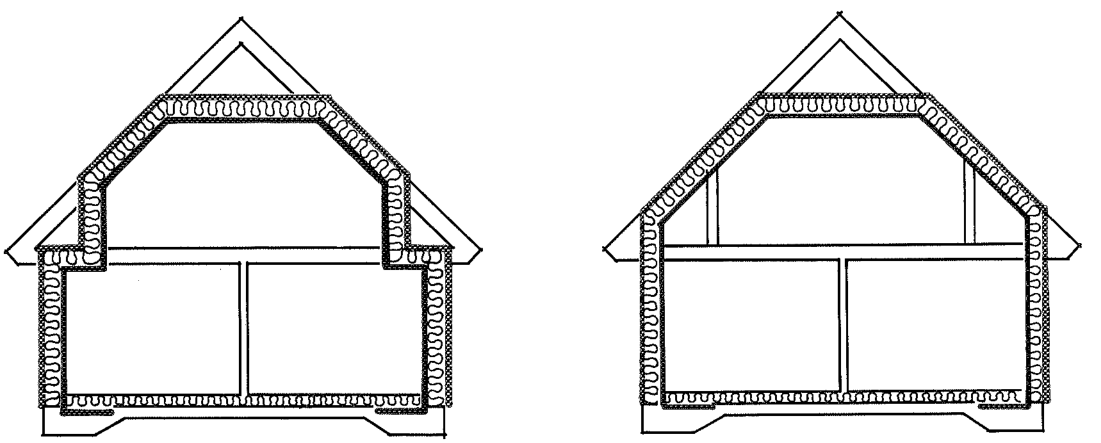


Figure 98. Roof truss between insulated column walls and roof truss with drawn-out support wall and framework section lightweight stud walls.

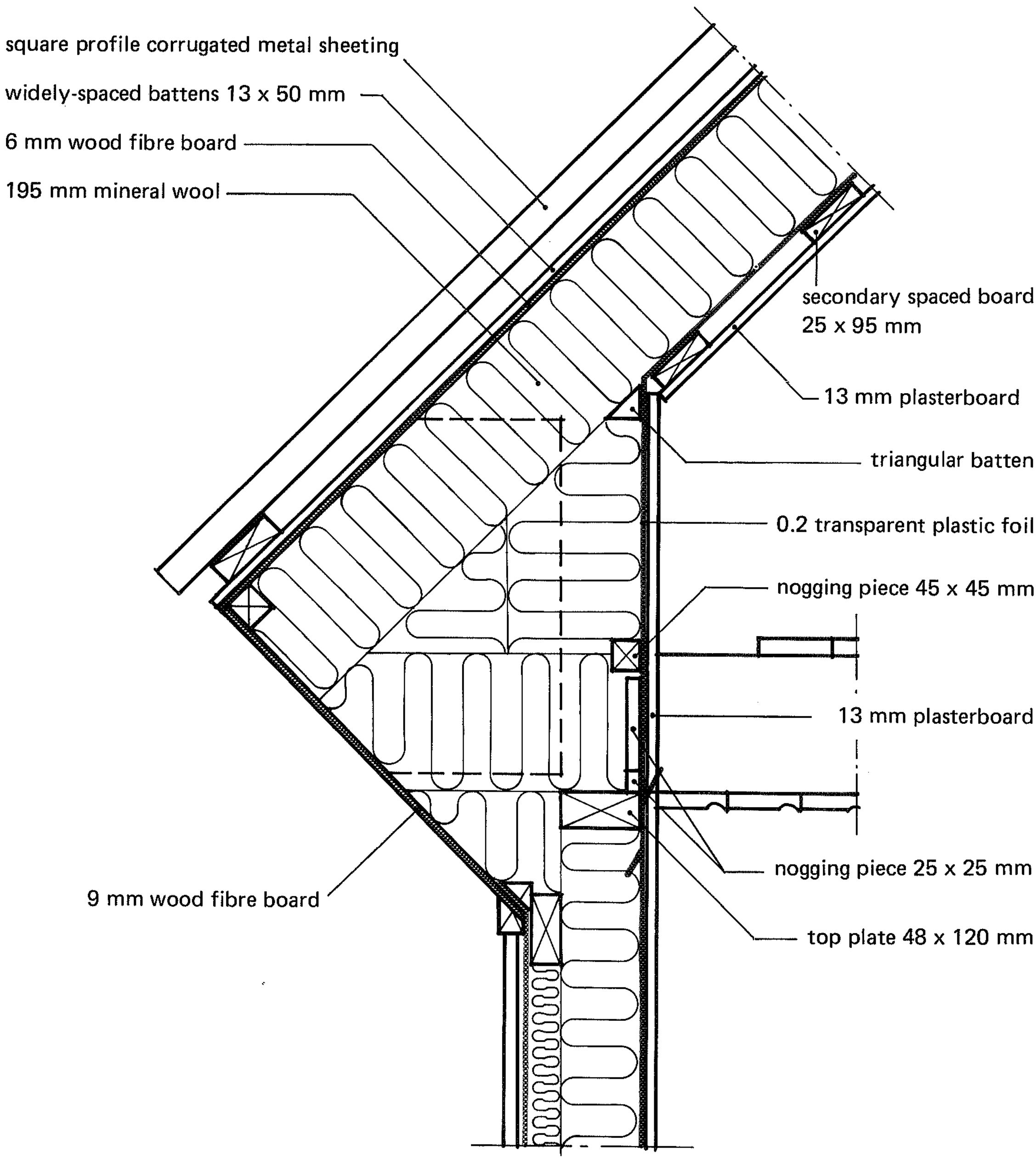


Figure 99. Eaves construction.

Figure 100. Nogging pieces are nailed in position thus clamping the plastic foil round the joists in the intermediate joist structure.

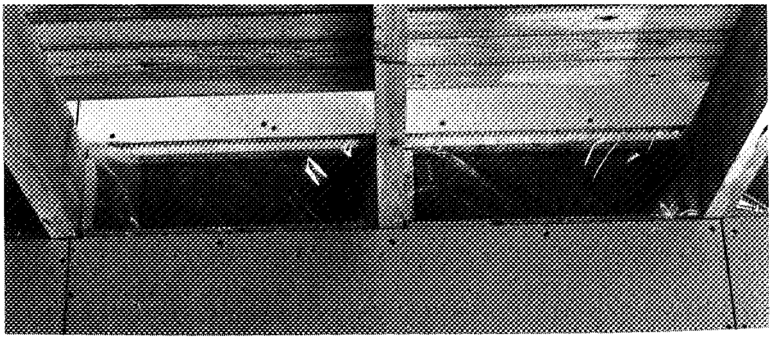


Figure 101. The plastic foil is clamped with the help of plasterboard sheets between the joists. To improve the airtightness further, sealing compound can be used adjacent to the joists.

of the shell (figures 100—101). Small pieces of plasterboard are used between the joists. To complement the clamp tightening, jointing compound is used round the joist.

Item 5: Window and door joints

There is naturally a joint between foil and frame in windows and doors. In the houses studied these joints amounted to approx. 80 m. This means that approx. 80% of the total length of joints is around windows and doors. For this reason these joints must be designed for simplicity and reliability.

The outside frame dimensions in the houses in question are adapted to a framework system with a centre-to-centre distance of 600 mm. In this way the number of framework members in the wall is reduced and the insulation work simplified. Swedish window standards are not adapted to a framework spacing of 600 mm.

Window and door frames are provided with a rebate so that the plastic foil can be easily clamped to the frame. This is done by nailing a strip of chipboard (figure 102) to the frame and the framework members. Chipboard is used because it is more rigid and more robust than plasterboard and can provide better clamping. Bearing in mind that timber shrinks and that nails become exposed, it is suggested that the chipboard be screwed in order to retain full clamping effect.

Mineral wool packing or one-component polyurethane foam has been used for sealing between frame and adjacent framework members. The best airtightness is achieved with polyurethane foam.

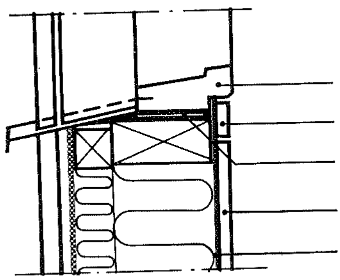


Figure 102. The joint between window sill and external wall.

Item 6: Penetrations for services

The requirements in SBN 1975 indicate that the effects of installations and airtightness must be observed at the planning stage. The first measure should be to minimize the number of penetrations. For example the electrical installations can be positioned adjacent to internal walls or in a special skirting board. Penetrations which cannot be avoided should be designed so that they can be easily sealed. Ventilation ducts can be fitted with soldered sheet metal flanges or tightly fitting butyl rubber collars. To seal around intersections made by vapour ducts from kitchens without conflicting with fire regulations is a particularly difficult problem. There is no particularly good and approved method available as yet.

In the houses studied, electrical installations have mostly been routed in internal walls, intermediate joist structures and in the ceiling's secondary spaced boarding. This means that only four electrical intersections are necessary – external lighting, ring mains, outdoor electricity meter and aerial cable. These intersections, and those for waste water ventilation, are sealed with tape. In the ventilation intersection in figure 103, the plastic foil is clamped between the lower fixing cleat of the ventilation head and the panel boards. The covering plate is screwed to the panel boards after which the ventilation ducts' intersections (2) through the covering plate are sealed with jointing compound. If the covering plate is moved inside the panel boards, so that the plastic foil is clamped between the lower fixing cleat and the cover plate, the tightness of the intersection can be further improved.

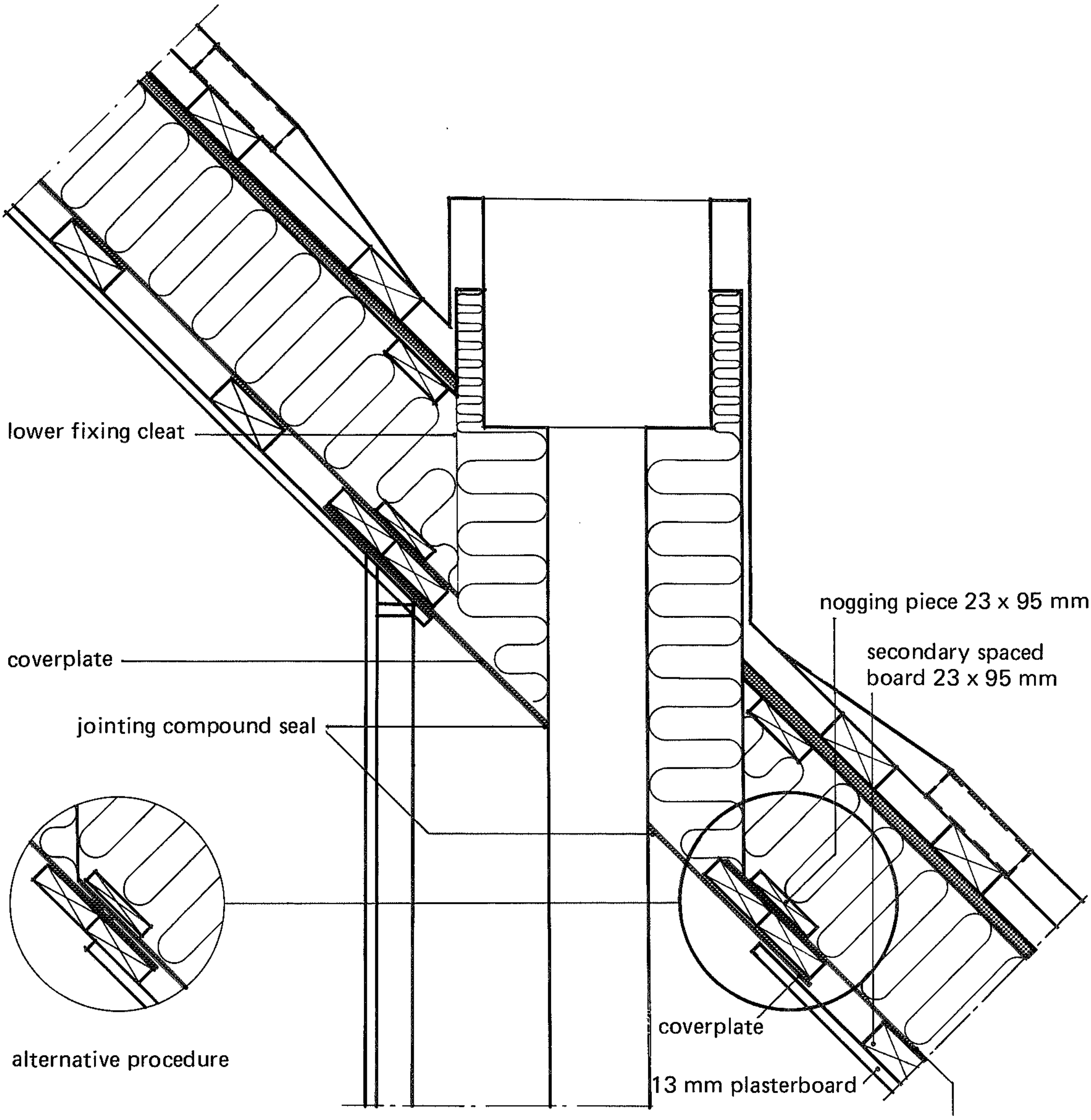


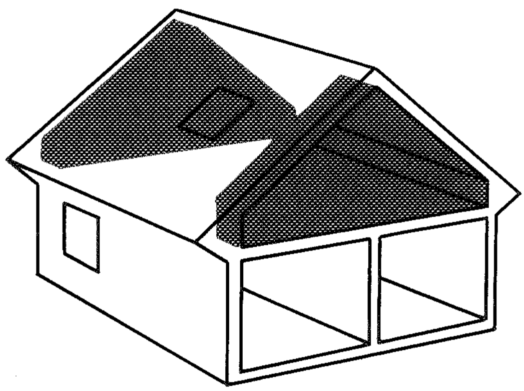
Figure 103. Intersection for ventilation ducts and the seals around these.

Fitting plastic foil

Two different sizes of transparent plastic foil with a thickness of 0.2 mm have been used. On the walls on the ground floor a 2.7 m wide foil is applied, i.e. wider than the height of the room. In the ceiling a 1.35 m wide foil is used and this covers the area between two roof trusses (centre-to-centre distance 1200 mm).

Upper floor

Plastic foil is fitted to the gable walls first (figure 104). It is rolled out on the floor along the walls and is cut so that approx. 800 mm is left over. The foil is then affixed to the roof truss after which the large fold is folded down and stapled to the wall. When the plastic foil has been set up on the gable it can be applied to the roof. This is attached starting at one of the eaves, up along the pitched roof and over to the other eave. About 400 mm should be left over at each respective eave so that there is an overlap against the plastic foil fitted to the ground floor wall. The foil in the roof must however be cut at the middle of each joist so that it can pass the joist structure. When it is cut it is folded through the joist structure and stapled to the joist, nogging pieces and top plates.



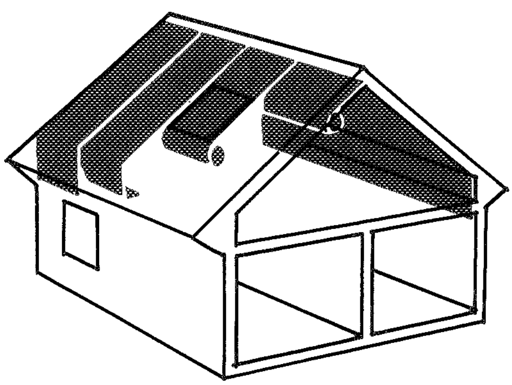
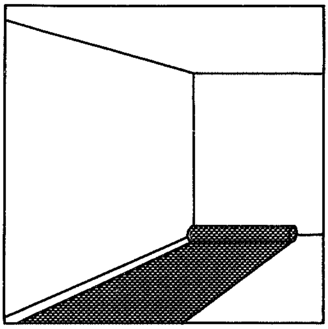
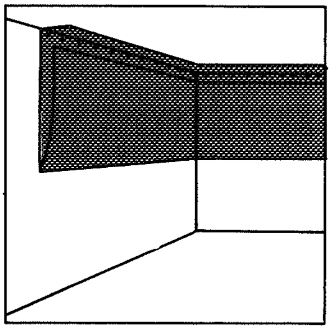


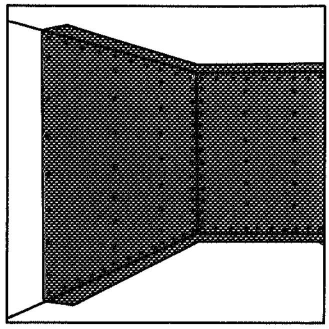
Figure 104. The upper floor's gables are covered in plastic foil first after which the roof is covered. In the roof, the foil is laid parallel with the roof trusses. The rolls can pass through an opening in the intermediate joist structure. The joints, with a good amount of overlap, are laid over supports and clamped with plywood strips or are taped.



Roll out along the outer wall.



Lift up, fold up the small flap against the ceiling, fix in under the flap.



Fold down the large flap and attach the foil to the wall.

Figure 105. The principle for fitting a 2.70 m wide sheet of plastic foil.

Ground floor

Finally the plastic foil is fitted in the ground floor (figure 105). The fact that the width of the foil is somewhat greater than wall height means that the number of vertical joints, i.e. the number of joints using foil strips between gable walls and intermediate walls is lower – preferably only four (figure 106).

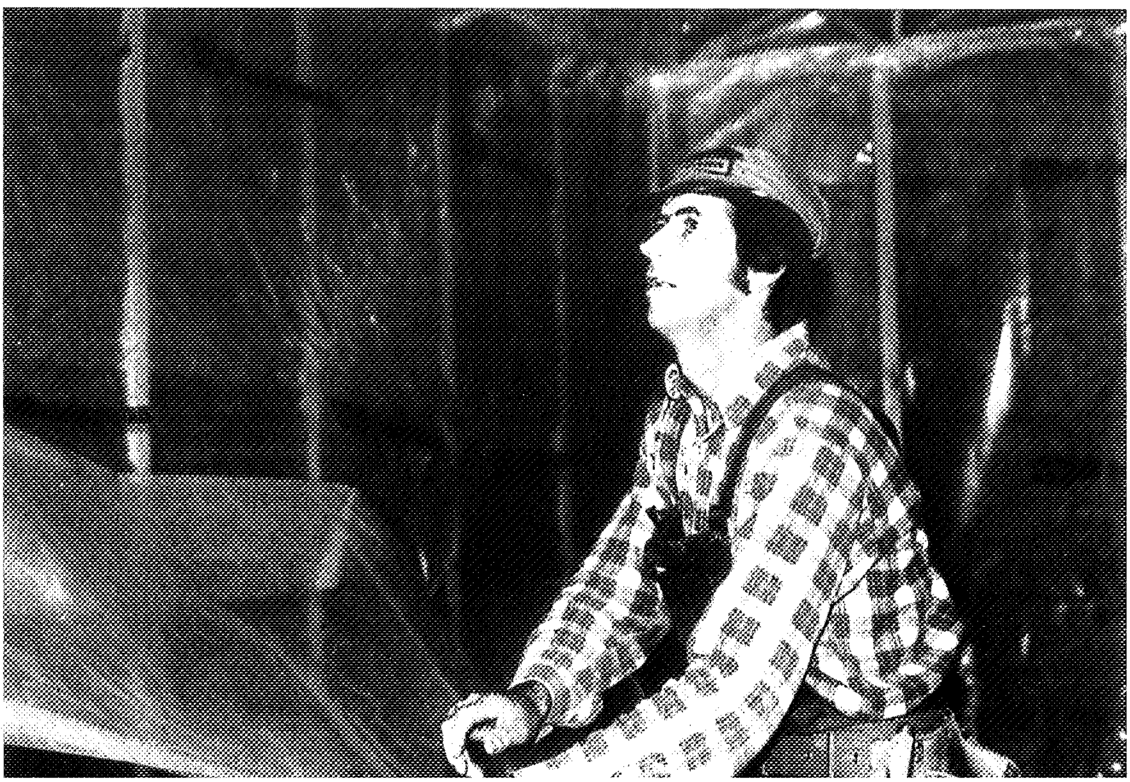


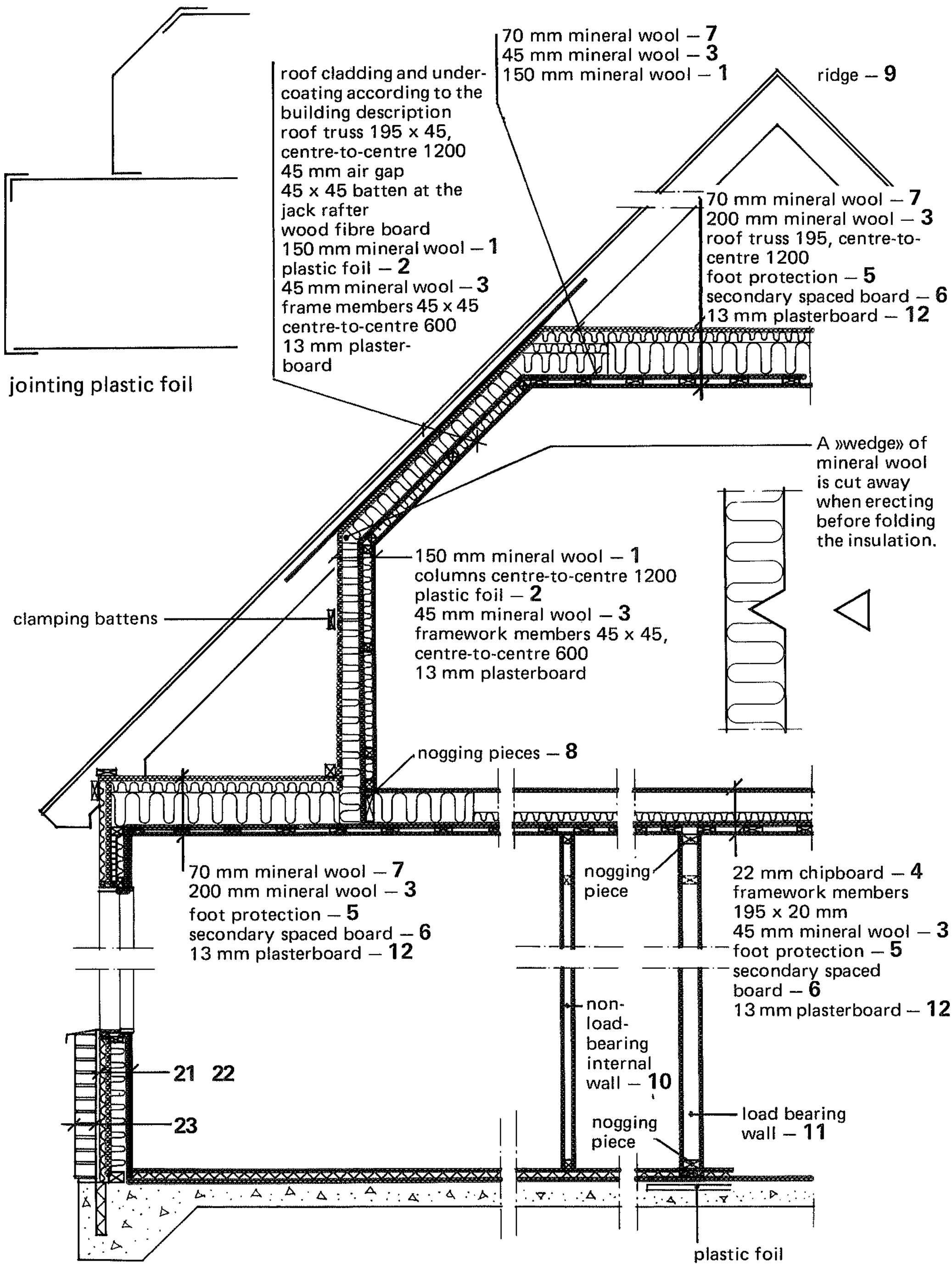
Figure 106. Large sheets of plastic foil are used so that the number of joints is kept to a minimum. The width of the foil is the same as the room height plus an extra amount for overlapping.

Examples of construction drawings

This example refers to a dormer single family dwelling. The drawings relating to the project are supplemented with instructions and references to standard parts. In the latter, an account is given of how repetitive constructional details are to be carried out, e.g. erecting the windows, joints in plastic foil, facade details. They also contain special instructions regarding material qualities and work procedures.

Standard solutions related to building details should be drawn on A4 paper and plenty of copies should be available for the actual work site. Large drawings of building details are impractical for use on building sites. The drawing example is not comprehensive and does not contain all the details and variations for a complete single family dwelling and only shows a system conceived for this example.

An interesting item is the separate account of the fitting procedure for the plastic foils. This procedure also clearly shows the sizes used and the joints which are acceptable. Note also that positioning electrical cables in external constructions has been avoided.



The numbers refer to special instructions.

Instructions

1 Mineral wool slabs with λ = 0.040 W/m°C. The slab shall be fitted with wind paper with an overlap of 80 mm on the outside and with paper that can be nailed having a 40 mm overlap on the inside. Where the angle of the wall changes, a wedge is cut out to half the slab so that the insulation remains unbroken.

2 Minimum 0.20 mm thick age-resistent and transparent plastic foil.

3 Mineral wool slab with λ = 0.040 W/m°C.

4 Floor chipboard with functional requirements. Type approved (refers also to formaldehyde content). Handled according to the erection instructions issued by the Chipboard Federation. Laid out according to the building description.

5 Safety foil. Fitting according to the manufacturer's instructions. The foil also functions as a diffusion barrier and an air seal.

6 22 x 95 mm, Type V, centre-to-centre 300 mm with a substructure centre-to-centre distance 600 mm. 28 x 95 mm, Type V, centre-to-centre distance 300 mm with substructure centre-to-centre 1200 mm.

7 Mineral wool slab with λ = 0.040 W/m°C. The slab must be covered with wind paper.

8 The nogging pieces are tosh nailed to the floor joist structure using a pattern of 6 + 6 at 100 x 37 mm. The nogging pieces also function as struts. (See also figure 113.)

9 In the case of terraced and semi-detached houses the ventilated ridge is to be made in accordance with the building description.

10 45 x 45 mm members. In bathrooms with bathroom furniture loads on walls, 45 x 70 mm. In toilets and bathrooms the whole of the wall thickness is insulated.

11 45 x 95 mm members. Top wall plates, beams according to shell plan. Nogging piece for skirting board.

12 The plasterboard is fitted to the ceiling before non-load-bearing walls.

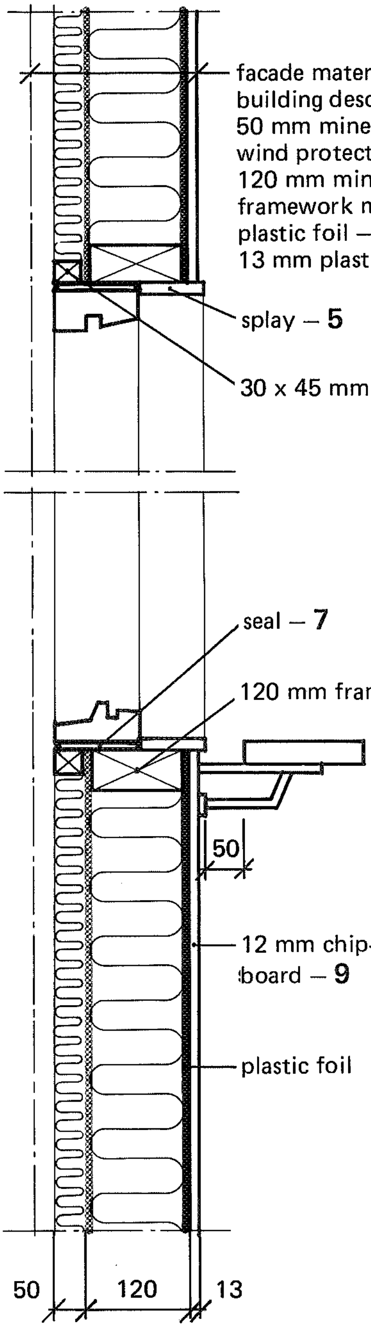
References

21 See standard detail figure 108.

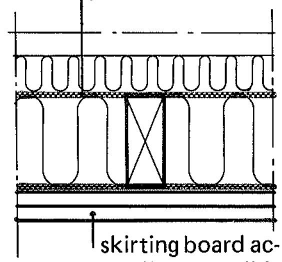
22 See standard detail figure 109.

23 See standard detail figure 110.

Figure 107. House standard. House with timber frame structure.



a



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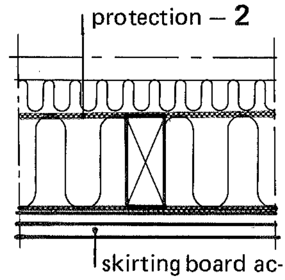


c

Instructions

1 Room height mineral wool slab with air permeability < 0.1 m^3/m^2 h Pa. $\lambda = 0.04$ W/m°C. Slab joints are always positioned above framework members. In all other respects assembly is carried out according to the manufacturer's instructions.

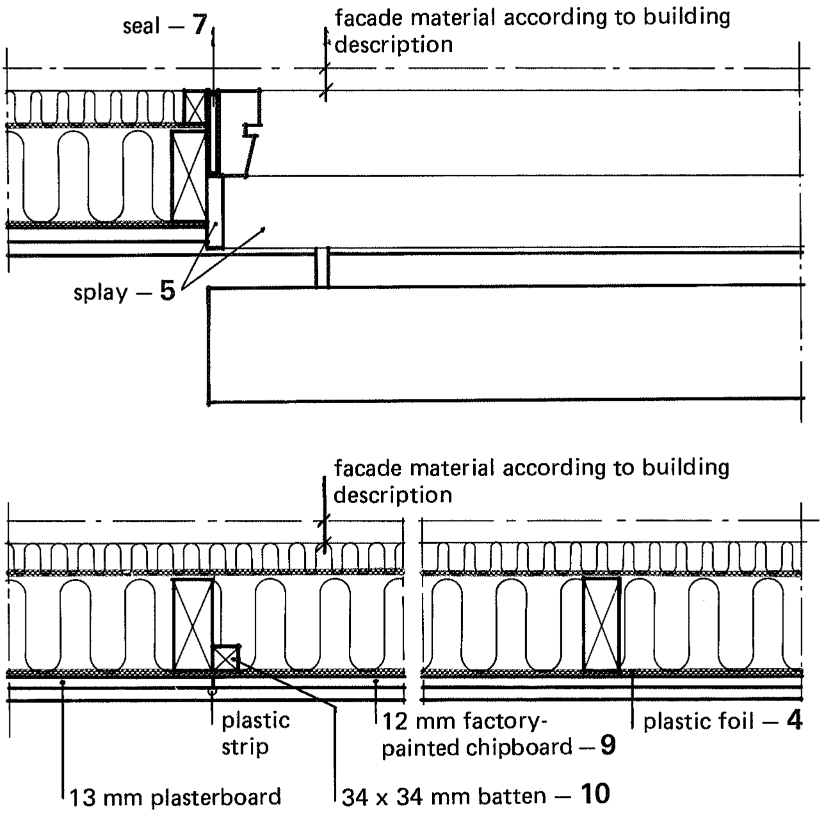
2 Wind paper or mineral wool slab with factory-fitted wind paper. Loose wind paper is jointed above framework members with a 150 mm overlap.

3 Mineral wool with $\lambda = 0.04$ W/m°C is attached between standing 120 mm framework members with centre-to-centre distance 600 mm. Framework member thicknesses according to documentation related to the project.

4 Minimum 0.20 mm thick age-resistent and transparent plastic foil. Assembly according to standard detail in figure 112.

5 Splay according to production standard.

6 30 x 45 mm framework around window, impregnated.



7 Joint polyurethane foam. Joint thickness 10—20 mm.

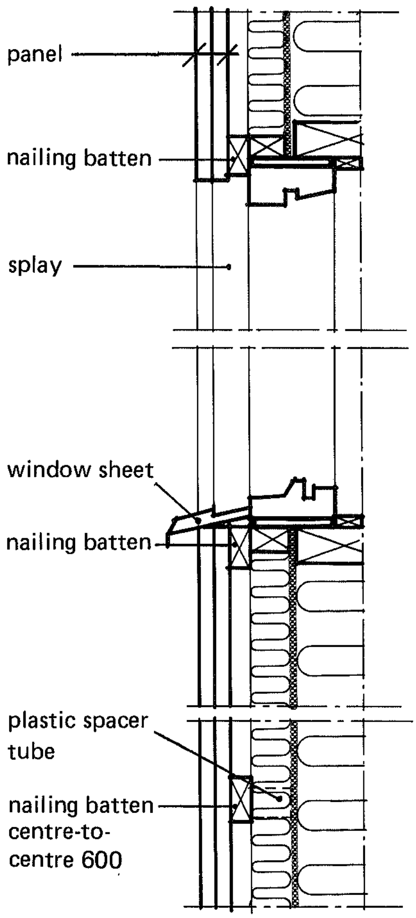
8 120 mm framework member. Thickness according to project-related documentation.

9 The chipboard sheet is nailed according to the building description. Radiators are attached to the chipboard sheet with rubber expander.

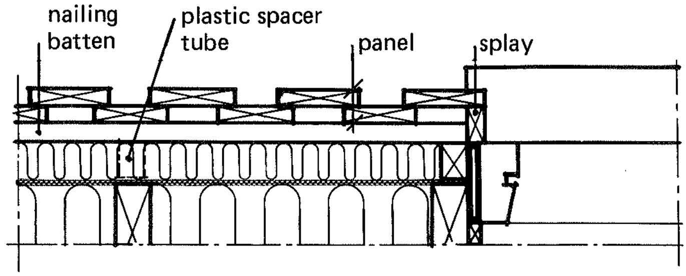
10 The insulation must be cut along the battens so that no air gaps occur.

Unless otherwise stated in project-related documentation, the following applies:
Framework members of rough planed timber. In all other respects the timber must be stress graded.
Windows are attached to the framework with screws and square headed wood screws under the window. Where two windows are erected together, the area between the frames is sealed with polyurethane jointing foam. A vertical framework member must always be fitted between windows and french windows. See the manufacturer's instructions regarding the use of jointing foam at low temperatures.

Figure 108. Standard detail outer wall for a single family dwelling, framework with 170 mm mineral wool insulation.
a. Vertical section at window.
b. Horizontal section at window.
c. Horizontal section under window.


panel
nailing batten
splay
window sheet
nailing batten
plastic spacer tube
nailing batten centre-to-centre 600

a

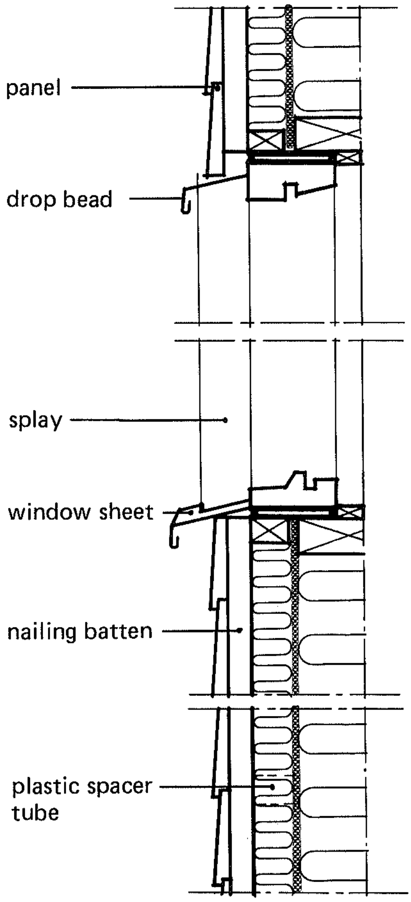

nailing batten
plastic spacer tube
panel
splay

b

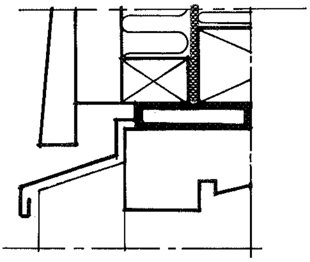
Instructions

Panel	Cover boarding with dimensions according to building description. Mortice and tenon jointed timber may be used. The bottom plank is nailed centrally with hot galvanised wire nails 75 x 28. The cover plank is double nailed with hot galvanised wire nails 100 x 34. The nails in the cover planks must not protrude.
Nailing batten	30 x 70 mm. The batten is attached to the shell framework with hot galvanised wire nails centre-to-centre 600 mm using 2 nails at every attachment point. A plastic spacer tube is fitted between batten and framework. The nailing dimensions around spacer tubes shall be 125 x 40.
Splay	Thickness 25 mm. The width is adapted to the panel in question. The splay is surface treated in the same way as the panel. The spaly is cut off 5 mm above the window sheet.
Window sheet	According to the building instructions.

Figure 109. Standard detail. Facade cladding covering boarding.
a. Vertical section at window.
b. Horizontal section at window


panel
drop bead
splay
window sheet
nailing batten
plastic spacer tube

a



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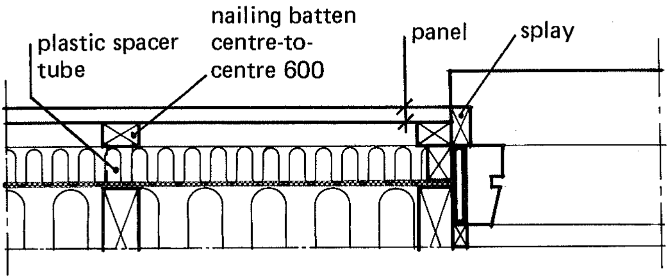

plastic spacer tube
nailing batten centre-to-centre 600
panel
splay

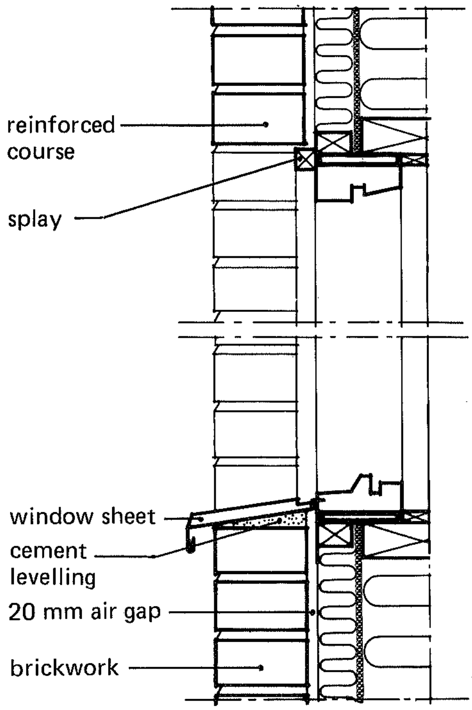
b

Instructions

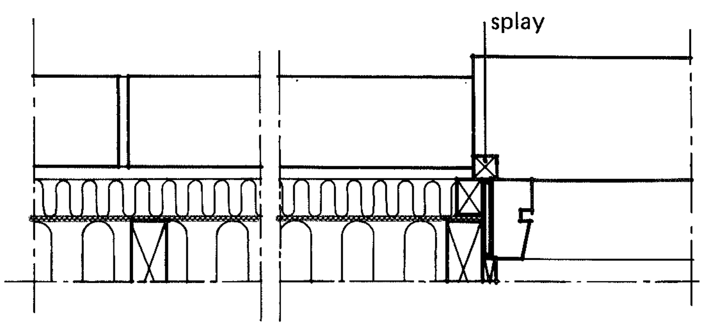
The following applies unless otherwise stated in project-related documentation:

Panel	Panel plank. The panel is double nailed with hot galvanised brads 75 x 40, centre-to-centre 600 mm.
Nailing batten	30 x 70 mm. The batten is attached to the framework with hot galvanised wire nails centre-to-centre 600 mm using 2 nails at every attachment point. A plastic spacer tube is fitted between batten and framework. The nailing distance around 50 mm spacer tubes shall be 125 x 40.
Splay	25 x 63 mm. The splay shall be impregnated and shall be surface treated in the same way as the panel. The spaly is cut off 5 mm above the window sheet.
Window sheet and drop strip	According to the building description.

Figure 110. Standard detail. Facade cladding, weather boarding.
a. Vertical section at window.
b. Horizontal section at window.
c. Detail of drop strip.


reinforced course
splay
window sheet
cement levelling
20 mm air gap
brickwork

a


splay

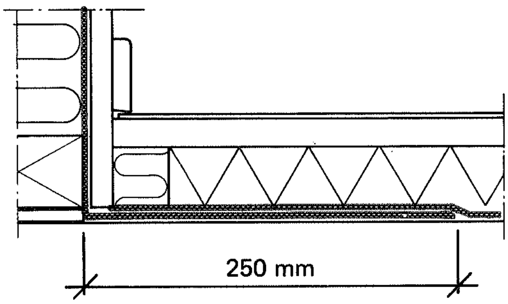
b

Instructions

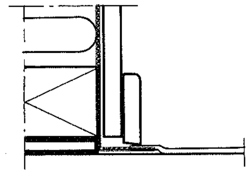
The following applies unless otherwise stated in project-related documentation:

Brickwork	Bricks, cement and cement joints according to building description. The brickwork is erected against the brickwork splay and the brickwork joint is drawn even with the brickwork surface. Wall opening = frame outside dimensions + 50 mm.
Tying	4 ties/m^2. Type of tie according to building description.
Splay	Planed splay 34 x 45 mm. The spalt is impregnated and is surface coated in the same way as the window. The splay is cut off 5 mm above the window sheet. The splay is attached with nails to the framework, not to the frame. On splays adjacent to side frames an EPDM rubber provile with a lip is applied.
Window sheet	According to the building description.

Figure 111. Standard detail. Brickwork facade.
a. Vertical section at window.
b. Horizontal section at window.

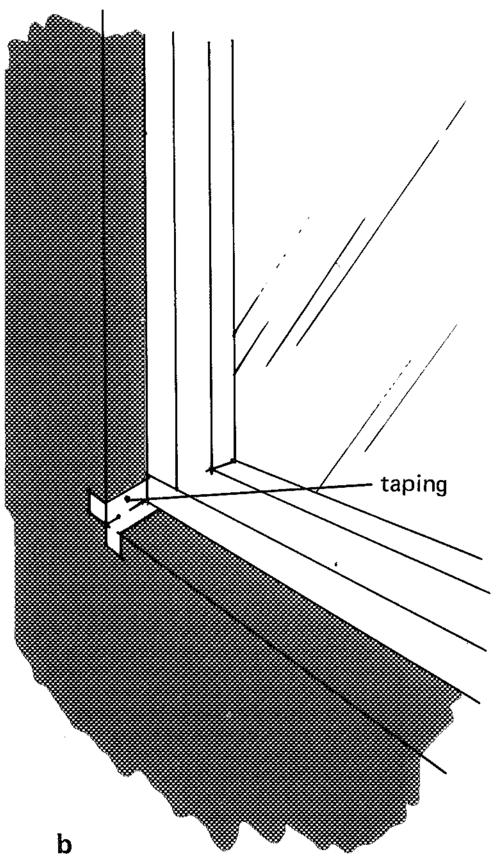


alternative 1

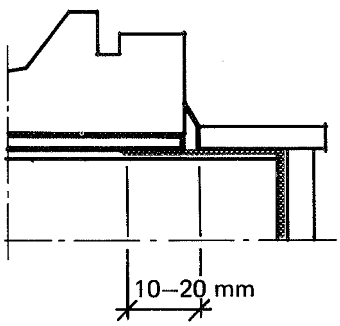


alternative 2

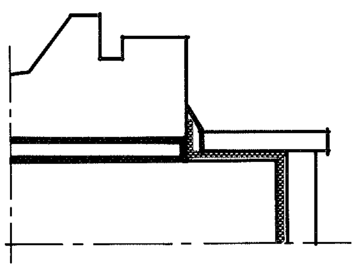
a



b

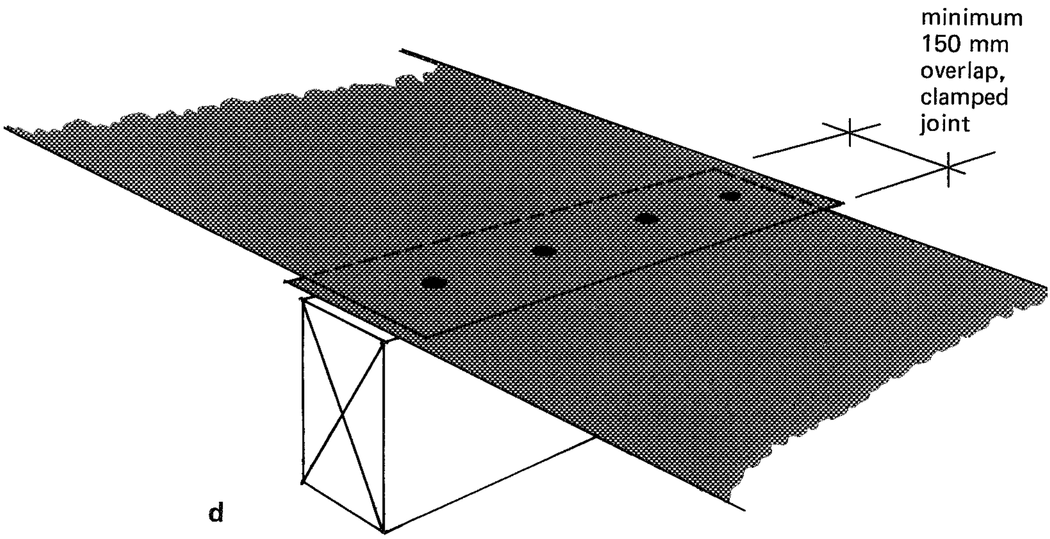


alternative 1



alternative 2

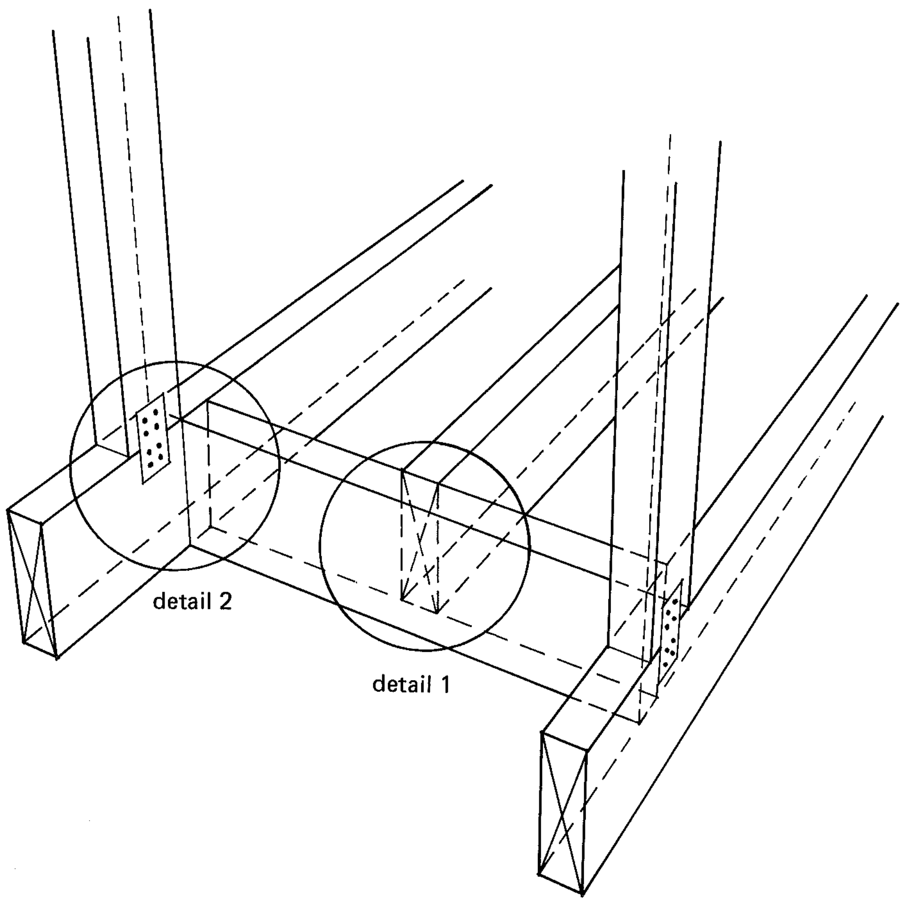
c

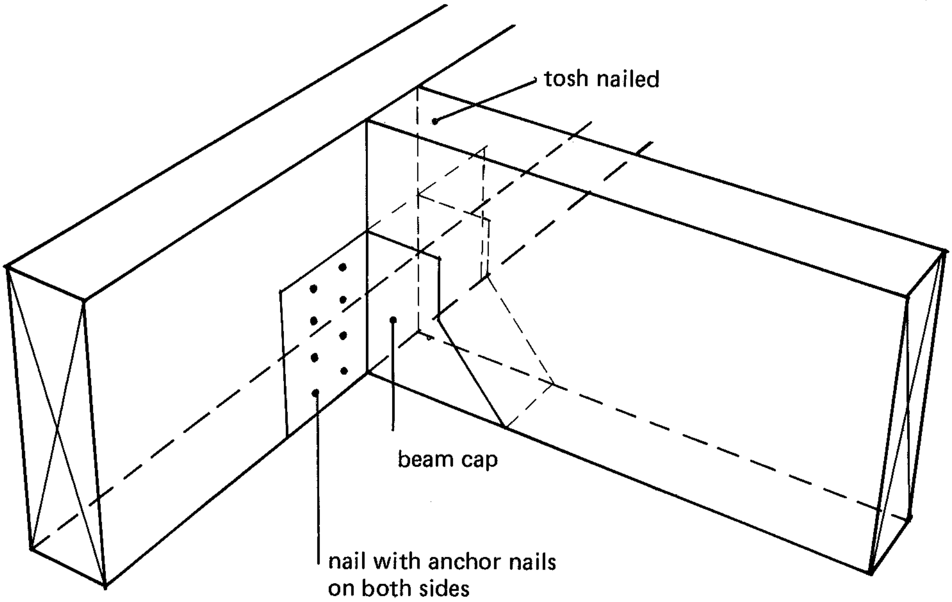


Instructions

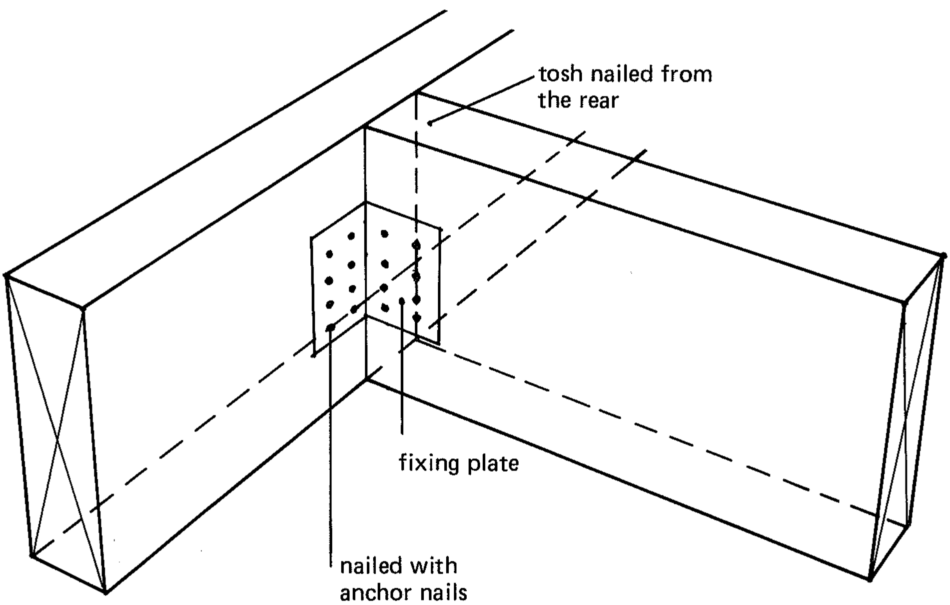
At window openings, the foil is carefully placed against the seal around the window frame (c).
Joints in the window splay are taped (b).
On floors, jointing or finishing is carried out as shown in detail a.
In general, jointing must be carried out above, where there are framework members, using an overlap as illustrated in detail d.
At transitions in the plastic foil, the joint must be carefully taped.
At joist structure transitions the plastic foil is cut and taped so that it seals properly against the joists.
Horizontal plastic foil which also serves as foot protections is jointed and fitted according to the manufacturer's instructions.
In the case of terraced and semi-detached houses, party walls are to be covered along the whole length with plastic foil. Partly walls with dilation joints shall be provided with mineral wool insulation at the joint against the cold side.
The insulation shall be the same as a sheet width.

Figure 112. Standard details. Fitting plastic foil. House with timber frame.
a. Joint foil – floor.
b. Sealing foil at window openings.
c. Jointing foil – window openings.
c. Overlapping foil.


detail 2
detail 1



detail 1 seen
from the »inside»



detail 2

Figure 113. Alternating floor joists.

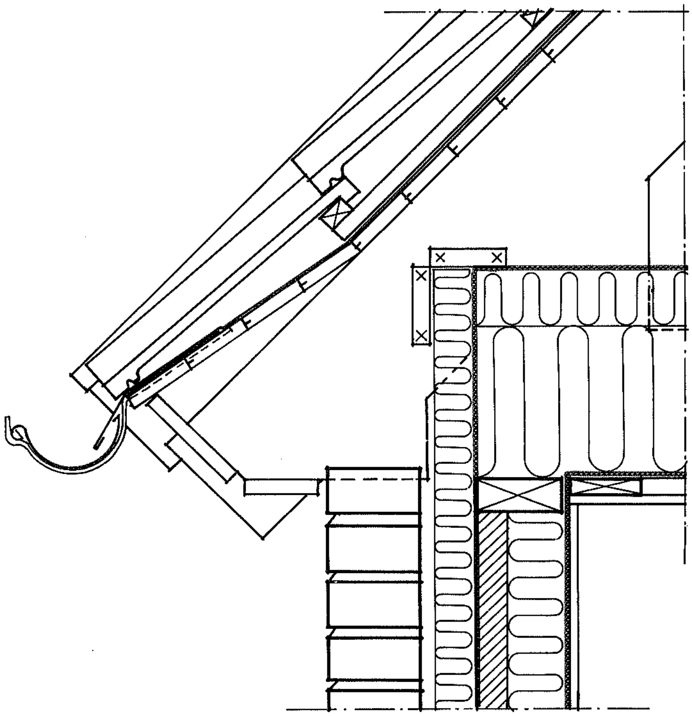


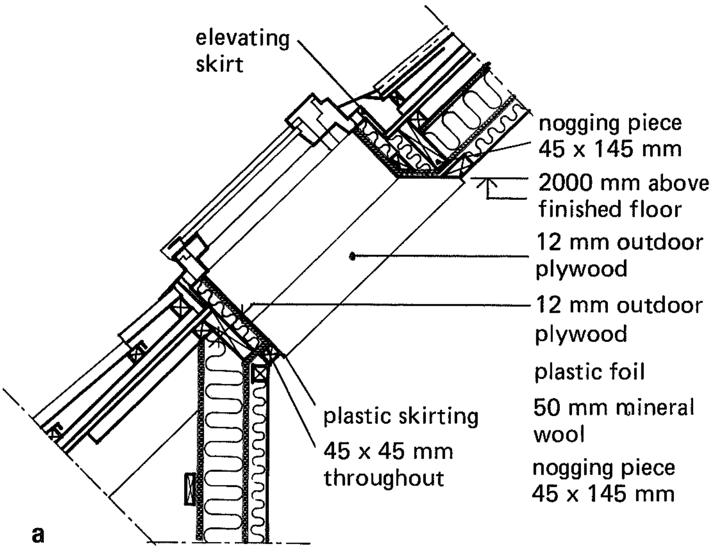
Figure 114. Standard detail. Eaves.

Instructions

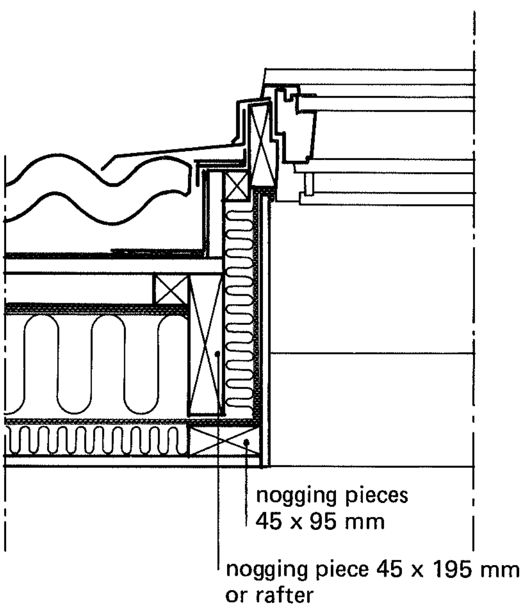
Roof light 550 x 700 mm supplied complete with elevating skirt. The roof light is fitted according to the manufacturer's instructions.

References

Surface treatment at the factory according to the building description.



a



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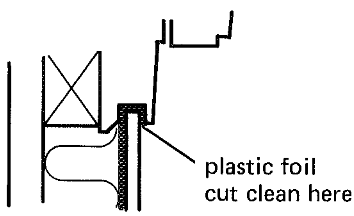

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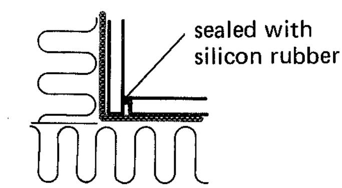

d

Figure 115. Roof light.
a. Section.
b. Joint roof light – roof structure.
c. Detail.
d. Detail.

Individuals and companies who have supplied information

One of the essentials for completing this survey work has been access to information from different companies and individuals. The companies listed below have been kind enough to supply material for our use and/or have arranged for interesting and valuable study visits to a number of different building sites. Visits have also been made to companies building single family dwellings. These study visits have greatly stimulated new ideas and solutions and have increased understanding of the practical difficulties which arise at work on different building sites.

Armerad Betong Vägförbättringar AB, Stockholm
BPA Byggproduktion AB, Stockholm
Byggnads AB Folkhem, Stockholm
Nya Asfalt AB, Stockholm
Platzer Bygg AB, Stockholm
SIAB Byggen AB, Stockholm and Malmö
AB Skånska Cementgjuteriet, Stockholm, Malmö and Luleå
Stockholms Fastighetskontor, Småhusavdelningen, Stockholm
Svenska Riksbyggen, Stockholm and Sundsvall
Tyréns Företagsgrupp AB, Stockholm
Åkessons Byggnads AB, Krylbo

Gullringshus AB, Gullringen
AB Hjältevads-Hus, Hjältevad
Hultsfreds-Hus, Hultsfred
LB-Hus AB, Bromölla

Gullfiber AB, Billesholm
AB Gyproc, Malmö
Rockwool AB, Skövde

AB Celloplast, Norrköping
Gränges Aluminium, Västerås
Lättbetong AB, Stockholm

Svenska Rawplug Co AB, Stockholm
Tremco — Göta Kemi AB, Stockholm
Ytong AB, Hällabrottet
P-O Collet, Teknologisk Institut, Tåstrup, Denmark

Norges Byggforskningsinstitutt, Norway
Statens Byggeforskningsinstitut, Denmark
John Timusk, University of Toronto, Canada
VTT/LVI tekniikan laboratorio, Espoo, Finland

Bygginfo, Stockholm
Chalmers Tekniska Högskola, Gothenburg
Kungliga Tekniska Högskolan, Stockholm
Lunds Tekniska Högskola, Lund
Svenska Träforskningsinstitutet, Stockholm
Träinformation, Stockholm

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Summary

Approx 40% of the energy consumption in Sweden is utilized in the heating of buildings. In order to reduce the amount of energy utilized for heating purposes, more stringent thermal insulation requirements for buildings were introduced in the 1975 Swedish Building Code as well as completely new requirements concerning the airtightness of buildings. Pilot studies that have been carried out indicate that considerable savings of energy can be achieved as a result of these new requirements.

In order to meet these requirements completely new structural designs for the building envelope are needed. It is the considerable increase in the thickness of insulation that has until now led to the non-application of new design solutions. The new airtightness requirements have in turn involved new working metods and, in many cases, have required both new materials and new combinations of materials. The main goal of the work presented here has been to compile and assemble design solutions, paying particular attention to how thermal insulation and airtightness requirements are to be met.

The main reason for making buildings airtight is to save energy. In this publication the relationship between ventilation and the airtightness of a building is presented in accordance with a theoretical method of calculation developed by P-O Nylund. In a study carried out in a small area of single-family houses, the results agreed well with these theories. By constructing airtight houses it is possible to regulate ventilation to the desired level and, in the main, independently of the effects of the outdoor climate. Unintentional or uncontrolled air leakage can thereby be minimized with resultant savings of energy.

Experience gained mainly from the construction of single-family houses during the Sixties and Seventies has shown that defects in the airtightness of the building envelope have in many cases been considerable. This has causes discomfort as a result of draughts and in some cases difficulty in obtaining acceptable indoor temperatures. Serious defects caused by damp, particularly in roof structures, can in many cases be ascribed to defects in the airtightness of these structures. The reasons for building airtight buildings are therefore many and are important.

The problem of airtightness should already be carefully considered during the desing phase. A well thought-out system for how airtightness is to be achieved will considerably facilitate its execution in practice. Depending on the materials and the structural designs involved, different principles can be applied in order to achieve a high level of airtightness. Common to all these principles is that great care should be taken in the design of different structural details. This means that not only the walls and roofs must conform to this principle, but that it must also be carried out consistently at all joints and connections. This publication provides examples of the air leakage that has been recorded for a number of different designs. Among other things it is quite clear that penetrations for services such as for electricity, water, space heating and ventilation are extremely difficult to make airtight. For this reason the number of points where these services enter a building or penetrate the airtight layer should be cut to a minimum. For example, electricity service points should, and can, avoid penetrating the building envelope.

Many relatively new polymer materials are utilized to create airtight envelopes, e g EPDM rubber strips, polyethylene sheets, polyurethane foam, tapes and joint sealing compounds. A compilation has been made of their important properties and experience of their use in terms of airtightness. Common for all the polymer materials is that their ageing resistance has only been tested and documented in a very few cases. For example, tests made on polyethylene sheets have shown that ordinary vapour barrier sheets can have a very short length of life even when used normally. Up to now only a couple of makes meet reasonable ageing resistance requirements. New quality standards for polyethylene sheets have been put forward in a trade standard, »Verksnorm 2000», that will form the basis for a standard approval certificate.

Joints in structures that are made airtight by using polymer materials should be designed so that later resealing is not required. The use of tapes should be avoided, which thus places high demands on good airtightness design.

This report presents a large number of design solutions together with brief descriptions and proposals for suitable methods for carrying out work. The proposed design solutions are based on a comprehensive survey. Different structures and designs have been studied – and this has usually involved on-site visits. Consideration has been given to construction methods, the selection of materials and our assessment of the opportunities available for successfully carrying out the work in accordance with the proposed designs. A number of thermography and pressurization tests have also facilitated the assessment of these structural designs. The general aim has been to present the best possible design solutions but we are also aware of the fact that experience of these new structural designs is not particularly great. In time it is expected that improvements and simplifications will be made.

Some examples are given of more detailed, projectrelated structural designs. These have been regarded as of interest because the particular buildings have been part of different development projects and have therefore been studied with extra care during the construction phase. In some cases there is also some experience of buildings in operation as well as the results of tests that have been carried out.

In conclusion the report gives an example of the way in which drawings can be prepared. The special requirements concerning the quality of materials and the way that the work should be carried out should be very carefully specified. Project drawings should be supplemented with references to standard details. On-site studies have clearly shown that there is a need for structural details being drawn up on A4 sheets and copies being available on the site. Large format drawings are difficult to handle on site with the result that some of the information in these drawings can often be completely forgotten. Improvements in the feedback of information from the building site to the designer would also contribute to structural design improvements as well as more suitable drawings and documents.

D37:1980 **Distribution:**

ISBN- 91-540-3345-4
Swedish Council for
Building Research,
Stockholm, Sweden

Svensk Byggtjänst
Box 7853
S-103 99 Stockholm,
Sweden
Art.nr. 6702037

Price: 40 Skr + moms

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